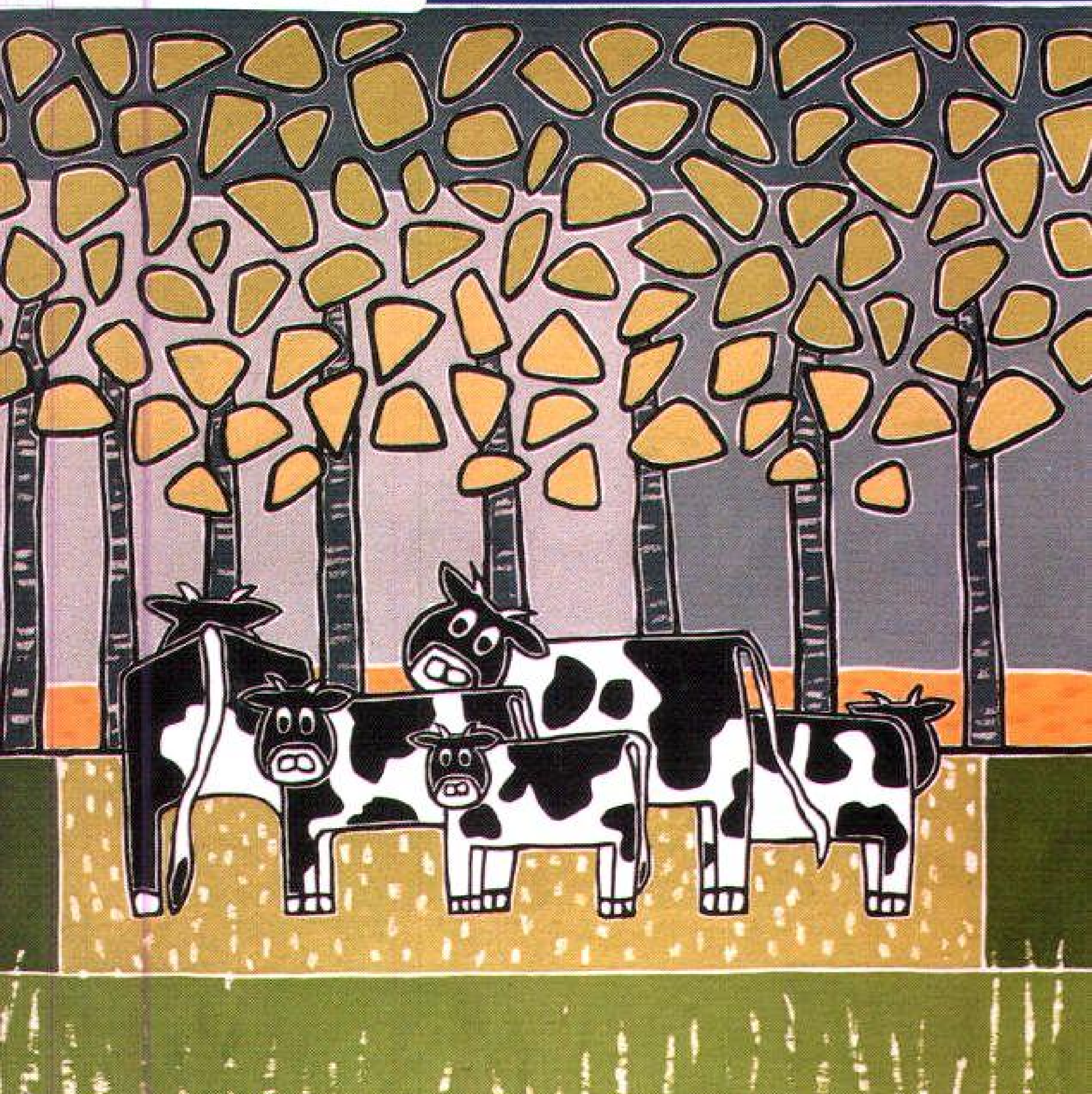
Modelling epidemiological and economic consequences of Bovine Respiratory Disease in dairy heifers



H.J. van der Fels - Klerx

Stellingen

1. Voor individuele melkveebedrijven in Nederland kan de economische schade als gevolg van BRD aanzienlijk oplopen. *(Dit proefschrift)*

2. De kwaliteit van 'expert'-informatie kan worden gewaarborgd middels een protocollaire procedure. *(Dit proefschrift)*

3. Het is niet alleen lógisch rekening te houden met het expertise niveau van deskundigen maar het leidt ook tot verbeterde resultaten. *(Dit proefschrift)*

4. "All data are imperfect representations of the things they are supposed to represent." *(Meyer, M.A., Booker, J.M., 1991. In: Boose, J., Gaines, B. (Eds.). Eliciting and analyzing expert judgement: A practical guide, vol 5. Academic press limited, London, UK).*

5. Het bouwen van simulatiemodellen dient niet gericht te zijn op het verkrijgen van precieze getallen maar op het verkrijgen van inzicht in de materie.

6. Een opvallend teken van marktwerking binnen de huidige universiteit is de differentiatie in de financiële beloning van promotieonderzoekers.

7. Met het gesleep van dieren in de veehouderij worden grenzen overschreden.

8. De invoering van de Euro leidt tot een sterke ontwaarding van spreekwoordelijke gezegden die te maken hebben met de huidige munteenheden.

9. De overeenkomst tussen een promotieonderzoek en een bevalling is dat, hoewel meerdere personen een handje helpen, het in feite op één persoon aankomt.

Stellingen bij het proefschrift 'Modelling epidemiological and economic consequences of Bovine Respiratory Disease in dairy heifers." H.J. van der Fels-Klerx, Wageningen, 21 december 2001

Modelling epidemiological and economic consequences of Bovine Respiratory Disease in dairy heifers

Promotoren: prof. dr. ir. A.A. Dijkhuizen
Hoogleraar Economie van Dierziekten en Dierziektebestrijding, Wageningen Universiteit

prof. dr. ir. R.B.M. Huirne
Hoogleraar Agrarische Bedrijfseconomie met bijzondere aandacht voor Diergezondheidszorg en Voedselveiligheid, Wageningen Universiteit

Co-promotor: dr. J. Verhoeff
Gezondheidsdienst voor Dieren te Deventer

Samenstelling promotiecommissie:

dr. J.T. Sørensen, Danish Insitute of Agricultural Science, Tjele, Denmark
dr. ir. L.H.J. Goossens, Technische Universiteit Delft
prof. dr. J.P.T.M. Noordhuizen, Universiteit Utrecht
prof. dr. ir. L.C. Zachariasse, LEI, Den Haag

H.J. van der Fels-Klerx

Modelling epidemiological and economic consequences of Bovine Respiratory Disease in dairy heifers

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
prof. dr. ir. L. Speelman
in het openbaar te verdedigen
op vrijdag 21 december 2001
des namiddags te half twee in de Aula

Modelling epidemiological and economic consequences of Bovine Respiratory Disease in dairy heifers

Modellering van epidemiologische en economische gevolgen van Bovine Respiratory Disease bij jongvee op melkveebedrijven

Ph.D.-thesis Wageningen University – With ref. – With summary in Dutch

H.J. van der Fels-Klerx, 2001

Department of Social Sciences, Farm Management Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

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Abstract

Bovine respiratory disease (BRD) is an important health problem in dairy heifers. BRD causes considerable losses, particularly on farms that experience high levels of the disease. However, an exact quantification of the economic losses due to BRD was not available yet. Despite this lack of economic insight, dairy farmers have to make decisions with regard to prevention of the disease. To make these decisions as economically sound as possible, more accurate insight is necessary into the economic consequences of BRD on the individual dairy farm. The main objective of the research project described in this thesis was to obtain insight into the on-farm economic consequences of BRD in dairy heifers by means of a PC-based simulation model. The second objective was to collect information on the epidemiological consequences of the disease indispensable for model input. The research started with a literature review aimed at obtaining the necessary qualitative and quantitative information on both the effects of BRD on the productivity of dairy heifers and risk factors of the disease. Because relevant literature turned out to be scarce, a formal expert judgement study was held to obtain additional data on the(se) variables of interest. As a next step, a simulation model was developed that calculates the economic losses due to BRD in dairy heifers for individual dairy farm conditions in the Netherlands. Following the results of the expert judgement study, the model distinguishes between two BRD types, being calf pneumonia and a seasonal BRD outbreak. Model calculations showed that for most dairy farms in the Netherlands the economic losses due to BRD will be relatively small: around 1 % of the farm's net return to labour and management for average situations, increasing up to 3-4 % at worst. For individual farms that experience high levels of BRD, the associated losses can be as high as 10-15 % of the farm's net return to labour and management, up to 25 % for large farms. Besides for calculation of the economic losses due to BRD, the model showed also to be useful for evaluation of the on-farm cost-effectiveness of prevention of the disease. Moreover, the model is flexible and user-friendly, hence, can be used as a tool to support decision-making in dairy practice.

Contents

Chapter 1

General introduction

1.1 Introduction

In modern dairy farming, control of the costs of production has become critically important in order to maintain farm income and to ensure continuity of the business (Dijkhuizen and Morris, 1997). The costs of raising replacement heifers represent one of the largest costs within the dairy farming system (Mourits, 2000). Hence, management decisions regarding dairy heifer rearing have a profound effect on the farm's net return to labour and management. A major aspect of dairy heifer management concerns health control (Quigley III et al., 1996).

Bovine Respiratory Disease (BRD) can be a serious health problem in dairy cattle, mainly affecting the younger animals. BRD is a broad term that covers a range of abnormal clinical signs of the respiratory tract caused by a variety of infectious pathogens (mainly viruses and bacteria). Clinical symptoms include increased respiratory rate, coughing, serous and nasal discharge, and fever (Radostits et al., 1994). Although the BRD complex essentially includes a variety of respiratory diseases caused by one or more specific agents, dairy farmers often diagnose and treat the disease without specifying the agent (into great detail). BRD may severely reduce the lifetime productivity of cattle affected. Effects on productivity ('productivity effects') associated with BRD in dairy heifers may include increased mortality, increased culling, reduced growth, reduced fertility, increased age at first calving, and decreased milk production (Waltner-Toews et al., 1986; Curtis et al., 1988a; Curtis et al., 1993; Van Donkersgoed et al., 1993; Warnick et al., 1994; Warnick et al., 1995; Virtala et al., 1996a; Warnick et al., 1997; Donovan et al., 1998a).

BRD is frequently observed on dairy farms. Results from a questionnaire held on nearly 1000 dairy farms in the Netherlands showed that on average approximately 10 % of the heifers had been treated for the disease. On about 40 % of the farms BRD was considered a major health problem (Van Calker and Reijs, 1999). The mean treatment rate for BRD in heifers on the dairy farms of the Research Institute for Animal Husbandry in the Netherlands was over 20 % (Duitman, 1999). Variation among individual farms was high, indicating a potential for improvement. Similar findings have been reported in other countries (Curtis et al., 1988b; Van Donkersgoed et al., 1993; Sivula et al., 1996; Virtala et al., 1996b; Donovan et al., 1998b).

Given the productivity effects associated with BRD and their potential impact, the economic losses due to the disease might be considerable, particularly on farms that experience high levels of frequency of the disease. This is supported by findings from individual Dutch dairy farms in practice. However, at present an exact quantification of the economic losses due to BRD is not available. Rough estimations, based on the Dutch dairy heifer rearing system, indicated that these losses were approximately € 26 per animal affected with clinical infections of *Bovine Respiratory Syncytial Virus* (Dijk, 1988) to € 36 per animal affected with BRD (Koole, 1995). These figures were mainly based on assumptions and averages, hence, they are neither accurate nor valid for specific farm conditions.

The economic losses due to BRD can be reduced by control and prevention of the disease. Control of BRD usually includes treatment of animals affected, whereas prevention includes (managerial) actions aimed at reducing the disease frequency by eliminating risk factors for the disease from the farm. Often, several prevention measures are available, with each a certain impact and a certain level of investment. In an attempt to make economically sound decisions, dairy farmers need to determine the optimum input level of prevention of BRD for their specific farm conditions. To support this decision-making process, more accurate insight is necessary into the economic losses due to BRD and the cost-effectiveness of prevention actions against the disease on the individual dairy farm.

The economic losses due to BRD consist to a large extent of treatment expenditures and losses associated with reduced productivity of cattle affected (Dijkhuizen and Morris, 1997). Treatment costs are relatively easy to calculate. However, the losses caused by the productivity effects are hard to estimate because clear underlying quantitative information on these parameters is lacking. Data currently available is incomplete, and often conflicting and uncertain. Hence, this data is not very useful as the only source for actual decision-making in the field. The same holds for data on prevention of BRD. The shortage of quantitative information makes it hard to make a solid evaluation of the economic consequences of BRD in dairy heifers, including prevention actions against the disease. Despite this lack of knowledge, however, dairy farmers have to make decisions on the prevention of BRD.

A PC-based decision-support tool based on simulation of the economic losses due to BRD in dairy heifers as well as the cost-effectiveness of prevention of the disease for individual dairy farm conditions would be helpful to obtain insight into the above-stated problem. The advantage of a simulation model is that it provides a basis for assessing and assimilating information available from various sources, and for using this information in the calculations. Sensitivity analyses can be used to explore the impact of uncertain input parameters on the model's outcome (Dijkhuizen and Morris, 1997). Such a simulation model will enhance quantitative insight into the economic consequences of BRD on the individual dairy farm, hence, support farmers to determine the optimum input level of prevention actions against the disease. In this way, they will be able to make better and more economically sound decisions on the prevention of BRD. Experiences with such PC-based model approaches for other decisions and diseases have shown to be successful (Huirne, 1990; Jalvingh, 1993; Houben, 1995; Saatkamp, 1996; Mourits, 2000).

1.2 Research objectives

The main objective of this research project was to obtain insight into the economic consequences of BRD in dairy heifers by means of a PC-based simulation model. The model can be used to calculate the economic losses due to BRD in dairy heifers as well as the cost-effectiveness of prevention actions against the disease for individual dairy farm conditions. It was applied to the dairy farming system in the Netherlands. The model was aimed to be user-friendly and flexible so that it could be used as a tool to support decision-making in dairy practice. The second objective of the research project was to obtain the necessary information on the epidemiological consequences of BRD in dairy heifers to be used as model input, in particular referring to 1) the impact of BRD on the productivity of dairy heifers and 2) risk factors of the disease. This data was obtained from a literature review and an expert judgement study.

1.3 Outline of the thesis

The research project consisted of two phases, being 1) the collection of input data, and 2) the development of the simulation model. Chapters 2 to 5 of this thesis focus on the first phase (data collection), whereas Chapters 6 and 7 deal with the second phase (simulation model). Figure 1.1 presents a schematic overview of the general modelling approach.

In Chapter 2, the scientific literature on the productivity effects and risk factors of BRD in dairy heifers is reviewed. The findings are interpreted and discussed for the dairy farming system in the Netherlands.

Experts were consulted to review the data available from literature and to obtain estimates on missing data. Chapters 3 to 5 focus on this expert judgement study, which was held especially for the purpose of this research project. More specifically, the expert study was aimed at obtaining quantitative expert judgement on the risk factors (Chapter 3) and the productivity effects (Chapters 4 and 5) of BRD in dairy heifers. Expert data on the risk factors was collected by means of Adaptive Conjoint Analysis (Metenagro, 1994). This method as well as the results obtained are presented and discussed in Chapter 3. Chapter 4 presents the methodology used to elicit and integrate expert judgement on the productivity effects of BRD, being the ELI-technique (Van Lenthe, 1993) and the Classical model (Cooke, 1991), respectively. Results of the expert judgement study concerning the productivity effects are presented and discussed in Chapter 5.

The data obtained on the productivity effects was, together with data on other parameters, used as input for the simulation model described in Chapter 6. This model calculates the economic losses due to BRD in dairy heifers for individual dairy farm conditions in the Netherlands. Sensitivity analyses provided information regarding critical input parameters.

The thesis concludes with a general discussion (Chapter 7), which focuses on perspectives of the simulation model developed, in particular its use for evaluation of the economic consequences of BRD, including prevention of the disease, and its characteristics. Furthermore, the quality of data from the literature is dealt with and the expert judgement study, including its design and the techniques applied, is discussed. Finally, the main conclusions of this research project are presented.

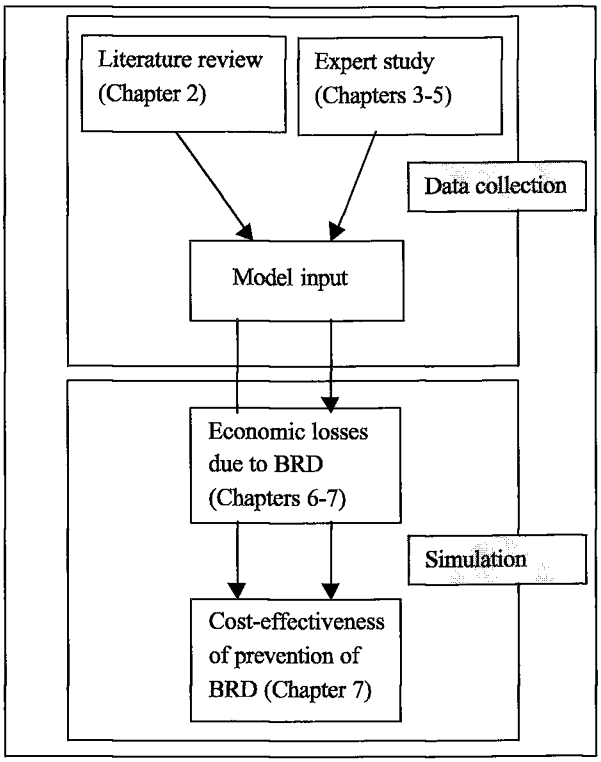

Figure 1.1 Schematic overview of the general modelling approach

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Chapter 2

Effects on productivity and risk factors of Bovine Respiratory Disease in dairy heifers: A review

Paper by Van der Fels-Klerx, H.J., Martin S.W., Nielen M.
Veterinary Record (submitted for publication)

Abstract

This Chapter presents a literature review on the impact of Bovine Respiratory Disease (BRD) on the productivity of dairy heifers as well as on risk factors for the disease, relevant to commercial dairy farming in the Netherlands or comparable dairy heifer raising conditions. Peer-reviewed publications from January 1980 to June 2001 on field studies that quantified the(se) variables of interest were included.

Study findings showed that BRD in dairy heifers increases the risk of mortality directly after the disease episode by approximately 6 times and reduces growth in the short term with up to 10 kg. In addition, the disease may increase both mortality in later stages of the rearing period and age at first calving, although not conclusive, as well as the likelihood of dystocia at first calving. Both herd size and other diseases in dairy heifers are evidently associated with the risk of BRD, and season and colostrum feeding management presumably affect this risk. Effects of birth circumstances, housing and the prophylactic administration of antimicrobials are less clear, as are effects of prophylactic vaccination against *Bovine Respiratory Syncytial Virus*, region, genetics, and herd milk production level.

It was concluded that, although several tendencies were seen, findings on most productivity effects and risk factors of BRD in dairy heifers were ambiguous or incomplete. Hence, on overall quantitative insight into these interest variables could not fully be obtained.

2.1 Introduction

Bovine Respiratory Disease (BRD) is an important health problem to the dairy cattle industry, mainly affecting the younger animals (Radostits et al., 1994; Quigley III et al., 1996). BRD embraces a range of abnormal clinical signs of the cattle's respiratory tract caused by one or more primary pathogens, including respiratory viruses and *Mycoplasma* spp., often complicated by a secondary bacterial infection, or by bacteria alone. The infectious agents commonly cited include *Bovine Respiratory Syncytial Virus* (BRSV), *Parainfluenza-3 Virus* (PI_3-V), the Mycoplasmas *M. dispar* and *M. bovis*, and bacteria including *Pasteurella haemolytica*, *Pasteurella multocida* and *Haemophilus somnus* (Roy, 1990; Radostits et al., 1994; Quigley III et al., 1996). Although infectious agents are primarily responsible for damage to the respiratory tract, several predisposing factors related to the animal and/or its environment markedly increase the likelihood and severity of the clinical signs, i.e., the disease is multifactorial (Roy, 1990; Radostits et al., 1994; Quigley III et al., 1996). The severity of BRD may range from subclinical, through mild clinical to an acute fatal form. Clinical signs vary, and may include fever, nasal and/or serous discharge, coughing, increased respiratory rate, decreased appetite, and sometimes mild diarrhoea (Roy, 1990; Radostits et al., 1994). Farmers and veterinarians usually diagnose BRD and treat affected cattle based on these signs, rather than on specific etiology.

BRD may severely reduce the lifetime productivity of cattle affected. Effects on the productivity ('productivity effects') associated with BRD in dairy heifers may include increased mortality, increased culling, reduced growth, reduced fertility, increased age at first calving, and reduced milk production. The losses associated with these productivity effects contribute, together with treatment expenditures, to the economic losses due to BRD. Field experiences indicate that on individual dairy farms in the Netherlands the economic losses due to BRD can be high. However, an exact quantification of these losses is unavailable at date. Because of variation in management among farms (Mourits et al., 2000) and the multifactorial causality of BRD, the on-farm frequency of the disease as well as the associated economic losses can be reduced by improvement of farm management. To make economically sound decisions upon the prevention of BRD, dairy farmers need to have more insight into the economic losses caused by the disease as well as the cost-effectiveness of various prevention actions on the individual dairy farm. To obtain this quantitative economic insight, enhanced knowledge of the underlying variables, including the productivity effects and the risk factors of BRD in dairy heifers, is necessary.

The current Chapter presents a literature review aimed at obtaining qualitative and quantitative information on the impact of BRD on the productivity of dairy heifers as well as on managerial risk factors of the disease, relevant to the commercial dairy farming system in the Netherlands or comparable heifer raising conditions. The information obtained was to be used as a basis for evaluation of the economic losses due to BRD and the cost-effectiveness of prevention of the disease on Dutch dairy farms.

2.2 Material and methods

The literature search used the computer program WinSPIRS version 2.0 and the three databases, CAB abstracts, Biological Abstracts and Current Contents. All peer-reviewed English-, German- and French-language publications from January 1980 to June 2001 were included that presented studies fulfilling the criteria of 1) quantification of productivity effects and/or risk factors of respiratory disease(s) in dairy heifers, 2) performed in the field (not based on infectious experiments), and 3) relevant for commercial dairy farms in the Netherlands. Hence, research performed on commercial or experimental farms in the Netherlands or elsewhere that was externally valid to Dutch dairy farming conditions in practice, i.e., were comparable with respect to climate, heifer raising system, production level, and genetics, were included. Technical reports, PhD-theses, and proceedings and abstracts of conference papers were not taken into account. Results from the included studies were restricted to findings that were statistically tested for their association with BRD and found significant at a level of 0.05.

2.3 Results

The results of the literature review are summarised in Table 2.1 for the productivity effects, and in Table 2.2 for the risk factors (restricted to two or more independent estimates). Background information on the epidemiological field studies cited is presented in Appendix 2.1.

Table 2.1
Productivity effects of Bovine Respiratory Disease (BRD) in dairy heifers found significant ($P<0.05$) in epidemiological field studies

Productivity effect	Effect[1]	Level analysis	Remarks	Authors
Mortality <90 days	$RR^2=6.5$	Calf		Curtis et al. (1988a)
Mortality <90 days	$OR^3=12$	Herd	$\text{Arcsin(BRD<90 days)}^{0.5}$	Curtis et al. (1993)
Above-median mortality	OR=2.3	Herd	Above-median treatment days per calf	Waltner-Toews et al. (1986a)
Weight gain <3 months	-0.8 kg per treatment week	Calf		Virtala et al. (1996a)
Weight gain 0-6 months	-10.5 g/day, per treatment day	Calf		Donovan et al. (1998b)
Weight gain 6-14 months	-2.3 g/day, per treatment day	Calf		Donovan et al. (1998b)
Girth growth in first month	-0.04 cm/day	Calf	Farmer-diagnosed	Van Donkersgoed et al. (1993)
	-0.05 cm/day	Calf	Veterinarian-diagnosed	
Mortality 90-900 days	OR=2.4	Calf		Waltner-Toews et al. (1986b)
Likelihood first calving	$HR^4=0.5$	Calf		Correa et al. (1988), Warnick et al. (1994)
Age at first calving	+3 months	Calf		Warnick et al. (1994)
Dystocia at first calving	OR=2.4	Calf		Warnick et al. (1994)

[1]If not stated otherwise, effects refer to the disease as defined in the particular study (see Appendix 2.1)
[2]Relative risk
[3]Odds ratio
[4]Hazard risk

2.3.1 Productivity effects

2.3.1.1 Mortality

Heifers that had respiratory disease before 90 days of age were at 6.5 times increased risk of dying in this period compared to their non-affected herd mates (Curtis et al., 1988a). However, others could not confirm this association (Perez et al., 1990; Donovan et al., 1998a). At the herd level, the risk of mortality before 90 days of age was increased with higher incidences of respiratory disease in this period (Curtis et al., 1993). Consistently, farms that had above-median treatment days per heifer for pneumonia were 2.3 times more likely to also have above-median mortality rates compared to farms that had below the median treatment days per heifer (Waltner-Toews et al., 1986a).

2.3.1.2 Growth

The effect of BRD on growth was investigated in three studies, all reporting a decrease (Van Donkersgoed et al., 1993; Virtala et al., 1996a; Donovan et al., 1998b). Pneumonia diagnosed before the age of three months reduced weight gain during this period by 0.8 kg per week of the disease which, given the mean duration of four weeks, resulted in a total reduction of 3.2 kg (Virtala et al., 1996a). Heifers that had pneumonia between birth and six months of age had reduced weight gain during this period of 10.6 kg on average. In addition, early pneumonia had a significant, but marginal, harmful effect on weight gain from six to 14 month by 3.1 kg (Donovan et al., 1998b). As 40 % of the heifers that left the herd before the age of six months did so because of the effect of chronic BRD on growth (selective loss of follow-up), the true impact of the disease on weight gain was likely to be higher (Donovan et al., 1998b). From the studies referred to, it is not known whether or not growth reduction due to BRD is compensated for in later stages of the rearing period.

2.3.1.3 Mortality and culling up to first calving

Heifers that were treated for pneumonia during the first three months of life were 2.4 times more likely to die between 90 and 900 days of age compared to heifers that were not treated for the disease, but BRD did not significantly alter the risk of being culled for beef or sold for dairy (Waltner-Toews et al., 1986b). In accordance with the latter finding, Curtis et al. (1989) reported no effect of respiratory disease before the age of 90 days on the likelihood of being sold thereafter. The effect of early BRD on the likelihood of dying after 90 days was also found to be non-significant (Curtis et al., 1989), in contrast with findings of Waltner-Toews et al. (1986b). In the latter study only more severely diseased heifers were treated and recorded as a morbidity event, whereas BRD need not have been treated in the study of Curtis et al. (1989).

2.3.1.4 Reproduction up to first calving

Heifers that suffered respiratory illness before 90 days of age were half as likely to calve (at any particular age) as heifers without this illness (Correa et al., 1988; Warnick et al., 1994). On the contrary, Waltner-Toews et al. (1986b) found no difference in the percentage of heifers that calved before 900 days of age between heifers with and without calfhood pneumonia.

The median age at first calving of heifers that had BRD before 90 days of age was delayed by three months compared to non-affected herd mates (Warnick et al., 1994). Two other studies reported no difference in age at first calving between heifers that suffered early pneumonia and their non-diseased herd mates (Britney et al., 1984; Waltner-Toews et al., 1986b). The direct effect of BRD on the occurrence of fertility disorders during the rearing period was not investigated.

2.3.1.5 Performance after first calving

Controlling for age at first calving, heifers that showed respiratory disease before 90 days of age were 2.4 times more likely to have dystocia at first calving compared to non-diseased heifers (Warnick et al., 1994). According to the authors, the detrimental effect of early respiratory disease on dystocia as well as on age at first calving might be related to diminished growth; however, this outcome was not measured in the study (Warnick et al., 1994). Both calving interval and proportion of live-born calves per lactation were not different for heifers that had suffered BRD and their non-BRD herd mates (Britney et al., 1984).

The effect of respiratory disease before 90 days of age on longevity after calving, indicated by milking herd life, was found to be non-significant, controlling for age at first calving (Warnick et al., 1997). In accordance with these findings, Britney et al. (1984) reported that the survival distribution from birth to over 96 months of age was not different for heifers that had BRD and their non-BRD herd mates. The latter study also found no difference in milk production, on a lactation basis, between the cohort of heifers that had respiratory disease and their non-affected controls (Britney et al., 1984). Accordingly, data from heifers that survived BRD and remained in the herd long enough to have milk production recorded showed that the disease had no adverse effect on first lactation milk production (Warnick et al., 1995). However, in the latter study the percentage of heifers that survived and were kept as herd replacements tended to be lower for heifers affected by calfhood BRD (Warnick et al., 1995).

To summarise, BRD in dairy heifers increases the risk of mortality directly after the disease episode by approximately 6 times and reduces growth in the short term with up to 10 kg. Whether the short term effects on growth extend into the later breeding and production periods is not clear. BRD does not seem to significantly affect the risk of being culled and/or sold during the rearing period. Results on effects of the disease on mortality in later stages of the rearing period and age at first calving were ambiguous. The risk of dystocia at first calving may be increased, although quantified in one study only. Furthermore, an extended effect of BRD on the heifers' productivity after first calving is unlikely. A potential productivity effect of BRD caused by fertility disorders during the rearing period has not been investigated.

Table 2.2

Managerial risk factors of Bovine Respiratory Disease (BRD) in dairy heifers found significant (P<0.05, ≥2 independent estimates) in epidemiological field studies

Risk factor	Risk factor levels	Effect[1]	Level analysis	Remarks	Study
Season of birth	Winter vs summer	Negative	Calf	Age at first treatment	Waltner-Toews et al. (1986a)
	Winter vs summer	OR[2]=1.93	Calf		Donovan et al. (1998a)
	Jan.-Feb. vs rest year	OR=2.6	Calf	Veterinarian-diagnosed	Virtala et al. (1999)
		OR=3.7	Calf	Farmer-diagnosed	
Geographic region	West vs mid-west	OR=2.6	Herd	High vs low mortality due to BRD	Losinger and Heinrichs (1996)
	South-east vs mid-west	OR=1.8			
	North-east vs mid-west	RR[3]=0.63	Calf	Univariate analysis	Wells et al. (1996)
	South-east vs mid-west	RR=0.49			
Herd size	Per calving per year	OR=1.02	Herd[4]	In winter	Waltner-Toews et al. (1986a)
		OR=1.01		In summer	
	Per heifer present	Increase	Herd		Kimman et al. (1988)
	Per heifer present	Increase by 0.12 times	Herd	Logit pneumonia, farmer-diagnosed	Van Donkersgoed et al. (1993)
		Increase by 0.04 times	Herd	Logit pneumonia, veterinarian-diagnosed	
	≥6 vs ≤5 preweaned heifers in herd	RR=2.2	Calf	Univariate analysis	Wells et al. (1996)
	Per animal present (incl. adults)	HR[5]=1.02	Herd		Norström et al. (2000)
Genetics	Various sires	OR per sire	Calf		Waltner-Toews et al. (1986a)
	Pure vs crossbred	RR=0.47	Calf		Perez et al. (1990)
	Holstein relative to dairy and crossbred calves	Increase by 4.11 times	Herd	Logit pneumonia, farmer-diagnosed	Van Donkersgoed et al. (1993)
		Increase by 2.92 times	Herd	Logit pneumonia, veterinarian-diagnosed	
Navel treatment	Other than chlorhexidine or iodine vs not	OR=2.94	Calf		Waltner-Toews et al. (1986a)
	Yes vs not	RR=0.41	Calf		Perez et al. (1990)
Antimicrobials preventively/previous use	Yes vs not	OR=0.46	Calf		Waltner-Toews et al. (1986a; 1986d)
	Yes vs not	OR=0.40	Herd[4]	In winter	Waltner-Toews et al. (1986a)
	Yes vs not	OR=0.2	Calf	Farmer-diagnosed	Virtala et al. (1999)

Table 2.2, *continued*

Risk factor	Risk factor levels	Effect	Level analysis	Remarks	Study
Maternal antibody level	Specific IgG titre (classes)	Decrease	Herd		Kimman et al. (1988)
		Decrease	Herd	Disease severity (scored)	
	Proportion (1 vs 0) serum positive titres to IgG (> 800 mg/dl) in herd	OR=0.41	Herd	Univariate analysis, veterinarian-diagnosed	Van Donkersgoed et al. (1993)
	Serum total protein (g/dl)	Decrease	Calf	Curvilinear association	Donovan et al. (1998a)
		OR=0.90	Calf	Ln(treatment days)	
	IgG ≤ 1200 mg/dl vs > 1200 mg/dl	OR=1.9	Calf	Veterinarian-diagnosed	Virtala et al. (1999)
Colostrum feeding	Assisted vs suckled	OR=3.31	Calf		Waltner-Toews et al. (1986a)
Colostrum feeding x time of birth	Pail feeding x day-born calves	OR=19.15	Calf		Waltner-Toews et al. (1986a)
Housing	Outdoor vs indoor	Increase	Calf	Mortality due to BRD	Peters (1986)
	Outdoor hutches vs individual inside pens	OR=0.04	Calf		Waltner-Toews et al. (1986a)
	Individual stall vs pens	RR=5.4	Calf	In one season-year only	Curtis et al. (1988a)
	Outdoor hutches vs pens	RR=5.1			
	Separate from older heifers vs in same building	Decrease	Herd		Kimman et al. (1988)
	Inside/outside hutches vs not	OR=0.5	Calf	Veterinarian-diagnosed	Virtala et al. (1999)
		OR=0.4	Calf	Farmer-diagnosed	
	In presence of adults vs not	OR=1.9	Calf	Veterinarian-diagnosed	Virtala et al. (1999)
Other diseases previously	Scours <14 days vs not	RR=2.5	Calf		Curtis et al. (1988a)
	Previous diarrhoea vs not	RR=3.8	Calf		Perez et al. (1990)
	Arcsin(scours <14days)$^{0.5}$ vs not	OR=4.9	Herd		Curtis et al. (1993)
	Scours <weaning vs not	OR=3.0	Calf		Waltner-Toews et al. (1986a)
Other diseases simultaneously	Scours <90 days vs not	RR=3.1	Calf		Curtis et al. (1988a)
	Scours <14 days x dullness <90 days vs not	RR=6.0	Calf		Curtis et al. (1988a)
	Scours <90 days x dullness <90 days vs not	RR=6.3	Calf		Curtis et al. (1988a)
	Scours <weaning vs not	OR=2.2	Herd[4]	Above-median scours treatment days, in winter	Waltner-Toews et al. (1986a)
		OR=3.0		In summer	
	Dullness <90 days vs not	RR=7.7	Calf		Curtis et al. (1988a)
	Arcsin(dull <90 days)$^{0.5}$ vs not	OR=23.7	Herd		Curtis et al. (1993)

[1]If not stated otherwise, effects refer to the disease as defined in the particular study (see Appendix 2.1)
[2]Odds ratio
[3]Relative risk
[4]Above-median treatment days per calf
[5]Hazard risk

2.3.2 Risk factors

2.3.2.1 Season and region

The frequency of BRD was reported to be higher in the winter months as compared to the summer period of the year (Perez et al., 1990). Heifers born during the winter (indoor) season were at increased risk for BRD (Donovan et al., 1998a; Virtala et al., 1999), and treated sooner (age first treatment) (Waltner-Toews et al., 1986a) than those born during the summer (outdoor) season. However, others could not confirm these findings (Curtis et al., 1988b; Perez et al., 1990; Olsson et al., 1993; Wells et al., 1996). All these studies had relatively short observation periods, varying from about a year (Perez et al., 1990; Olsson et al., 1993; Wells et al., 1996; Donovan et al., 1998a; Virtala et al., 1999) to nearly two years (Curtis et al., 1988b) or 2.5 years (Waltner-Toews et al., 1986c).

Data collected nationally on dairies in the USA showed that both the frequency of BRD (Wells et al., 1996) and mortality rates attributable to the disease (Losinger and Heinrichs, 1996) varied significantly with region.

2.3.2.2 Herd size

Many studies found the frequency of BRD to be positively associated with herd size (Waltner-Toews et al., 1986a; Kimman et al., 1988; Van Donkersgoed et al., 1993; Wells et al., 1996; Virtala et al., 1999; Norström et al., 2000), although this effect could not be confirmed by two other studies (Curtis et al., 1988a; Olsson et al., 1993). The reason underlying the effect of herd size is unknown. It was proposed that the larger herds might be at increased risk of BRD due to more indirect contacts with other herds. In addition, in a large herd any infectious agent may establish itself more easily because of greater degree of animal-to-animal contact (Norström et al., 2000). Herd size may also be an indirect measure for other management variables, such as stocking density and overcrowding (Curtis et al., 1988a; Van Donkersgoed et al., 1993; Wells et al., 1996).

2.3.2.3 Genetics and milk production

Pneumonia frequency during the pre-weaning period was affected by the sire of the heifers, although this finding was primarily driven by a few bulls whose daughters experienced higher treatment rates for pneumonia than the ones from other bulls (Waltner-Toews et al., 1986a). In addition, several studies reported BRD to be associated with breed (dairy versus cross breeds) but their findings were ambiguous (Perez et al., 1990; Van Donkersgoed et al., 1993), and others found no effect (Olsson et al., 1993; Virtala et al., 1999). The associations between BRD, sire and breed could have been partly related to the genetic component of calving ease, as selected for in long term breeding policy of the farmer (Waltner-Toews et al., 1986a; Perez et al., 1990) or by differences in genetic susceptibility to disease (Van Donkersgoed et al., 1993).

Herds with high milk production were found to be less likely to have a high mortality rate due to BRD as compared to herds that had low milk production. This might have been related to genetic differences as well as to better management of the high producing herds (Losinger and Heinrichs, 1996).

2.3.2.4 Preventive treatment of dam

BRD was not found to be associated with prepartum vaccination of the dam against one or more of the most common respiratory viruses, including BRSV (Van Donkersgoed et al., 1993; Sivula et al., 1996a). Prepartum vaccination of dams against scours was associated with an increased risk for pneumonia, both at the herd and the animal level (Waltner-Toews et al., 1986a). Others found no relation between prepartum vaccination of the dam against *Escherichia coli* and BRD (Curtis et al., 1988a; Sivula et al., 1996a). The prepartum administration of vitamins or selenium was not associated with BRD (Waltner-Toews et al., 1986a).

2.3.2.5 Calving factors

Heifers from primiparous cows were more likely to develop BRD compared to heifers of multiparous cows (Curtis et al., 1988a), however, a tendency for the opposite (Perez et al., 1990) or no association (Olsson et al., 1993) were also reported. Other variables related to calving ease, such as calving history, dystocia at birth and (routinely) assisted deliveries, were not found to be associated with the risk of BRD (Waltner-Toews et al., 1986a; Curtis et al., 1988a; Perez et al., 1990; Sivula et al., 1996a).

Heifers born on pasture were shown to have shorter duration of pneumonia treatment compared to non-pasture births, as well as better two week weight gains (Waltner-Toews et al., 1986a). Furthermore, a good hygiene at the place of birth has shown to be protective (Virtala et al., 1999). Other studies found no relationships between birth place (Curtis et al., 1988a; Perez et al., 1990; Sivula et al., 1996a; Virtala et al., 1999) or related variables (Curtis et al., 1993; Sivula et al., 1996a) and the frequency of BRD.

2.3.2.6 Preventive treatment

The effect of navel disinfection of the new-born heifer on the risk of BRD is ambiguous. Perez et al. (1990) reported a protective effect, but authors of two other studies reported no effect of routine navel treatment on pneumonia risk at the herd level (Waltner-Toews et al., 1986a) and, in particular, chlorhexidine or iodine at the individual level (Waltner-Toews et al., 1986a; Sivula et al., 1996a). Moreover, using anything other than these two products, versus no navel treatment, was found to increase the new-born heifer's odds for pneumonia (Waltner-Toews et al., 1986a).

A herd policy of using a medicated milk replacer or starter (Waltner-Toews et al., 1986a) and the prophylactic or previous administration of antimicrobials to individual heifers decreased the odds for pneumonia treatment (Waltner-Toews et al., 1986a; Waltner-Toews et al., 1986d; Virtala et al., 1999). However, Sivula et al. (1996a) found no effect of routine injection of antibiotics at birth. In the latter study pneumonia risk was increased for farms that routinely fed a coccidiostat before weaning (Sivula et al., 1996a). Others reported a detrimental effect of offering mineral supplements on the farm's pneumonia treatment days in winter (Waltner-Toews et al., 1986a). Vaccination of the new-born heifer against scours and administration of vitamins or selenium were not significantly associated with BRD (Weiss et al., 1983; Waltner-Toews et al., 1986a; Curtis et al., 1988a; Sivula et al., 1996a; Virtala et al., 1999). However, a study on *Escherichia coli* vaccination held on a large dairy heifer raising facility reported a protective effect on the risk of respiratory disease (Daigneault et al., 1991).

In a double blind field trial by Verhoeff and Van Nieuwstadt (1984), a live attenuated BRSV vaccine provided some protection against lower respiratory disease in dairy heifers. In two other studies, no effect of preventive vaccination of heifers against BRSV (Ploeger et al., 1986) or against one or more respiratory viruses, including BRSV (Sivula et al., 1996a) was found. Accordingly, a study on the use of prophylactic vaccination with *Pasteurella haemolytica* reported no effect on the frequency of respiratory disease in dairy heifers (Stevens et al., 1997).

2.3.2.7 Colostrum feeding

New-born heifers with failure of passive transfer of colostral immunoglobulins were at increased risk for pneumonia compared to heifers that received adequate colostral antibodies (Kimman et al., 1988; Van Donkersgoed et al., 1993; Donovan et al., 1998a; Virtala et al., 1999). Failure of passive transfer is also reported to increase the severity of clinical signs (Kimman et al., 1988) and the number of treatment days required (Donovan et al., 1998a). The odds for pneumonia treatment was increased for new-born heifers that were assisted to suckle colostrum, perhaps because they may have been weak to begin with (Waltner-Toews et al., 1986a). Furthermore, heifers that were given first colostrum by pail, specifically those born during the day, were at increased risk for pneumonia compared to heifers that suckled (Waltner-Toews et al., 1986a). The authors suggested that night-born heifers were more likely to have suckled before morning when the farmer would initiate pail feeding. Despite its often stated value, several studies did not find method of colostrum feeding or related variables, such as time post-partum at which colostrum was first offered and amount of first colostrum feeding or intake, to be associated with BRD (Waltner-Toews et al., 1986a; Curtis et al., 1988a; Perez et al., 1990; Curtis et al., 1993; Olsson et al., 1993; Sivula et al., 1996a; Virtala et al., 1999).

2.3.2.8 Weaning and feeding management

The decision to wean heifers, based on age, weight, or grain intake, was not associated with the risk of BRD (Sivula et al., 1996a), although size-based weaning tended to increase the herd's chance for BRD (Curtis et al., 1993).

Both farms that offered fresh water to heifers and farms that used pail feeding, as opposed to nipple feeders, subsequent to the colostral period had reduced odds of having above-median winter pneumonia treatment days (Waltner-Toews et al., 1986a). Heifers that were fed more than five litres of milk replacer daily had a greater risk of BRD than those that were fed less than this quantity (Perez et al., 1990). Others did not find these variables or numerous other variables related to feeding after the colostral period, such as type of liquid feed fed, frequency of feeding, and age at which starter was first offered, to be associated with BRD (Waltner-Toews et al., 1986a; Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996a; Virtala et al., 1999).

2.3.2.9 Housing

Heifers raised in outdoor hutches were less likely to be treated for pneumonia compared to heifers raised in inside individual pens (Waltner-Toews et al., 1986a). Accordingly, Virtala et al. (1999) reported that housing in hutches, either indoors or outdoors, decreased the probability for developing pneumonia. In another study, initial housing was found to affect BRD frequency, but effects were conditional on season and year and without consistent trends (Curtis et al., 1988a). In an observational study on an intensive heifer rearing unit the incidence of pneumonia was not affected by group versus individual housing nor by outdoor versus indoor housing, however, mortality rates were higher for pneumonic heifers housed outdoors compared to those housed indoors (Peters 1986). Housing young heifers in the same building with the older ones (Kimman et al., 1988) or with adult cattle (Virtala et al., 1999) has been reported to increase the risk of respiratory disease. Accordingly, Ploeger et al. (1986) reported a negative relationship between contact of young heifers with older cattle at pasture or after stabling and the onset of clinical BRSV infections. In contrary to its often recognised value, several others found no association between housing and BRD (Perez et al., 1990; Curtis et al., 1993; Van Donkersgoed et al., 1993). Two factors related to housing that affected the risk of BRD included additional artificial light and frequency of changing bedding material (Perez et al., 1990), although an effect of the latter factor was not confirmed by another study

(Sivula et al., 1996a). Several other housing variables, such as bedding condition and floor type, were not found to be associated with BRD (Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996a; Virtala et al., 1999).

Dairies that housed pre-weaning heifers individually or in groups of six or less were less likely to be classified in the high respiratory mortality rate category opposed to dairies that housed heifers in groups of seven or more (Losinger and Heinrichs, 1996). On the contrary, Kimman et al. (1988) found no correlation between population density and respiratory disease. Criteria used for grouping of heifers after weaning (Curtis et al., 1993; Sivula et al., 1996a) and flow through group pens (Sivula et al., 1996a) were not found to be related with BRD.

2.3.2.10 Other diseases

Diarrhoea occurring either previously to BRD (Curtis et al., 1988a; Perez et al., 1990; Curtis et al., 1993) or during the same period (Waltner-Toews et al., 1986a; Curtis et al., 1988a) increased the risk of respiratory illness 2 to 6 times, although this association could not be confirmed by Virtala et al. (1999). Authors of the latter study argued they probably have missed cases of diarrhoea. BRD and diarrhoea might be caused by common agents, similar husbandry practices might predispose to both diseases, heifers with diarrhoea might be more susceptible to BRD than others, or once a heifer has been treated for diarrhoea, veterinarians and farmers may watch it more closely and diagnose respiratory disease earlier compared to other heifers (Waltner-Toews et al., 1986a). Heifers that were dull, but exhibited no other detectable signs, before the age of 90 days were more likely to have BRD compared to their non-affected herd mates (Curtis et al., 1988a; Curtis et al., 1993). Dullness may in part be a separate entity, but could also be a sign of BRD (Curtis et al., 1993).

To summarise, herd size and other diseases, especially diarrhoea, are evidently associated with the on-farm risk of BRD in dairy heifers, and season and colostrum feeding management presumably affect this risk. Effects of birth circumstances, housing and prophylactic administration of antimicrobials are less clear, as are effects of region, genetics, and milk production. Preventive vaccination does not affect the frequency of BRD, with the exception of vaccination against BRSV, which might be protective. Navel-disinfection, preventive treatment of the dam prior to calving and the basis for the weaning decision do not seem to affect BRD frequency. Little work has been done on the association between feeding management after the colostral period and BRD.

2.4 Discussion

This review was restricted to peer-reviewed literature to ensure that the data obtained are of high quality and easily accessible. Furthermore, as the variables of interest entailed multiple effects and interactions, the major interest was in epidemiological field studies, taking into account the entire farm system. Moreover, the findings had to be applicable to commercial dairy farms, hereby excluding infectious experiments. The selection criteria applied resulted in observational field studies, the majority of which were from the USA, and only a few from Europe (The Netherlands). Therefore, care must be taken when extrapolating the results to Dutch dairy farming conditions.

Findings of this review revealed that BRD reduces the heifers' productivity, but associations between the disease and the various production parameters, as well as their magnitude, could not always be clearly demonstrated. The same accounts for the risk factors of BRD in dairy heifers. Thus, at date, quantitative insight into the productivity effects and the risk factors of BRD in dairy heifers is lacking. Hence, a precise evaluation of the economic losses due to BRD and the cost-effectiveness of preventive actions against the disease can not yet be made. However, from the study findings several general recommendations for BRD prevention can be made that apply to heifers raised on dairy farms in the Netherlands or under comparable conditions.

The first option would be to ensure that the new-born heifer receives enough colostral immunoglobulins soon after birth. Furthermore, measures that reduce the on-farm frequency of both BRD and other illnesses in dairy heifers, in particular diarrhoea, are promising. In this perspective, improvement of the heifer's birth place and housing circumstances, e.g., by using outdoor hutches, seem to be important as well (Waltner-Toews et al., 1986a; Curtis et al., 1988a; Perez et al., 1990; Frank and Kaneene, 1992; Curtis et al., 1993). As the latter factors seem to be associated with BRD from the current study findings and are known to be important from earlier work, future research should focus on further quantification of their impact. Given the fact that less than 10 % of heifers raised on commercial Dutch dairy farms is housed in individual hutches (Mourits et al., 2000) more research on the impact of this factor is justifiable as well.

Herd size and intensity, milk production and breed vary widely among Dutch dairy farms (Mourits et al., 2000) and might have a considerable impact on the on-farm frequency of BRD. However, these factors can not easily be modified, hence, are not relevant for short-term prevention of the disease. The association between herd size and BRD might be related with the concepts of herd immunity; the greater the herd size, the more likely it is that both infectious and susceptible animals will be present, maintaining the spread of infection on the farm. Therefore, at the large dairy farm prevention of BRD should in particular be aimed at measures that increase the animal's resistance against clinical disease, e.g., by adequate colostrum management.

The effect of season may be important to the frequency of BRD on Dutch dairy farms because of the general preference of calving during autumn and winter due to higher milk prices in this period of the year (Mourits et al., 2000). Winter calvings almost always occur indoors, resulting in many heifers born and raised in less favourable conditions for BRD prevention. Changing the calving pattern to summer, on pasture, calvings may reduce the on-farm frequency of BRD.

The effect of preventive vaccination of the new-born heifer against BRSV was not investigated exhaustive but might be beneficial. Data of the referred survey (Mourits et al., 200) showed that new-born heifers are vaccinated against BRSV on 30 % of the Dutch dairy farms, hence, the impact of this factor should be further investigated in a series of well-designed field trials.

The studies on the productivity effects and/or risk factors of BRD in dairy heifers focused on the disease occurring before the age of six months only, and not thereafter. Data from Dutch dairy farms (Mourits et al., 2000) learned that BRD also occurs after the age of six months, although less frequently than in the first few months of life. However, due to the higher age of affected heifers, the economic impact of the disease might be substantial. Thus, future research should include heifers older than six months.

2.5 Conclusion and future outlook

At present, an overall quantitative insight into the productivity effects and risk factors of BRD in Dutch or comparable raised dairy heifers is lacking. Findings on most of the parameters are either incomplete or ambiguous. Hence, quantitative data to accurately evaluate the economic losses due to BRD on the Dutch dairy farm and the cost-effectiveness of prevention actions against the disease is lacking. More research is needed to obtain the necessary data, preferably held by means of well-designed prospective observational field studies that take into account the relevant factors at the same time. These studies should not only focus on the pre-weaning period but on the complete period from birth to calving. However, such field studies probably are difficult to complete successfully as well as expensive and time-consuming.

An alternative way of conducting disease impact and risk factor research that makes use of expert knowledge in a formal manner may be utilised (Goossens et al., 1996, Cooke and Goossens 1999). Expert data on the productivity effects and risk factors of BRD in dairy heifers, added to the information available, may provide useful information for evaluation of the economic consequences of the disease and its prevention. Such enhanced quantitative economic insight will support the decision-making process with regard to the prevention of BRD on the dairy farm.

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Appendix 2.1

Background information on epidemiological field studies on productivity effects and/or risk factors of Bovine Respiratory Disease (BRD) in dairy heifers

Region, Country	Period of data collection	Number herds	Number animals	Study period	Basis of diagnosis of respiratory disease	Crude BRD incidence (%)	Authors
Ontario, Canada	Born during almost 8-year period	2[1]	460[2]	Birth to 4 months	Clinical signs and treatment for BRD, by farmer and/or veterinarian	about 5.8	Britney et al. (1984)
UK	Entering during 3.5-year period	1[3]	1996	1 week to 6 weeks	Clinical signs of pneumonia, by farmer and/or veterinarian	48.3	Peters (1986)
The Netherlands	Cross-sectional	123	-	-	Clinical BRSV infection, confirmed by veterinarian	18.5[4]	Ploeger et al. (1986)
Ontario, Canada	Born during 2.5-year period	35	1968	Live-born to weaning	Treatment for pneumonia, by farmer	15.4	Waltner-Toews et al. (1986a; 1986c)[5]
New York, USA	Born during almost 2-year period	26	1171	1 to 90 days	Clinical signs of BRD, by farmer	7.4	Curtis et al. (1988b)[6]
Friesland, The Netherlands	Present at start and born during 3-month period	21	434	Birth to 1 year	Clinical signs of BRD, by farmer and/or veterinarian	-	Kimman et al. (1988)
Utrecht, The Netherlands	Born during 1-year period, followed until last-born was 4 months	63	919	Birth to 4 months	Clinical signs of BRD, by veterinarian	5.8	Perez et al. (1990)
Sweden	Born during about 1-year period, followed until last-born was 3 months	131	4839[2]	Live-born to 90 days	Clinical signs of coughing/ pneumonia, by farmer	0.8	Olsson et al. (1993)
		-	885[2]	91 days to 12-15 months		1.6	
Saskatchewan, Canada	Born during 4.5-month period, followed until last-born was 6 months/end study	17	325[2]	Birth to 6 months/end of study	Clinical signs of pneumonia, by veterinarian	26	Van Donkersgoed et al. (1993)
					Treatment for pneumonia, by farmer	39	

Appendix 2.1, *continued*

Region, Country	Period of data collection	Number herds	Number animals	Study period	Basis of diagnosis of respiratory disease	Crude BRD incidence (%)	Authors
28 states, USA	3-month period, retrospective	1685	47,057	Birth to weaning	Mortality due to BRD, by farmer	-	Losinger and Heinrichs (1996)
Minnesota, USA	Born during 1-year period, followed until last-born was 16 weeks	30	845	Birth to 16 weeks	Treatment for pneumonia, by farmer	7.6	Sivula et al. (1996a)[7]
New York, USA	Born during 1-year period, followed until last-born was 3 months	18	410	Birth to 3 months	Clinical signs of BRD, by veterinarian	25.6	Virtala et al. (1996a)[8]
					Treatment for BRD, by farmer unless done on advice of veterinarian	11	
					Treatment for BRD, by farmer and verified by veterinarian	17.3	
28 states, USA	Present at start and born during 1-year period	906	12,228	Live-born to 8 weeks	Clinical signs of BRD, by farmer	8.4	Wells et al. (1996)[9]
Florida	Born during 1-year period, followed until age of 6 months	2	3103	2 days to 6 months	Clinical signs and treatment for pneumonia, by farmer	21	Donovan et al. (1998a; 1998b)
				6 to 14 months		1	
2 veterinary districts, Norway	5-month period, retrospective	431[10]	-	-	Cinical signs of herd outbreak of BRD, by veterinarian	35[4]	Norström et al. (2000)

[1]Institutional herds
[2]Few males included
[3]Intensive rearing unit with dairy bred calves
[4]Herd level incidence
[5]Data also used by Waltner-Toews et al. (1986b; 1986d)
[6]Data also used by Correa et al. (1988), Curtis et al. (1988a; 1989; 1993), Warnick et al. (1994; 1995; 1997)
[7]Data presented in Sivula et al. (1996b)
[8]Data presented in Virtala et al. (1996b), data also used by Virtala et al. (1999)
[9]More information presented on http://www.aphis.usda.gov/vs/ceah/cahm/dairy_cattle
[10]Various herd types with dairy cattle of all ages

Chapter 3

Risk factors for Bovine Respiratory Disease in dairy heifers in the Netherlands; the perception of experts

Paper by Van der Fels-Klerx, H.J., Horst H.S., Dijkhuizen, A.A.
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Abstract

This Chapter describes a study aimed at quantification of expert opinion on risk factors for Bovine Respiratory Disease (BRD) in dairy heifers in the Netherlands. For this purpose, a panel of 21 experts working in the field of BRD was selected. The total expert elicitation process consisted of five different stages and included four stages that comprised questionnaires held by mail and a one-day group meeting (last stage). During the expert consultation different elicitation methods were used, such as the Delphi procedure and Adapted Conjoint Analysis (ACA).

The most important risk factor for, respectively, mild and severe pneumonia in dairy heifers aged 0-3 months was perceived to be '(poor) air circulation' and 'purchase of cattle'. The latter risk factor was also considered as having the highest impact on the incidence of severe outbreak cases in dairy heifers aged 3-6 months, whereas 'previous BRD' was considered to be the most important risk factor for mild outbreak cases. Outbreaks (both mild and severe) in dairy heifers aged 6-24 months were perceived to be influenced most by 'air circulation'.

3.1 Introduction

'Bovine Respiratory Disease' (BRD) is important to the dairy industry, especially to rearing of replacement heifers, because of the losses associated with both treatment and reduced performance of the affected animals. Insight into the risk factors for BRD can help farmers to improve their rearing system in attempt to reduce the risk and/or incidence of the disease on their farms. The risk factors for BRD in dairy heifers were investigated both at the farm and the animal level in several epidemiological studies (Waltner-Toews et al., 1986; Curtis et al., 1988; Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996). The results of the majority of these studies might not be relevant to dairy heifers elsewhere because of differences in rearing conditions of the heifers under consideration. Moreover, the results of the studies reviewed varied widely.

To review and complement data that are available from literature, useful information can be obtained by eliciting expert opinion and experiences (Cooke, 1991; Meyer and Booker, 1991). Expert judgement data has been widely used in management and technical science (Meyer and Booker, 1991). Several previous studies showed that elicitation of expert knowledge in the field of veterinary epidemiology and economics is of extra value (Horst et al., 1996; Stärk et al., 1997; Horst et al., 1998; Van Schaik et al., 1998).

This Chapter describes a study aimed at the quantification of expert information with regard to risk factors related to the incidence of BRD in dairy heifers in the Netherlands. The focus of this study was to identify and rank the most important risk factors for the disease.

3.2 Material and methods

3.2.1 Participants

At the beginning of 1998, 22 people who had been working in the field of BRD for several years and often are consulted as experts on the disease in dairy practise were approached to join the expert panel. Except for one person, all these experts responded positively. Two experts came from Belgium and the other 19 were Dutch. The experts' background varied from practice to research, but many had had recent experiences in both these fields. At the time of the expert consultation, the experts had an occupation at the government (3 persons), the Animal Health Service (5 persons), the Institute for Animal

Science and Health (3 persons) or other institutes (2 persons), or were veterinary practitioners (8 persons).

3.2.2 Design expert elicitation process

The total expert elicitation process consisted of five different stages held over a total period of eight months. Stage 1 to 4 were done by mail, whereas the last stage included a one-day workshop (group meeting). In each of the first four stages the so-called Delphi procedure was used to reach a consensus among the experts (Cooke, 1991; Meyer and Booker, 1991). These stages, therefore, could include several mailings (iterations). The Delphi stages focused on qualitative aspects of BRD, especially the definition of BRD, classes to be distinguished with respect to BRD type, severity of disease and age of heifers, and the definitions of each of these classes. Furthermore, the experts were asked to define, select and rank the most important risk factors[1] for the incidence of BRD, assuming the disease (agents) to be present on the farm. Different types of BRD, disease and age classes were distinguished because the incidence and/or risk factors for the disease were expected to differ between the various classes considered. To select the most important risk factors, the experts were asked to 1) complement an extensive list of risk factors based on a literature search, 2) select a set of ten (at the most) most important risk factors from this list (including the ones added), and 3) rank these risk factors according to their impact on the incidence of BRD. They were asked to go through the last two steps for each of three different combinations of BRD type, age and disease class ('BRD combinations') separately.

During a one-day workshop (stage 5) the relative importance of the various risk factors for each of the BRD combinations considered was quantified using fully computer-supported questionnaires. These questionnaires were based on a method called 'Adapted Conjoint Analysis (ACA)' and designed using ACA software (Sawtooth Software, Evanston, IL).

3.2.3 Adaptive Conjoint Analysis

<u>*3.2.3.1 The ACA questionnaires*</u>

ACA is based on the principles of conjoint analysis, a questionnaire technique frequently used in marketing and consumer research in order to elicit the consumers' preference for a product (Green and Srinivasan, 1990). Products are thought of as

[1]Prophylactic vaccination against BRD was not considered

possessing specific levels of defined characteristics or attributes. The consumer has a certain preference for each of the different attribute levels, and the product-specific combination of these attributes determines the consumer's overall preference for the particular product (Steenkamp, 1987; Metenagro, 1994). ACA's main distinguishing characteristic is its computerised administered format which is customised to each respondent (explaining the term 'adaptive' of ACA). Data are analysed as the interview progresses so that the respondent is asked in detail only about those attributes he/she indicated to be most important. This approach minimises the number of questions and the time required to complete the interview, and therefore avoids fatigue bias (Metenagro, 1994). Using ACA, respondents can work with a large number of attributes and levels in relatively short a time: up to ten attributes with nine levels each (with the various attribute levels satisfying the requirement of independence) in the current system used.

In the context of the current study, a 'product' stands for a farm situation with attributes in this case representing risk factors that increase the risk and/or incidence of BRD on the farm. For example, a farm could be characterised by one of the levels of the risk factor 'house type', including 'closed barn', 'open front stall' or 'porched stall'. In the ACA interview, the experts were asked to judge the various risk factors for their expected impact on the incidence of BRD on the farm. The ACA interview consisted of several sections, each with a specific purpose, which proceeded each other in a fixed order. First, the experts were asked to rank the levels (per risk factor) with regard to their impact on the on-farm incidence of BRD, and to rate the relative importance of each risk factor. After this first section, the most important risk factors together with their most salient levels were known and the initial estimates of the relative importance of the risk factor levels were calculated by the program. In the following section, i.e., the 'paired-comparison' section, the experts were asked to compare several pairs of farm concepts or 'profiles', and to rate the difference (in expected farm incidence of BRD) between each of the two profiles. The two profiles of a pair each consisted of two or three (identical) risk factors with differences in one or more risk factor levels. An example of a pair of profiles is given below:

Profile 1	Profile 2
Poor ventilation	Adequate ventilation
High density	Low density
Adequate bedding	Poor bedding

The ACA program selects each profile according to earlier answers given by the expert in order to maximise the information gain while still limiting the number of combinations of profiles to be evaluated. After each paired-comparison response, the additional scores provided by the expert are used to update the expert's relative importance values for the various risk factors, and a new profile is chosen. In the final section, each expert was provided with a series of customised profiles or 'calibrating concepts', each consisting of several risk factor levels. These profiles were chosen to cover the entire range of their expected farm incidence of BRD based on the expert's earlier answers. The profiles were presented one-at-the-time and the experts were asked to give an overall rate (scale 0 to 100) for the expected farm incidence of BRD. ACA uses the information gained in this section to calibrate the (individual) experts' estimates for the risk factors, and to calculate the internal consistency of their answers. The consistency is expressed by the correlation coefficient R^2 that varies between 0 (very inconsistent) to 1 (very consistent). It is estimated by comparing the expected responses to the customised profiles (based on answers given previously) and the expert's actual response (Metenagro, 1994). After the interview is completed the experts' correlation coefficients are directly available. Respondents having answered the interview inconsistently could be excluded from further analyses. According to Horst et al. (1998) results of inconsistent respondents should not be included in the analysis, regardless of the fact that they are outliers or not, to avoid a false sense of reliability.

Conjoint analysis is a so-called 'de-compositional' method. It starts with the respondent's overall judgement of a profile, and breaks this total score down into the contributions of its attributes, also so-called 'part-worth scores', using ordinary least squares regression analysis. Thus, in this case the expert's total score for a farm concept was broken down into its components belonging to the separate risk factors. These part-worth scores indicated the influence of each risk factor on the expert's judgement for the particular farm profile. The scores given by the respondent are evaluated applying the following additive model:

$$\text{profile score} = \beta_0 + \beta_1 * x_1 + \ldots + \beta_n * x_n$$

In this formula, the profile score is the (overall) score given by the respondent to a particular profile, β_0 is the intercept (a constant), the β_{1-n} are the estimated coefficients (part-worth scores) associated with the attributes (risk factors in this case), and the x_{1-n} represent the attribute levels (with value 0 = attribute base level and value 1 = attribute level). Interactions were not taken into account as the risk factors were assumed to be independent. Besides, also when interaction occurs the additive model typically shows high robustness (Steenkamp, 1987). The relative importance of each risk factor is estimated as its regression coefficient divided by the total sum of coefficients (thus, all relative importances together add up to 100 %).

At first sight, more 'direct' methods to quantify systematic components that underlie people's evaluation of objects, such as direct questioning, may look less complicated. Such compositional methods ask respondents to assess values for attributes, and use these values to construct overall judgements for attribute profiles (Huber, 1974). However, many researchers have compared the predictive performance of Conjoint Analysis with self-explicated approaches and in most studies Conjoint Analysis outperforms the latter (Green et al., 1983; Huber et al., 1993). For a more detailed description of Conjoint Analysis the reader is referred to Green and Srinivasan (1990); an exhaustive description of the backgrounds and estimation procedure of ACA can be found in Metenagro (1994) and Johnson (1987 and 1993).

3.2.3.2 The ACA sessions (workshop)

A different ACA questionnaire was drawn up for each BRD combination considered because the risk factors for BRD as well as the relative importance of their levels (might) differ between the different BRD types, disease severity classes and/or age classes. The risk factors together with their levels considered in each BRD combination as well as their definitions were based on the results of the Delphi stages. The ACA questionnaires were pre-tested by 19 people who had a background in veterinary medicine and/or animal science and were currently working at the Faculty of Veterinary Medicine in the Netherlands or the Department of Social Sciences in the Netherlands.

During the workshop each expert was provided with a personal computer to work on the self-explanatory ACA questionnaire individually and independently from the other experts. In this way interaction between the participants as well as between the participants and the workshop facilitators was minimised. Each expert was given two different ACA questionnaires held in two consecutive ACA sessions. The ACA questionnaires were distributed among the experts such that each BRD combination was evaluated by about the same number of experts. Half of the experts who evaluated a particular BRD combination did this during the first ACA session, and half of the experts did so during the second one. Each expert was provided a handout with the definitions of the risk factors (as defined during the Delphi stages) for use during the ACA task at hand. Directly after each ACA session, the experts were asked to evaluate the particular ACA interview by completing a written questionnaire. This questionnaire consisted of five questions about, for example, the realism of the profiles and the clarity of the descriptions of the risk factors. The questions had to be answered by giving a score on a scale of 1 to 5, in which 1 meant bad and 5 very good. After the workshop, each expert was sent an overview of his/her own estimates of the relative importance of the risk factors for BRD, together with the average results of all experts. The experts were asked to check whether their estimates given during the ACA sessions reflected their true opinion.

3.2.3.3 Analyses

All questionnaires that had a consistency level of 0.6 or higher were included in the analyses. The relative importance estimates of the various risk factor levels were evaluated for each BRD combination, separately. First, the relative importance values of the various risk factor levels, provided at the individual level, were standardised so that they could be compared among the experts. This was done in such a way that, for each respondent, the sum of the importance values across all risk factor levels was equal to the number of risk factors times 100. Next, these values were converted to percentages, and the median relative importance value (percentage) of the combined group of experts was calculated for each level.

The risk factors were ranked according to their relative importance. For each risk factor, the rank was based on the (median) relative importance value of the level of that risk factor that was considered most important, i.e., received the highest (median) importance value. As the relative importance values of some of the risk factors levels were not normally distributed, a non-parametric Spearman Rank Correlation test ($\alpha<0.05$) was used to investigate differences in the ranking of the risk factors within disease classes using a (higher) cut-off value of 0.8, as well as between two different disease classes of a particular combination of BRD type and age class. All data transformations and analyses were done using SPSS 8.0 (Norusis, 1993).

3.3 Results

3.3.1 Delphi stages

3.3.1.1 Response

Four of the 21 experts responded to the first two Delphi stages only, and not to the other ones. The majority of the other 17 experts responded to each Delphi stage. In each of these stages, the experts agreed on the subjects of the particular stage after two to five mailings. On average, 15 experts (not always the same people) responded to the eight mailing rounds held in total.

3.3.1.2 Definition and classes

BRD in dairy heifers between birth and two years of age was defined as 'a clinical disease of the respiratory tract caused by a viral, bacterial or mycoplasmal infection (parasites excluded) or a combination of these infections'. Heifers were divided into three age classes with regard to BRD: a) 0-3 months, b) 3-6 months, and c) 6-24 months. Two types of BRD, being pneumonia and 'BRD outbreaks', were distinguished and defined as follows:

Calf pneumonia: BRD cases seen one after the other, periodically or whole year round, mostly occurring in heifers < 3 months of age. These cases can be caused by a variety of primary pathogens, but commonly are caused by bacteria, mainly *Pasteurella spp.*, with a previous infection with respiratory viruses.

BRD outbreaks: A certain number of animals in a group suddenly shows clinical signs of BRD. Outbreaks of BRD mostly occur during the housing period, but also regularly during the grazing period. Mainly dairy heifers aged ≥ 3 months are affected, but also regularly < 3 months. BRD outbreak cases are mostly caused by a primary viral infection, mainly *Bovine Respiratory Syncytial Virus*, with or without a secondary bacterial infection.

Table 3.1
Definition of mild, severe and chronic Bovine Respiratory Disease (BRD) in dairy heifers by common and additional (clinical) signs seen on animal level without treatment

	Mild BRD	Severe BRD	Chronic BRD
Duration/ start	Duration < 14 days	Duration < 14 days	Starts >14 days after onset of mild/severe disease
Common signs	*2 or more of:* Nasal discharge Coughing Increased respiratory rate Body temperature increased to 40° C	*1 or more of:* Nasal discharge Coughing Increased respiratory rate	*1 or more of:* Nasal discharge Coughing Increased respiratory rate
Additional signs	Normal level of activity (vital)	*1 or more of:* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing	*1 or more of:* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing

Three (clinical) BRD disease classes, i.e., mild, severe, and chronic BRD, were considered. These disease classes were defined by signs that can be seen at the animal level without treating the animal and which are most characteristic of and distinguishing for the particular disease class as well as by the duration of these signs. The signs of the BRD disease classes were divided into common signs which can be seen in each of the three disease classes and specific signs which can only be seen in the particular disease class. The definitions of the three disease classes are presented in Table 3.1.

3.3.1.3 Identification of risk factors

The experts considered six additional risk factors, not mentioned in the original list, also to be of relevance. To the experts' opinion, some risk factors were very closely related and should be aggregated or combined to one risk factor. Therefore, for several risk factors, including the ones added, the particular risk factor was included as an additional level of a very closely related risk factor. The most important risk factors were selected for each of the three combinations of BRD type, disease severity and age class (BRD combinations) presented in Figure 3.1. These combinations were chosen because they were thought to be the most relevant.

BRD combination	BRD type	Disease class	Age class
1	Pneumonia	Severe	0-3 months
2	Outbreak cases	Mild	3-6 months
3	Outbreak cases	Ssevere	6-24 months

Figure 3.1 BRD combinations, i.e., combinations of type of Bovine Respiratory Disease (BRD), disease class and age class, considered during the Delphi stages

The risk factors identified as being highly important for the incidence of one or more of the three BRD combinations considered were:

- Colostrum management during 1st day of life
- Season of birth
- Group size
- Density
- Housing system
- House type
- Bedding condition
- Air circulation
- Cattle flow through pens
- Grazing during summer
- Purchase of cattle
- Introduction of cattle
- Previous respiratory illness

The definitions of these risk factors together with their levels are given in Appendix 3.1. Because the experts considered the most important risk factors to be identical for both the mild and severe disease class for each of the three combinations of BRD type and age class, the most important risk factors were actually identified for six different BRD combinations.

3.3.2 Workshop

3.3.2.1 Response and consistency

One person only went through the ACA questionnaire given in the first session of the workshop. The other 19 experts each completed two ACA interviews, resulting in 39 completed ACA interviews in total. For each of the six BRD combinations, the relative importance values of the various risk factors were estimated by six to seven (different) experts. After the workshop all experts considered their estimates made during the ACA session to be in accordance with their opinion.

The average duration of the 20 ACA questionnaires held in the first session was 29 minutes (variation 13 to 44 minutes) whereas the duration of the 19 ACA questionnaires held in the second session averaged 16 minutes (variation 9 to 28 minutes). Both the median correlation coefficient (for consistency) of the ACA interviews held in the first and in the second sessions separately, as well as the overall median correlation coefficient of all 39 completed ACA questionnaires was 0.86. Thirty-two questionnaires had a R^2 that was equal to or higher than the cut-off value of 0.6, and were included in the analyses.

3.3.2.2 Relative importance of risk factors

The (median) relative importance values (expressed as percentages) of the risk factors are presented in Table 3.2 for both mild and severe pneumonia in dairy heifers aged 0-3 months (youngest age group), in Table 3.3 for both mild and severe outbreak cases in dairy heifers aged 3-6 months (middle age group), and in Table 3.4 for mild and severe cases of outbreak cases in dairy heifers aged 6-24 months (highest age group).

Table 3.2
Median relative importance values (expressed in percentage) and ranks of risk factors for mild and severe pneumonia in dairy heifers aged 0-3 months ($R^2 \geq 0.6$, n=4 for mild and n=6 for severe cases)

Risk factor	Mild cases		Severe cases	
	Importance in % (min-max)	Rank	Importance in % (min-max)	Rank
Air circulation	14.1 (4.4-19.1)	1	11.8 (3.7-18.1)	3
Housing system	13.8 (8.5-17.2)	2	10.9 (2.6-16.8)	4
Density	10.8 (0-17.3)	3	8.2 (7.6-17.9)	6
Group size	10.2 (0-18.7)	4	7.0 (2.4-15.0)	7
Season of birth	9.5 (4.9-26.1)	5	9.8 (6.3-15.4)	5
Colostrum management during 1st day of life	8.8 (5.9-12.4)	6	14.1 (2.9-23.2)	2
Bedding condition	8.4 (1.7-12.2)	7	3.5 (0-9.8)	8
Purchase of cattle	8.2 (4.9-17.0)	8	15.7 (10.6-23.6)	1

Table 3.3
Median relative importance values (expressed in percentage) and ranks of risk factors for mild and severe outbreak cases of Bovine Respiratory Disease (BRD) in dairy heifers aged 3-6 months ($R^2 \geq 0.6$, n=5 for both mild and severe cases)

Risk factor	Mild cases		Severe cases	
	Importance in % (min-max)	Rank	Importance in % (min-max)	Rank
Previous BRD	11.4 (4.7-13.0)	1	8.9 (3.7-15.4)	3
Cattle flow through pens	10.3 (8.1-13.2)	2	8.5 (0.0-11.9)	4
Housing system	10.3 (7.1-10.3)	3	7.2 (4.3-11.0)	7
Air circulation	8.8 (5.1-14.2)	4	9.4 (3.8-15.8)	2
Density	7.9 (6.2-8.9)	5	7.4 (5.1-15.7)	6
Purchase of cattle	7.3 (5.5-9.0)	6	12.3 (2.2-14.0)	1
Group size	6.1 (4.9-6.2)	7	7.7 ((2.2-11.0)	5
House type	5.3 (2.0-9.8)	8	4.8 (0.0-5.9)	9
Grazing during summer	5.2 (3.2-8.3)	9	3.7 (0.0-8.0)	10
Bedding condition	4.9 (0.0-7.7)	10	6.2 (0.0-9.0)	8

From Table 3.2 it can be seen that the two risk factors that were perceived to increase the incidence of pneumonia in dairy heifers aged 0-3 months most (rank 1 and 2) were air circulation and housing system for mild cases, and purchase of cattle and colostrum management during the first day of life for severe cases, respectively. The most important risk factor (rank 1) for mild and severe outbreak cases in dairy heifers aged 3-6 months (Table 3.3) was considered to be, respectively, previous BRD and purchase of cattle. Additional risk factors perceived to be important for these two BRD combinations were cattle flow through pens, air circulation and housing system (mild cases only). Two of the risk factors that were identified during the Delphi stages to be important for pneumonia in the youngest age group (Table 3.2), being season of birth and colostrum management during the first day of life, were not selected to be so for outbreak cases in the middle age group (Table 3.3). For the latter combination of BRD type and age class (both disease classes), four additional risk factors were identified during the Delphi stages, two of which (previous BRD and cattle flow through pens) received high ranks during the workshop. To the experts' opinion two risk factors, being air circulation and purchase of cattle (severe cases only), have a relatively high impact on the incidence of both pneumonia in the youngest age group and outbreak cases in the middle age group. Note that the relative importance values of these risk factors cannot be compared across the two combinations of BRD type and age group, because the number of attributes differ and the values sum to 100 within BRD combinations. Because the risk factors and levels selected were identical in both the mild and severe disease classes they can be compared within the two disease classes of a particular BRD type and age group.

Table 3.4
Median relative importance values (expressed in percentage) and ranks of risk factors for mild and severe outbreak cases of Bovine Respiratory Disease (BRD) in dairy heifers aged 6-24 months ($R^2 \geq 0.6$, n=5 for mild and n=7 for severe cases)

Risk factor	Mild cases		Severe cases	
	Importance in % (min-max)	Rank (max)	Importance in % (min-max)	Rank (max)
Air circulation	11.8 (5.3-16.5)	1	12.5 (8.4-18.9)	1
Density	10.4 (5.5-10.9)	2	8.1 (3.5-13.8)	3
Introduction cattle	10.0 (7.4-14.8)	3	9.6 (0.0-14.6)	2
Housing system	9.1 (6.8-12.4)	4	7.0 (4.7-10.7)	5
Cattle flow through pens	7.7 (0.0-10.9)	5	7.8 (0.0-13.0)	4
House type	6.5 (0.0-10.0)	6	6.2 (4.4-12.4)	6
Previous BRD	6.7 (1.9-10.2)	7	6.2 (0.0-11.4)	7
Bedding condition	4.1 (2.8-7.9)	8	5.1 (1.9-11.4)	8
Grazing during summer	2.6 (0.0-2.6)	9	2.5 (0.0-2.5)	9

The perceived most important risk factors for outbreaks in the highest age groups (Table 3.4) were almost identical to those selected for outbreaks in the middle age group (Table 3.3), but most of them were given different ranks.

Increasing the cut-off value for consistency to $R^2 \geq 0.8$ led to the exclusion of some questionnaires in most of the BRD combinations considered. However, it made no significant (Spearman's rho; $\alpha > 0.05$) difference for the within disease class ranking of the risk factors. Differences between the two disease classes were significant (Spearman's rho; $\alpha < 0.05$) for both pneumonia in the youngest age group (4 observations for each of the two disease classes) and outbreaks in the middle age group (3 observations for each of the two disease classes), but not for outbreaks in the highest age group (5 and 6 observations for mild and severe cases, respectively). This also held when the (lower) cut-off value of 0.6 was used.

3.3.2.3 Evaluation of ACA interviews

The experts were very positive about the ACA interviews as can be seen from Table 3.5, which summarises the results of the evaluation of the ACA interviews. The ACA questionnaires in the first and second sessions received approximately the same credits for every question.

Table 3.5
Average (with minimum and maximum) credits given to the five evaluation questions for the ACA interviews, for both the 1st (n=20) and 2nd session (n=19) separately, and for all interviews

Question asked:	ACA interviews		
The ACA interview had/was	1st session	2nd session	Average
Unclear (1) - very clear (5) description of risk factors	4.3 (2.0 – 5.0)	4.1 (3.0 – 5.0)	4.2
Unrealistic (1) – realistic (5) profiles	3.6 (2.0 – 5.0)	3.9 (3.0 – 5.0)	3.8
Low relation (1) – high relation (5) with Delphi stages	4.2 (3.0 – 5.0)	4.2 (3.0 – 5.0)	4.2
Very short (1) – long (5) duration	2.8 (1.0 – 4.5)	3.1 (1.0 – 4.5)	2.9
Uninteresting (1) – interesting (5)	4.1 (3.0 – 5.0)	4.0 (3.0 – 5.0)	4.1

3.4 Discussion

3.4.1 Risk factors for BRD

Most respiratory diseases in dairy heifers are infectious in nature but are multifactorial in causality, i.e., environmental and management factors are necessary to precipitate the disease. Among other things, aspects related to housing are considered very important for the risk of respiratory diseases in dairy heifers and include, for example, climatic conditions such as ventilation, spatial conditions, and type of housing (Quigley III et al., 1996). However, only a few of the various risk factors related to housing circumstances that were studied in the epidemiological literature reviewed were found to be of significant importance (Waltner-Toews et al, 1986; Curtis et al, 1988; Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996). Curtis et al. (1988) reported that calves initially housed in hutches or individual stalls were at increased risk of respiratory diseases, conditional to season, compared to those initially housed in pens or loosely housed. Other studies observed no significant effects of risk factors related to housing (Waltner-Toews et al., 1986; Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996). The majority of these studies, however, found several housing factors to increase the risk of diarrhoea, and the risk of respiratory disease being increased by a previous case of diarrhoea. Therefore, an indirect effect of these housing factors on the risk of respiratory diseases, mediated by a previous case of diarrhoea, may exist (Waltner-Toews et al., 1986; Curtis et al., 1988; Perez et al., 1990; Curtis et al., 1993). In contrary to the findings from epidemiological literature, the majority of the risk factors identified by the experts in this study (Delphi stages) to be important for the incidence of BRD in dairy heifers were related to housing condition, but a previous case of diarrhoea was not selected. A previous case of BRD was identified to increase the risk of another case of this disease in heifers between 3-6 months, in accordance with the studies reviewed (Waltner-Toews et al., 1986; Curtis et al., 1988; Perez et al., 1990; Curtis et al., 1993). In addition, the experts considered season of birth and colostrum management during first day of life to be a risk factor for pneumonia in dairy heifers younger than three months. The incidence of respiratory disease was also found to be affected by season of birth in most studies reviewed (Waltner-Toews et al., 1986; Curtis et al., 1988; Curtis et al., 1993), and factors related to colostrum management were also reported to be a risk factor for respiratory disease by Waltner-Toews et al. (1986), but not by some other studies (Curtis et al., 1988; Perez et al., 1990; Curtis et al., 1993; Sivula et al., 1996).

In general, some of the factors perceived by the experts to highly increase the incidence of BRD in dairy heifers were also reported to be a significant risk factor for the disease in (epidemiological) literature, but others were not. The differences might, at least partly, be explained by variation in rearing conditions of the heifers under consideration, for example, caused by differences in geographical areas and production systems.

3.4.2 Methods used

Experiences gained in this study reveal that ACA is an easy-to-use technique that enables the quantification of expert opinion on the relative importance of risk factors related to an animal disease, supporting reports from earlier studies that dealt with a comparable task (Horst et al., 1996; Stärk et al., 1997; Van Schaik et al., 1998). The median correlation coefficient of the ACA questionnaires in this study was high, both absolutely and relatively to previous studies (Stärk et al., 1997; Van Schaik et al., 1998). The experts' answers being very consistent may be due to the fact the experts experienced the duration of the interviews not (too) long, the risk factors to be defined well and the profiles very realistic (Table 3.5). The high correlation coefficient might, at least partly, also have been caused by the very extensive Delphi stages held prior to the ACA interviews. Besides the fact the Delphi procedure leaded to a clear definition of risk factors and other aspects of BRD, this method indirectly resulted in the experts being confronted with and reflecting upon their opinion on aspects related to BRD many times. This might have helped them to prepare a well-defined view on the subjects.

The cut-off value of the correlation coefficient of 0.6 was chosen arbitrarily, but results were very similar when a higher cut-off value was used. Van Schaik et al. (1998) used a cut-off value of 0.3 and reported no significant differences in results increasing this value to 0.5. So apparently, increasing the cut-off value has only a minor influence on the outcomes, at least not for small changes.

In general, the procedures and methods applied in this study together with the high consistency have led, although based on a small number of observations (per BRD combination), to an accurate elicitation of expert perception (identification and ranking) of the most important risk factors for BRD in dairy heifers in the Netherlands.

3.4.3 Final remarks

As the importance values of the risk factors are relative they need to be converted to absolute values in most instances for further use. Once the absolute risk of BRD for one particular set of risk factor (levels) is known, it is known for all combinations of risk factors, so a 'reference' value is needed.

In general, expert opinion on the importance of the risk factors might not reveal the true impact of these risk factors. However, it is very difficult, although not impossible, to obtain the unambiguous truth, i.e., the 'gold standard', concerning the impact of risk factors for animal diseases. Expert perception investigation can not replace traditional (epidemiological) field surveys and experimental research, but is considered to be undoubtedly useful as a complement to these studies. Until (these) better data are available, quantitative expert knowledge elicited using accurate methods, will be valuable information. Such information can be used, for example, as input for simulation models or to highlight fields of interest.

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Appendix 3.1 Definitions of risk factors and their levels

Season of birth:

- Winter: September 1st to February 28th
- Summer: March 1st to August 31st

Colostrum management during the first day of life:

- Adequate: new-born heifer receives : 1) 1-2 litres of colostrum depending on weight at birth (possibly in two times) within two hours after birth, 2) a second dosis of 1.5 litres of colostrum within six hours after birth, and 3) in total a minimum of 10-15 % of weight at birth during the first day (24 hours) given in 3-4 doses
- Poor: one or more of these three requirements are not met

Housing system:

- Separate space: not housed in one space (under one roof) with older heifers and milking cows
- Milking cows: housed in one space with milking cows only
- Older heifers: housed in one space with older heifers and possibly milking cows

Grazing during summer months:

- Yes
- No

Bedding condition:

- Adequate: solid floor that allows adequate drainage of urine, and which is covered with absorbent material such as straw or wood shavings which is cleaned every time it gets (too) wet
- Poor: one or more of these criteria are not met

Air circulation (refers to barn in which heifers are housed):

- Adequate: air quality is maintained at an adequate level by a continuous flow of fresh outside air with an adequate speed through the barn
- Poor: air refreshment does not meet one or more of these requirements and/or draught is present

Density, i.e., total number of animals in the pen/group divided by the total surface of the pen:

- High: number of animals per m^2 exceeds the standards on space requirements for animals in the particular age group as given in Quigley III et al. (1996)
- Low: number of animals per m^2 is less than or equal to these standards

Group size, i.e., number of heifers (in particular age class) present in a group/pen for cattle housed in groups (selected for heifers < 6 months of age):

- Small: 2-6 animals per group
- Large: 7 or more animals per group

Purchase new cattle/precautions:

Potential risk factor because of introduction of 'new' pathogens or variants of pathogens already present on farm (selected for heifers < 6 months of age)

- No purchase
- Purchase/precaution: (any) precaution measure is taken before mixing the newly purchased cattle with cattle of the same age already present on the farm
- Purchase/no precaution: no precaution measure (at all) is taken before mixing

Appendix 3.1, *continued*

Introduction cattle/precautions:

Introduction of cattle on the farm is distinguished to newly purchased heifers and cattle that are returned from export (selected for heifers between 6-24 months).

- No introduction
- Introduction/precaution: (any) precaution measure is taken before mixing with cattle of the same age already present on the farm
- Introduction/no precaution: no precaution measure (at all) is taken before mixing with cattle of the same age already present on the farm

Cattle flow through pens:

- All-in-all-out system: the composition of a group of cattle is constant during the complete growing period
- Continuous flow: individual animals go back to the previous group or on to the next group based on their weight

House type:

- Porched stall: one side completely open and closed at the other three sides
- Open front stall: front is half open and half closed, and other three sides are closed
- Closed barn: closed at all four sides but air inlet via both longest sides and air outlet via open ridge

Previous respiratory illness/by lungworm, i.e., respiratory disease that has been seen in the same animal when it was in a previous age class of the growing period and from which the animal has recovered

- No previous BRD
- Previous BRD, not caused by lungworm
- Previous BRD, caused by lungworm

Chapter 4

Elicitation of quantitative data from a heterogeneous expert panel: Formal process and application in animal health

Paper by Van der Fels-Klerx, H.J., Goossens, L.H.J., Saatkamp, H.W., Horst, H.S.
Risk Analysis (in press)

Abstract

This Chapter presents a protocol for a formal expert judgement process, using a heterogeneous expert panel, aimed at the quantification of continuous variables. The emphasis is on the process' requirements related to the nature of expertise within the panel, in particular the heterogeneity of both substantive and normative expertise. The process provides the opportunity for interaction among the experts so that they fully understand and agree upon the problem at hand, including qualitative aspects relevant to the variables of interest, prior to the actual quantification task. Individual experts' assessments on the variables of interest, cast in the form of subjective probability density functions, are elicited with a minimal demand for normative expertise. The individual experts' assessments are aggregated into a single probability density function per variable, thereby weighting the experts according to their expertise. Elicitation techniques proposed include the Delphi technique for the qualitative assessment task and the ELI method for the actual quantitative assessment task. Appropriately, the Classical model was used to weight the experts' assessments in order to construct a single distribution per variable. Applying this model, the experts' quality typically was based on their performance on seed variables.

An application of the proposed protocol in the broad and multidisciplinary field of animal health is presented. Results of this expert judgement process showed that the proposed protocol in combination with the proposed elicitation and analysis techniques resulted in valid data on the (continuous) variables of interest.

In conclusion, the proposed protocol for a formal expert judgement process aimed at the elicitation of quantitative data from a heterogeneous expert panel provided satisfactory results. Hence, this protocol might be useful for expert judgement studies in other broad and/or multidisciplinary fields of interest.

4.1 Introduction

Quantitative data on continuous variables are usually a prerequisite for sound decision-making. Preferably, such data are derived from field studies and experiments. However, these data are often not (yet) available or, if available, are incomprehensive, unreliable, and/or only indirectly or not at all applicable, resulting in knowledge that is incomplete for decision-making purposes. In such cases, expert judgement is the only way to complete the required knowledge (Cooke, 1991; Meyer and Booker, 1991). Expert data obtained under rigorous methodological rules are increasingly being recognised as a valuable asset in numerous scientific fields (Otway and Von Winterfeldt, 1992; Goossens et al., 1996; Goossens et al., 1998), including chemistry, nuclear sciences, and seismic and civil applications (Harper et al., 1995; Goossens and Cooke, 1997; Budnitz et al., 1998; Goossens and Harper, 1998; Goossens et al., 1998; Slijkhuis et al., 1998).

Ideally, one expert would be sufficient to provide all the quantitative data necessary if this expert is unbiased and has excellent knowledge covering the entire field of interest, but, such an 'ideal' expert is not likely to exist, particularly if the field of interest is broad and/or multidisciplinary. Therefore, expert judgement studies frequently make use of a panel of experts who bring in different information, arising from different interpretations, different analytical methods and/or different experiences, and hence can provide more information than a single expert (Clemen and Winkler, 1999). The various experts may be more or less specialised in different areas of the total field of interest, i.e., the expert panel used is *heterogeneous*. Expert judgement studies in a broad and/or multidisciplinary field of interest usually make use of such a heterogeneous expert panel.

Expert knowledge is not a certainty but it is entertained with an implicit level of confidence or degree of belief (Keeney and Von Winterfeldt, 1989; Goossens et al., 1996; Cooke and Goossens, 1999). Uncertainty about continuous quantities can be formalised through subjective probability density functions (PDFs). The top ('peak') of a PDF represents the most likely value (mode) of the uncertain variable, whereas its range is reflected in the lower and upper bounds (Van Lenthe, 1993a; Van Lenthe and Molenaar, 1993). Often, a single PDF of each variable is needed for further use, e.g., as input in a large model requiring distributions of many variables, and the PDFs of the individual experts need to be combined into one PDF per variable (Clemen and Winkler, 1999). The ultimate goal of a study aimed at the quantification of expert knowledge on continuous variables, therefore, is to obtain one (aggregated) PDF per variable that is as reliable and accurate as possible.

To meet basic scientific standards, the expert judgement process must follow a formal approach (Keeney and Von Winterfeldt, 1991; Otway and Von Winterfeldt, 1992; Goossens et al., 1996; Cooke and Goossens, 1999). In the case of a heterogeneous expert panel, special attention should be paid to the broad nature of expertise within the panel. This Chapter presents a formal expert judgement process for the elicitation of quantitative data on continuous variables from a heterogeneous expert panel, in particular focusing on the elicitation and analysis procedures. An expert judgement study in the (broad) area of respiratory disease in dairy cattle illustrates its practical application. First, some background information on this application's problem area is outlined in section 4.2, and then in section 4.3, the expert judgement process is described both in general (section 4.3.1) and with respect to its application (section 4.3.2). Finally, the results are presented and discussed in section 4.4 and 4.5, respectively, and general implications are given.

4.2 Background

Bovine Respiratory Disease (BRD) is a major health problem of dairy cattle, particularly affecting animals younger than two years (i.e., heifers: cattle from birth to calving). BRD is a broad term embracing a range of clinical signs that can be caused by a wide variety of respiratory micro-organisms, such as viruses and bacteria (Radostits et al., 1994). Although BRD is frequently observed on dairy farms in the Netherlands, the exact economic losses associated with the disease are not known. Evidence on individual dairy farms indicates that these losses can be enormous. To reduce the on-farm losses due to BRD, thereby increasing profitability, dairy farmers need to decide on prevention strategies, which requires more insight into the related losses.

Economic losses associated with BRD include treatment costs and productivity losses as a consequence of the disease. Effects on productivity ('productivity effects') following BRD in dairy heifers may include increased mortality, increased culling, reduced growth, reduced fertility, increased age at first calving and decreased milk production (Waltner-Toews et al., 1986; Correa et al., 1988; Warnick et al., 1994; Warnick et al., 1995; Virtala et al., 1996; Donovan et al., 1998). Treatment costs are relatively easy to calculate, whereas losses associated with the productivity effects are very difficult to estimate because of the lack of clear underlying quantitative information on these variables. There is no comprehensive study currently available that considers all the productivity effects of BRD. Most of these variables have been investigated separately in one or two studies only, or not at all. The individual variables that have been studied more intensively show widely varied results, making them less suitable for economic decision-making. In short, a comprehensive and reliable insight into all productivity effects of BRD is lacking at this moment. To bridge this gap we decided to quantify the most important productivity effects of BRD in heifers raised on dairy farms in the Netherlands by undertaking an expert judgement study making use of a heterogeneous expert panel.

4.3 Material and methods

4.3.1 General description of the expert judgement process

4.3.1.1 Elicitation approach

Behavioural and mathematical approaches are available for the elicitation and aggregation of the PDFs of individual experts (Clemen and Winkler, 1999). Mathematical aggregation methods construct a single 'combined' PDF per variable by applying procedures or analytical models that operate on the individual PDFs. In contrast, behavioural aggregation methods involve interaction of the experts with a view to accomplishing homogeneity of information of relevance to the PDFs of the variables of interest. Through this interaction, some behavioural approaches, e.g., Kaplan's expert information approach (Kaplan, 1992), aim at obtaining agreement among the experts on the final PDF per variable. In others, e.g., approaches discussed by Keeney and Von Winterfeldt (1991) and Budnitz et al. (1998), the interaction process is followed by simple mathematical combining, such as equal weighting, of the individual experts' assessments in order to obtain a single (aggregated) PDF per variable. Fixed interaction procedures can be applied, or alternatively, the study team could design a dedicated procedure to suit a particular application. Both mathematical approaches with some modelling and behavioural approaches seem to provide results that are inferior to simple mathematical combination rules (Clemen and Winkler, 1999). Furthermore, a group of experts tends to perform better than the average solitary expert but the best individual in the group often outperforms the group as a whole (Clemen and Winkler, 1999). This motivates the elicitation of the PDFs of individual experts without any interaction, followed by simple mathematical aggregation in order to obtain a single PDF per variable, thereby weighting the individual experts' assessments based on their quality.

Two problems can arise with a heterogeneous expert panel: 1) being more or less specialised in parts of the total field of interest, the experts might have different views on this total field, particularly when this field is broad and/or multidisciplinary; and 2) not all experts have a high level of normative expertise, i.e., knowledge related to the form in which they are asked to give a judgement (e.g., probabilities, ranks or ratings) (Meyer and Booker, 1991). By revealing these problems the quality of the experts' assessments can be maximised by adjusting expert judgement processes that make use of a heterogeneous expert panel, such that 1) the experts completely understand and agree upon the problem at hand, including qualitative aspects relevant to the variables of interest, e.g., definitions to be used, prior to the quantitative assessment task; and 2) the demand for the experts' normative expertise during the actual quantification task is minimised. Taking into account these two requirements may also improve expert judgement processes that make use of a (more) homogeneous expert panel.

4.3.1.2 Protocol

Starting from protocols described previously (Keeney and Von Winterfeldt, 1991; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999), a protocol was designed for a formal expert judgement process in a broad and/or multidisciplinary field of interest using a heterogeneous expert panel consisting of the following steps:

1. Definition of case structure document describing the field of interest, including the study's aim and background information;
2. Identification of the variables of interest or 'target' variables;
3. Identification of experts;
4. Selection of experts;
5. Definition of the qualitative aspects relevant to the target variables and refinement of the target variables in terms of parameters to be assessed, both by expert interaction;
6. Identification of control or 'seed' variables;
7. Design of the quantitative elicitation session;
8. Try out of elicitation of quantitative assessments to a few experts;
9. Training experts for the quantitative assessment task;
10. Elicitation of individual experts' assessments (PDFs) on the query variables (target and seed variables), hereby minimising the demand for normative expertise;
11. Analysis of expert data, i.e., aggregation of individual experts' assessments to one combined PDF for each of the query variables, hereby weighting the experts according to their expertise;
12. Robustness and discrepancy analysis;
13. Feed back communication with the experts; and
14. Documentation of the results.

The total expert elicitation is distinguished into two steps, i.e., step 5 and step 10. Step 5 of the protocol focuses on getting the experts to fully understand and agree upon the problem at hand. In fact, this step serves as an introduction to step 10 which focuses on the actual elicitation of experts' (quantitative) assessments on the query variables.

Agreement among the experts on qualitative aspects relevant to the target variables (step 5) can best be generated by having them interact in some way. Of the various methods available to facilitate this task, the Delphi technique (Cooke, 1991; Meyer and Booker, 1991; Hardaker et al., 1997) was considered most useful, particularly in case of a heterogeneous field of interest (see section 4.3.1.3). A technique to elicit expert assessments on continuous variables, with a minimal demand for normative expertise (step 10), is the ELI method (Van Lenthe, 1993a). Cooke's Classical model (Cooke, 1991) is appropriate to construct a single PDF per variable by weighting the individual experts' assessments according to the experts' quality (step 11). Applying this technique, the experts' quality is based on their performance on so-called seed variables (see section 4.3.1.3) which are included in the elicitation procedure especially for this purpose (steps 6 and 10). The proposed elicitation and analysis techniques are dealt with in detail below, starting with a general description of the proposed techniques (section 4.3.1.3) followed by a description of their application in the BRD study (section 4.3.2).

4.3.1.3 Elicitation and analysis techniques

Delphi

The Delphi technique offers a high level of interaction among the experts while avoiding the disadvantages of group dynamics, like domination of the discussion by one or more individuals. Important features include anonymity, controlled feed-back, reassessment, and group response. It involves iterative (several mailings) questionnaires that need to be filled in by the individual experts, assuring the anonymity of their response. In each mailing, the experts are provided with the results of the previous mailing, and given the opportunity to reassess (Cooke, 1991; Meyer and Booker, 1991; Hardaker et al., 1997).

If the field of interest is complex, the various subjects of the Delphi procedure can be grouped according to their nature, and distributed over several stages, starting with the most general subjects and ending with the most detailed and/or complex ones (Figure 4.1). In addition, the use of several Delphi stages, comprising one or more mailings (iterations) to the individual experts, prevents the questionnaires (per stage) from being too extensive. Each mailing also includes the group results (average or overall response of all experts) of the preceding mailing, giving the individual experts the opportunity to revise their answers and to put forward arguments for or against the group opinion. Consensus among the experts on the subject(s) of a Delphi stage is aimed at before commencing the next Delphi stage. The desired type of consensus (Budnitz et al., 1998) depends on the aim of the (total) Delphi session, and should be defined a priori. The number of mailings per stage can be held flexible, dependent on the number required to reach consensus. Compared to other elicitation methods, the Delphi technique can handle many subjects and/or expert views within a short time span and asks for little input from the experts.

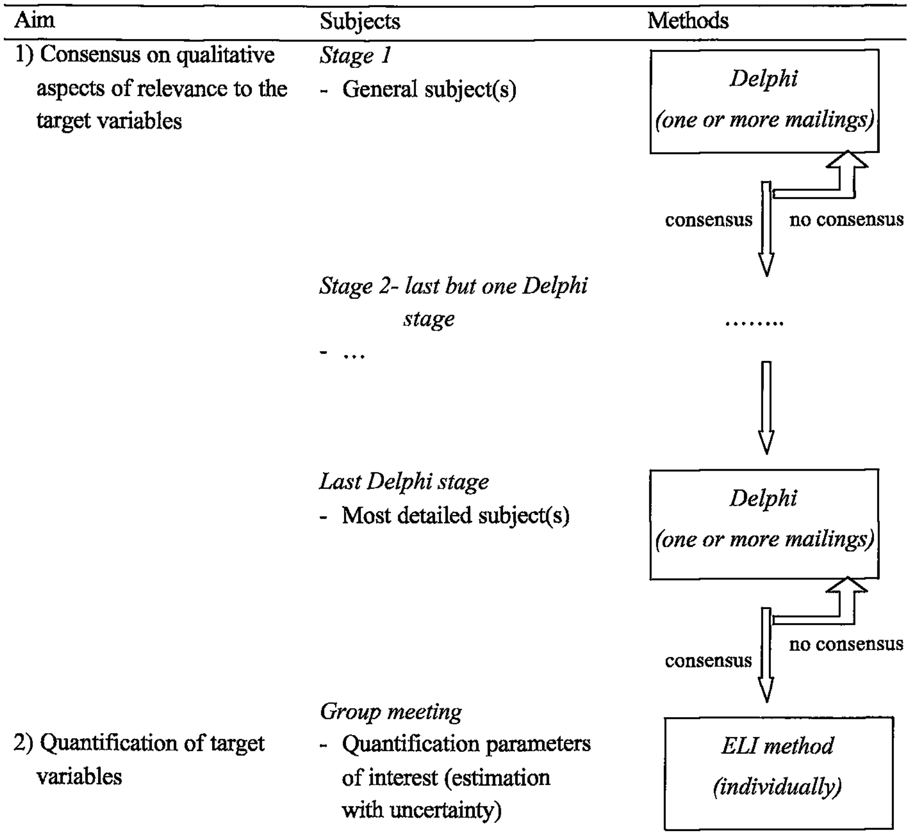

Figure 4.1. General design of an expert judgement study aimed at the elicitation of quantitative data from a heterogeneous expert panel

<u>*ELI*</u>

ELI ('ELIcitation') is a graphically-oriented computer program that facilitates the quantification of expert knowledge on uncertain continuous quantities. The interactive program assists the user with transformation of uncertain knowledge into unbiased subjective PDFs by providing an easily understood and simple-to-use working environment (Van Lenthe, 1993a; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). Evaluation studies in which the ELI method was compared to various classical elicitation methods revealed that ELI had the lowest information processing demands, and the program contributed to very reliable and valid PDFs (Van Lenthe, 1993a; Van Lenthe and Molenaar, 1993). Moreover, overconfidence bias was almost eliminated and estimates were most accurate which, at least partly, can be explained by the fact that ELI uses 'proper scoring rules' in the probability assessment task (Van Lenthe, 1993a).

A scoring rule is a function that provides a score that reflects how the expert's PDF corresponds with the actual outcome of the quantity (Morgan and Henrion, 1992; Van Lenthe, 1993a; Van Lenthe, 1993b; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). During the assessment task, i.e., in the absence of knowledge of the actual values, the expected rather than the actual scores are of primary interest (Van Lenthe, 1993a; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). With a *proper* scoring rule, individual experts can maximize their expected scores if, and only if, their stated PDFs correspond with their subjective judgments (Cooke, 1991; Morgan and Henrion, 1992; Van Lenthe, 1993a; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). Therefore, a proper scoring rule stimulates the experts to express their true feelings about uncertain knowledge, and minimises unrealistic strategic or opportunistic responses. In this way, over- and under-confidence bias is reduced to a minimum, enhancing the quality of the PDFs obtained (Van Lenthe, 1993a; Van Lenthe, 1993b; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). In a training session with ELI, i.e., when the experts do not know the actual answers or 'true' values, the scoring system enables the experts to get an idea about the quality of their answers. After each training question, the individual experts are provided with trial-by-trial score feedback, and they are stimulated to maximise their (total) scores (Van Lenthe, 1993a; Hardaker et al., 1997). A training session with feedback also improves the results of additional questions for which no feedback is given, such as the questions of interest (Van Lenthe, 1993a). Therefore, in the ELI interview a training session precedes these questions (of interest). The individual experts' assessments on the variables of interest, provided by the program by key parameters of the underlying distributions (either beta or normal), form the ultimate outcome of ELI. A more detailed description of ELI can be found in Van Lenthe (1993a).

<u>*Classical model*</u>

Cooke's Classical model, embedded in the software package EXCALIBR (Cooke and Solomantine, 1992), is a linear pooling or weighted averaging model based on statistical hypothesis testing. It aims at constructing a weighted combination of experts' probability assessments for each variable estimated (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). Experts can be weighted equally, or according to their (relative) expertise, typically indicated by their performance on seed variables.

Seed variables are variables the true values or realisations of which are unknown to the experts but known to the analyst at the time of the elicitation, or become known post hoc (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). The experts should be able to adequately state their uncertainty on these variables. As the individual experts' performance on the seed variables is taken as an indication for their performance on the target variables, the seed variables must resemble the target variables as much as possible (Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). Ideally, the seed variables are randomly mixed with the target variables within the elicitation session, being indistinguishable from the target variables themselves. Domain variables are preferred, but if not available, adjacent variables could also be used. Domain variables have the same physical dimensions as the target variables, and represent measures of past realisations or 'near field' realisations. Adjacent variables are of different dimensions than the target variables, but are judged to be drawn from the experts' relevant knowledge base (Goossens et al., 1996). Although there is no mathematical evidence for the minimal number of seed variables required, too few seed variables will not provide sufficient discrimination between individual experts. For assessments of uncertain quantities with continuous ranges, eight to ten seed variables proved to be sufficient (Cooke, 1991; Goossens et al., 1996; Goossens et al., 1998); six seed variables might be enough but must be considered a minimal option (Goossens et al., 1996).

The individual experts' performance-based weights are based on two quantitative measures of performance, namely calibration and information (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). Calibration reflects the degree, in a statistical sense, to which the expert's performance on seed variables 'supports' the hypothesis that the expert's probability statements 'correspond with reality'. According to the expert's distribution there is, for example, a 10 % probability that any true value lies outside his/her 90 % confidence interval, i.e., lies below the 5^{th} percentile value or above the 95^{th} percentile value. If this actually occurs for a high percentage of the seed variables, then these seed data give little support to the hypothesis that the expert's probabilities correspond with reality (Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). Calibration is scored on a 0 to 1 scale, a high score implicating that the expert's assessments are supported by the set of seed variables (Cooke, 1991; Harper et al., 1995; Cooke and Goossens, 1999). The information score represents the degree to which an expert's distribution of a variable is concentrated or 'peaked', relative to some user-selected background measure, and is always positive (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Cooke and Goossens, 1999). 'Good expertise' corresponds with good calibration (high statistical likelihood) and high informativeness (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999). The experts' weights in the classical model are proportional to the product of calibration and information, with calibration 'dominating' over information (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996; Goossens et al., 1998; Cooke and Goossens, 1999).

Combination of assessments of two or more experts results in a virtual combined assessment, defined as the decision maker's or virtual expert's (VE) assessment (Goossens et al., 1998). Mathematically written, the virtual expert's PDF for an uncertain variable, indicated by p_{VE},, can be calculated as follows:

$p_{VE} = \sum_e w_e p_e \quad e = 1, 2, \ldots, E$ with $\sum_e w_e = 1$ and $w_e \geq 0$

where,

p_{VE}: weighted combination of $p_1, p_2, \ldots, p_E$;

$p_e\ [e = 1, 2, \ldots, E]$: the distributions of the experts $1, 2, \ldots, E$ for the same variable.

The VE also has a calibration and information score attached so that its (unnormalised) weight can be calculated (Goossens et al., 1996; Cooke and Goossens, 1999). Within the Classical model, the experts' calibration and information measures are combined in such a way that the (unnormalised) weight of the VE is (in the long run) a strictly proper scoring rule (Cooke, 1991; Goossens et al., 1996; Cooke and Goossens, 1999). To fulfil this requirement the calibration score is combined with classical significance testing. An expert's weight is set to zero if his/her calibration score is lower than a certain significance or 'cut-off' level. This cut-off level is not predefined but, following an optimisation procedure, set at the level at which the (unnormalised) weight of the VE is optimal (Cooke, 1991; Goossens et al., 1996; Cooke and Goossens, 1999). The optimised VE represents the subset of experts used to construct the aggregated performance-based distributions of the target variables. This subset of experts may consist of several or one expert only, even though the excluded experts might also have performed well. An expert may be unweighted, not because his/her performance is low but because his/her distributions do not differ much from the distributions of better calibrated experts. Including this expert does not improve the (unnormalised) weight of the VE, i.e., does not add new information (Goossens et al., 1996). For more detail on the Classical model, please refer to Cooke (1991).

4.3.2 Application to BRD

4.3.2.1 Expert identification and selection

The target variables were defined (step 2, section 4.3.1.2) as the productivity effects of BRD in heifers raised on dairy farms in the Netherlands. Following previous definitions (Waterman, 1986; Hardaker et al., 1997) experts were identified (step 3, section 4.3.1.2) as having:

- a DVM degree from the Netherlands or Belgium;
- at least several years of experience related to BRD in heifers raised on Dutch or Belgian dairy farms, preferably in both the scientific and practical field;
- expertise in several specific respiratory micro-organisms, rather than in one pathogen only;
- some relevant normative expertise, i.e., knowledge and understanding of probability assessment.

A total of 22 experts met these criteria, and hence were considered to cover virtually all the relevant scientific community. All experts, except one, were available and interested in participating in the expert judgement study, forming an expert panel of 21 experts. The experts' backgrounds varied from practice to research, over half of them had had recent experience in both these fields. Most of them had specialised in one or several specific respiratory micro-organism(s) but also had knowledge on the other respiratory pathogens as well as some normative expertise. At the time of the expert selection (step 4, section 4.3.1.2), the experts were employed by the government (3 persons), the Animal Health Service (5 persons), the Institute for Animal Science and Health (3 persons) or by other scientific institutes (2 persons), or were veterinary practitioners (8 persons).

4.3.2.2 Design of the elicitation

Delphi

Qualitative aspects relevant to the quantification of the productivity effects of BRD were identified and combined according to their nature into four different groups of subjects, which were distributed over four different Delphi stages (stage 1 to 4, Figure 4.2). Each stage commenced after consensus on the subject(s) of the previous stage was reached, hence, the number of mailings per stage was not predefined. Consensus meant that all experts agreed that the outcome of the particular subject represents them as a group, i.e., type 3 consensus in terms of Budnitz et al. (1998).

Aim	Subjects	Method
1) Consensus on qualitative aspects of relevance to the productivity effects of BRD in dairy heifers	*Stage 1* - Definition of BRD	*Delphi (one or more mailings)* consensus ↓ / no consensus ↑
	Stage 2 - Distinguish BRD to: - types - disease classes - age classes - Definition of disease classes	*Delphi (one or more mailings)* consensus ↓ / no consensus ↑
	Stage 3 - Definition of BRD types	*Delphi (one or more mailings)* consensus ↓ / no consensus ↑
	Stage 4 - Complete list of productivity effects from literature - Identify and rank the most important productivity effects	*Delphi (one or more mailings)* consensus ↓ / no consensus ↑
2) Quantification of the productivity effects of BRD in dairy heifers	*Group meeting* - Quantify the most important productivity effects (estimation with uncertainty)	*ELI method (individually)*

Figure 4.2. Design of expert judgement study aimed at the quantification of the productivity effects of Bovine Respiratory Disease (BRD) in dairy heifers

Delphi stages 1 to 3 focused on the definition of BRD, classes to be distinguished with respect to BRD type, disease severity and age of heifers affected, and the definitions of these classes. Note, the different types of BRD, disease (severity) classes and age classes should be distinguished to rule out discrepancies between the various productivity effects of BRD as well as their magnitude and/or range. In Delphi stage 4, the experts were given an extensive list of productivity effects based on a literature search and asked to complete this list with missing parameters (if any). Next, they were asked to identify and rank the productivity effects they considered most important (seen most) together with the heifers' age (class) in which these effects are seen. They were asked to do so for three different combinations of BRD type, disease class and age class ('BRD combinations') considered most relevant, separately.

ELI

After completion of Delphi, a group meeting (Figure 4.2) was held during which the experts individually quantified the most important productivity effects of each of the three BRD combinations (selected during Delphi stage 4) using ELI. The ELI interview started with ten training questions on quantitative aspects related to BRD in dairy heifers, derived from literature. This training phase (step 9, section 4.3.1.2) was followed by the questions of interest (step 10, section 4.3.1.2) which were distributed among the experts such that each expert assessed the productivity effects of two out of the three BRD combinations considered. Each expert also quantified seven seed variables that were randomly mixed with these target variables. The seed variables were based on parameters related to productivity effects of BRD in heifers raised on dairy farms of the Research Institute for Animal Husbandry in the Netherlands (i.e., experimental and field data). Familiar to the experts, the rearing conditions on these farms are very similar to the rearing conditions on Dutch dairy farms in practice. Therefore, the seed questions largely resembled the target variables. The true values of the seed variables were quantified recently by the first author using data of the Research Institute for Animal Husbandry, and will be published in future (paper in progress). At the time of the ELI session the experts had no knowledge of the realisations of the seed variables and were even unaware of the fact that the ELI interview included seed questions.

The ELI interview was fully computer-supported and self-explanatory so that it could be completed individually, and interaction between the experts as well as between the experts and the process facilitators could be minimised. The ELI interview was pre-tested (step 8, section 4.3.1.2) by 19 persons who did not participate in the expert panel. They had a background in veterinary medicine and/or animal science and were currently working at the Faculty of Veterinary Medicine (Utrecht University, The Netherlands) or the Department of Social Sciences (Wageningen University, The Netherlands).

Immediately after completion of the ELI interview, the experts were asked to evaluate it by completing a written questionnaire consisting of four questions, which had to be answered on a scale of 1 to 5, 1 meaning bad and 5 very good. After the group meeting, the individual experts received the overall answers (median with spread) of all experts as well as their own assessments on each target variable. They were asked to check whether their assessments truly reflected their opinion elicited by ELI, and to compare them with the group results. They were given the opportunity to revise their answers.

Data analysis

Using SPSS (Norusis, 1993), the 5^{th}, 50^{th}, and 95^{th} percentiles of the individual experts' PDFs of all (target and seed) variables were calculated from the ELI output. By combining the experts' assessments of each of these variables one (aggregated) PDF per variable was obtained by means of the Classical model (step 11, section 4.3.1.2). The performance of the experts was explored applying both the equal weighting scheme and the performance-based item weighting scheme (Cooke, 1991; Harper et al., 1995; Goossens et al., 1996). This was done for the three variable sets, each consisting of the target variables related to one BRD combination[1] as well as the seven seed variables, separately. The weighting scheme that performed best was used to construct the final aggregated (VE) distributions of the seed variables and the target variables.

4.4 Results

4.4.1 Delphi

4.4.1.1 Participation

Four of the 21 experts responded to the first two Delphi stages only, and not to the other two. An average of 15 of the remaining 17 experts (not always the same persons) responded to each of the four Delphi stages. Consensus among the experts on the subject(s) of each stage was received after three to five iterations (mailings). Table 4.1 presents, for each subject of the four Delphi stages, the number of iterations required to reach consensus. The four Delphi stages were held between March and July 1998.

[1]Target variables related to BRD combination 1 to 3 (Table 4.2) were represented in variable set 1 to 3 respectively

Table 4.1
Subjects per Delphi stage and number of iterations required to reach consensus (per subject)

Subject	Delphi stage	Number iterations
Definition of BRD[1]	1	4
BRD types	2	4
Disease (severity) classes	2	3
Age classes	2	4
Definitions of disease classes	2	3
Definitions of BRD types	3	5
Most important productivity effects of BRD	4	2

[1]Bovine Respiratory Disease

4.4.1.2 Results

The experts distinguished two types of (clinical) BRD, i.e., pneumonia and outbreaks, and three classes of severity of the disease, i.e., mild, severe and chronic (Appendix 4.1). Three age classes were identified for dairy heifers: 0-3 months, 3-6 months, and 6-24 months. As a result, 18 different combinations for BRD type, disease class and age class (i.e., 2 BRD types * 3 disease classes * 3 age classes) were theoretically possible. However, as the relevance of these BRD combinations was believed to vary considerably, both Delphi stage 4 and the ELI session focused on the following three relevant BRD combinations: 1) severe pneumonia in heifers aged 0-3 months, 2) mild BRD outbreaks in heifers aged 3-6 months; and 3) severe BRD outbreaks in heifers aged 6-24 months (Table 4.2).

Table 4.2
BRD combinations[1] considered during Delphi stage 4 and the ELI session

BRD combination	BRD type	Disease class	Age class
1	Pneumonia	Severe	0-3 months
2	Outbreak	Mild	3-6 months
3	Outbreak	Severe	6-24 months

[1]Combination of type of Bovine Respiratory Disease (BRD), disease class and age class

During Delphi stage 4 the experts selected the following productivity effects to be most important for one or more of these three BRD combinations:

- Increased risk of mortality;
- Increased risk of culling;
- Reduced weight gain and resulting body weight;
- Increased risk of fertility disorders (foetal losses and abortion);

- Increased age at first insemination and age at first calving; and
- Reduced milk production in first lactation.

The ELI session solely focused on those productivity effects from the ones listed above those are not usually affected by the farmer's management. As a result, the ELI interview did not include target variables related to risk of culling and age at first insemination.

4.4.2 ELI

4.4.2.1 Participation

Sixteen of the 21 experts attended the group meeting and completed the ELI interview. Four experts attended an additional ELI session organised for those unable to attend the group meeting. One expert was not able to join any of the two ELI sessions. All 20 experts completed the ELI interview without interaction with each other or the process facilitators. The experts were very positive about the ELI interview as revealed in Table 4.3, which summarises the results of the evaluation questionnaire.

Table 4.3
Credits (mean with range) given to the evaluation questions of the ELI interview (n=20 experts)

Evaluation question	Credits
Clearness of the ELI interview and its questions: unclear (1) - very clear (5)	3.9 (2.0-5.0)
Relation with the Delphi stages: low (1) – high (5)	3.6 (2.0-4.0)
Duration: very short (1) – long (5)	3.4 (2.0-4.0)
Interesting method: not at all (1) – very (5)	4.3 (3.0-5.0)

One expert felt a posteriori that her assessments on some productivity effects, as elicited by ELI, did not entirely reflect her opinion but she did not revise them. Consequently, data from this expert were excluded from further analysis. Each expert assessed the productivity effects of BRD for two out of the three variable sets and, as a result, estimates (PDFs) on the relevant parameters were obtained from 12 experts for BRD combinations 1 and 2, and from 14 experts for BRD combination 3. The seven seed variables were assessed by each of the 19 experts.

4.4.2.2 Performance of experts

Table 4.4 presents the performance of the experts, applying both equal weights and item weights (using the Classical model), for each of the three variable sets. The experts' performance is indicated by the calibration and information score of the VE as well as its unnormalised weight, and compared with the 'best' expert out of the various (12 or 14) experts who assessed the particular variable set. The cut-off level for the calibration score at which the VE's performance was optimal was 0.55, 0.09, and 0.14 for variable sets 1 to 3, respectively. In the first variable set, one expert's calibration score equalled this optimal level, whereas five experts exceeded this level in the other two variable sets.

Table 4.4
Performance of the virtual expert, applying both item weights and equal weights, and the best expert for each of the three variable sets as well as the number of target and seed variables per variable set

Variable set	Number of target/ seed variables	Performance measure	Virtual expert		Best expert
			Item weights	Equal weights	
1[1]	9/7	Calibration	0.55	0.65	0.55
		Information	1.05	0.29	1.05
		Unnormalised weight	0.67	0.20	0.67
2[2]	8/7	Calibration	0.65	0.42	0.67
		Information	1.15	0.45	0.62
		Unnormalised weight	0.78	0.16	0.41
3[3]	7/7	Calibration	0.65	0.42	0.67
		Information	0.70	0.33	0.69
		Unnormalised weight	0.45	0.13	0.42

[1]Target variables related to severe pneumonia in dairy heifers aged 0-3 months as well as the seven seed variables; optimal level at 0.55, n = 1 expert
[2]Target variables related to mild outbreaks of respiratory disease in dairy heifers aged 3-6 months as well as the seven seed variables; optimal level at 0.09, n = 5 experts
[3]Target variables related to severe outbreaks of respiratory disease in dairy heifers aged 6-24 months as well as the seven seed variables; optimal level at 0.14, n = 5 experts

In Table 4.4 it can be seen that, for variable set 1, the performance (unnormalised weight) of the optimised item weight VE was equal to the best expert's performance (0.67), and higher than the equal weight VE's performance (0.20). The optimised item weight VE in variable sets 2 and 3 performed better (higher unnormalised weight) than the best expert, which in turn outperformed the equal weight VE. In each of the three variable sets, the calibration scores of the item weight VE and the equal weight VE as well as the best expert were roughly equal. However, the performance-based (item weight) VE had a higher information score, and hence was more informative, than the equal weight VE. The latter had a larger confidence interval (lower information score) than the best performing expert.

In each of the three variable sets, both the calibration and information score as well as the unnormalised weight of the VE were assumed to be good for both weighting schemes applied. The difference between the unnormalised weight of the item weight VE and the equal weight VE was less than a factor ten, which was considered to be small, and (slightly) in favour of the item weighting scheme, implying a better performance using this weighting scheme compared to the equal weighting scheme.

4.4.2.3 Aggregated distributions

In Table 4.5, the seven seed variables with their realisations (true values) as well as their optimised item weight (VE) distributions, expressed by the 5^{th}, 50^{th} and 95^{th} percentiles, are shown for each of the three variable sets. The second and third columns of this table present the seed variables, in terms of the various productivity effects of BRD, together with their reference values. The reference value of a productivity effect was defined as this variable's value in heifers of the same age raised on the same farm, but not affected by BRD. In the ELI interview, the experts were asked to quantify each (seed and target) variable relative to its particular reference value.

To serve an example, it can be read from Table 4.5 that in variable set 2, the median (50^{th} percentile) of the aggregated item weight VE distribution for first insemination age (seed variable 4) of heifers that had had BRD was 15.1 months, with 5^{th} and 95^{th} percentiles of 14.3 and 15.9 months, respectively. The true value of this parameter, being 14.9 months, is equal to its reference value, implying no difference in first insemination age between heifers with BRD and their non-affected herd mates. This was supported by expert data since the true value fell within the 90 % confidence interval (14.3-15.9) of the aggregated VE distribution.

For the majority of the seed variables (taking into account the three variable sets), the median of the aggregated VE distribution was of the same order of magnitude as the particular variable's true value. In addition, the true values of most variables fell within the particular 90 % confidence intervals of their aggregated VE distribution (Table 4.5). Except for two variables, confidence intervals of the optimised VE distributions of the seed variables were smallest in variable set 1 compared to the other two variable sets. This can be explained, at least partly, by the fact that the VE distributions in variable set 1 were based on the assessments of one expert only. Except for one variable, confidence intervals of the optimised VE distributions of the seed variables in variable set 3 were larger than in variable set 2, explaining the lower information score of the VE (Table 4.4) in the former variable set.

Table 4.5

Seed variables with their true values as well as their optimised item weight distributions, expressed by their 5th, 50th and 95th percentiles, for each of the three variable sets

Seed item	Description[1]	Reference value[2]	True value	Percentiles of optimised item weight distribution								
				Variable set 1[3]			Variable set 2[4]			Variable set 3[5]		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
1	Increase mortality (n times)	1	2.4	0.8	2.9	5.0	0.9	1.5	7.1	0.5	1.8	7.2
2	Heifers that had BRD and died that could have stayed alive (%)	0	58	41	50	59	22	47	93	16	45	61
3	Mortality due to BRD (%)	0	18	13	20	27	19	20	46	8	20	49
4	Age at first insemination (months)	14.9	14.9	15.0	15.3	15.7	14.3	15.1	15.9	14.0	15.3	16.4
5	Age at first calving (months)	24.8	24.8	24.4	25.4	26.4	24.3	24.8	25.4	24.3	24.9	27.0
6	Body weight at 24 months (kg)	550	550	532	539	547	530	548	556	528	544	556
7	First lactation milk production (kg)	6866	6866	6605	6766	6927	6855	6943	7057	6642	6919	7054

[1]Seed variables related to productivity effects following Bovine Respiratory Disease (BRD) in heifers raised on dairy farms of the Research Institute for Animal Husbandry

[2]Value in non-affected herd mates

[3]Target variables related to severe pneumonia in dairy heifers aged 0-3 months as well as the seven seed variables; optimal level at 0.55, n = 1 expert

[4]Target variables related to mild outbreaks of respiratory disease in dairy heifers aged 3-6 months as well as the seven seed variables; optimal level at 0.09, n = 5 experts

[5]Target variables related to severe outbreaks of respiratory disease in dairy heifers aged 6-24 months as well as the seven seed variables; optimal level at 0.14, n = 5 experts

Table 4.6
Optimized item weight distributions, expressed by their 5th, 50th and 95th percentiles, of productivity effects following severe pneumonia in dairy heifers aged 0-3 months

Effect on productivity	Reference value[1]	Percentiles of optimized item weight distribution[2]		
		5th	50th	95th
Body weight at 3 months (kg)	100	82	90	98
Body weight at 6 months (kg)	180	164	170	176
Body weight at 14 months (kg)	380	344	351	357
Mortality between 0-3 months (% above rates due to all but BRD)	0	16	20	24
Age at first calving (months)	24.0	24.1	24.5	24.9
First lactation milk production (kg)	6800	6550	6650	6760

[1]Value in non-affected herd mates
[2]Optimal significance level at 0.55, n= 1 expert

To illustrate results on the target variables, Table 4.6 presents the aggregated item weight VE distributions of the productivity effects associated with severe pneumonia in heifers aged 0-3 months (variable set 1). This table shows that body weight of heifers that had had this disease was estimated to be 90 kg (median of aggregated VE distribution) at three months of age. Compared to this parameter's reference value of 100 kg, this implies a reduction in weight gain during the first three months of life of 10 kg which is considered substantial as the reference value fell outside the 90 % confidence interval (82-98 kg) of the aggregated VE distribution. The same held good for the other productivity effects of severe pneumonia in dairy heifers aged 0-3 months.

4.5 Discussion

4.5.1 Elicitation approach

Although various other procedures are available for the elicitation of experts' assessments on continuous variables, both from the group of mathematical approaches and aggregation approaches (Clemen and Winkler, 1999), the protocol proposed in this Chapter was considered the most appropriate for expert judgement studies that make use of a heterogeneous expert panel. It made use of expert interaction to facilitate sharing and discussing information on the qualitative aspects of relevance for the target variables. In this way, the experts reached a similar view on the items at hand before the actual quantification task. The experts' assessments were elicited individually as opposed to approaches that aim for a 'group assessment' by expert interaction, like the expert information approach of Kaplan (1992). Moreover, it does not require the experts to negotiate and make comprises for the sake of the group assessment (Kaplan, 1992; Clemen and Winkler, 1999).

To obtain a single PDF per variable, the individual experts' assessments were weighted, thereby optimising the final PDF by selecting the best performing expert(s) from the panel on the merit of their assessments. This approach was motivated by results from previous studies showing the best expert from a group outperforms the group as a whole (Goossens et al., 1996). Simple combination rules may result in bias arising from dependence among the experts, i.e., the tendency of various experts to report a similar PDF for each variable (Clemen and Winkler, 1999). However, where a heterogeneous expert panel is used, the potential risk of this type of bias is minimised as a direct consequence of the nature of expertise within the panel.

4.5.2 Techniques used

One of the elicitation methods applied, i.e., the Delphi technique, has been widely used and accepted, whereas the other, the ELI method, has only recently been developed. Both methods are new to the field of animal health: the former method has been applied in this field only a few times (Forbes, 1992; Miller et al., 1994) and the latter only once (Horst et al., 1998). The technique used for data analysis, i.e., the Classical model, has been successfully applied in various fields of interest (Harper et al., 1995; Goossens and Harper, 1998; Goossens et al., 1998) but has not yet been used in the present one. Combined use of these elicitation and analysis techniques has not been reported before. From our experience the protocol we followed as well as the techniques applied proved to be promising for use in expert judgement studies that deal with the elicitation of quantitative data on continuous variables from a heterogeneous expert panel.

The Delphi technique has led to consensus among the experts on the various subjects considered in the first part of the expert elicitation. As a result, there were no side discussions during the quantification task, and the experts could completely focus on the actual task at hand. In addition, due to the classification of BRD into various types, disease (severity) classes and age classes, the productivity effects of BRD could be assessed very accurately.

Using the ELI method, assessments were elicited from the experts directly instead of transforming the opinion of one or more experts into one PDF per variable by the process facilitator, as done by Keeney and Von Winterfeldt (1991), Kaplan (1992), and Budnitz et al. (1998). Although both approaches minimise the demand for normative expertise, preference was given to the ELI method as it avoids possible transformation errors.

Important features of the ELI method reported previously include its easiness to explain to experts who know little about probability concepts, its user-friendliness, and its practically usefulness (Van Lenthe, 1993a; Van Lenthe, 1993b; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). These experiences were supported by the present application in that the experts were able to work with the program without any help, and evaluated the program as being very useful (Table 4.2).

In accordance with earlier findings (Goossens et al., 1996; Cooke and Goossens, 1999), the present application showed that the performance of the VE was (slightly) higher with the performance-based (item) weighting scheme than with the ordinary equal weighting scheme (Table 4.4), motivating the use of the former. In addition, it also makes sense to weight the experts according to their expertise or quality, particularly if the heterogeneity of the expert panel is high. The weights of the individual experts can be based on: 1) self-ratings of the experts; 2) the process facilitator's judgement of the expert's quality; or 3) the expert's actual performance on seed variables (Cooke, 1991; Morgan and Henrion, 1992). The last-mentioned approach is preferred, provided appropriate seed variables are available, as it avoids subjective bias associated with the first two approaches, and is the reason why we used it.

Ideally, many domain variables are used as seed variables, derived from various studies from which the results have not (yet) been published (Goossens et al., 1996). But, in an ideal setting, if these data were available, the judgements from the experts would not have been needed. Our preference was given to the use of domain variables that had conditions consistent with the conditions of the target variables, rather than retrieving seed variables from various studies. This criterion resulted in the availability of only one study (at the time of the expert judgement study) from which the minimal number of domain variables could be derived. More seed variables would have contributed to robustness of the results against these variables (Cooke, 1991; Goossens et al., 1996). However, analysis of the seed variables (results not presented) showed robustness was moderate for variable set 1, and high for the other two variable sets, hence, the seed variables used were considered to be adequate.

The seed variables we used were ideal in that they closely resembled the target variables and were, just like these (target) variables, related to an event frequently observed in practice, i.e., BRD in dairy heifers. However, expert judgement studies often deal with infrequent or rare events, and often too few or not enough domain variables are available. In these cases, adjacent variables, e.g., referring to experimental settings or invitro studies, could (also) be used as they also have shown to provide adequate results in assessing the experts' quality (Goossens et al., 1996; Goossens et al., 1998).

Seed variables serve to distinguish between the actual performance on the target variables of the individual experts, rather than accurately predict the performance (Goossens et al., 1996). In each of the three variable sets, the experts' PDFs of the target variables were examined for the group of best performing experts, i.e., the subset of experts used to construct the optimised VE distributions for the particular variable set, and the group of experts that was excluded from this subset separately. Results (not presented) showed that, for most variables, the estimated medians were comparable between both groups of experts, but the stated 90 % confidence intervals were wider for the experts that were excluded from the subset. Exclusion of these experts from the optimised item weight VE levels off irrelevant noise from the data obtained. This validates the use of seed variables as the basis for comparing the performance of the experts as probability assessors of target variables.

4.5.3 Data obtained

The formal protocol followed, the adequate techniques used, and the high performance of the experts in the expert judgement process presented resulted in data that are as reliable and accurate as feasible. These data, cast in the form of aggregated PDFs of the productivity effects of BRD, have been shown to be useful in estimating the economic losses associated with the disease. Moreover, they were used as input variables for an economic model that calculates the losses associated with BRD in dairy heifers (Van der Fels-Klerx et al., 2000; Van der Fels-Klerx et al., 2001). This model enhances insight into these economic losses, including its variation due to uncertainty related to the productivity effects. Hence, its can be used as a tool to support the on-farm decision making process with respect to the prevention of BRD.

4.6 Conclusion

The proposed protocol is useful for a formal expert judgement process aimed at the elicitation of quantitative data on continuous variables from a heterogeneous expert panel. Together with the proposed techniques, i.e., Delphi followed by ELI for the elicitation, and the Classical model for the analysis, it has shown to result in valid data, cast in the form of probability density functions, on the variables of interest. From experience gained in its application presented in this Chapter we believe that the protocol can be useful for expert judgement studies that make use of a heterogeneous expert panel in other broad and/or multidisciplinary areas of interest, for example, in the field of transfer of radio nuclides in animals, animal products and/or plants. Needless to say, the proposed protocol represents just one of the various approaches that could be followed in this type of expert judgment processes. Each study has its own properties, and the process leader(s) should select or create the approach that best suits its requirements.

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Appendix 4.1: Definition of Bovine Respiratory Disease, classes considered with respect to disease type, disease severity and age of heifers affected, and definitions of these classes

Bovine Respiratory Disease (BRD):
A clinical disease of the respiratory tract caused by a viral, bacterial or mycoplasmal infection (parasites excluded) or by a combination of these infections

BRD types:
Calf pneumonia: BRD cases seen one after the other, periodically or whole year round, mostly occurring in the first three months of life. These cases can be caused by a variety of primary pathogens, but commonly are caused by bacteria, mainly *Pasteurella spp.*, and preceded by an infection with respiratory viruses.
BRD outbreak: A certain number of heifers in a group suddenly shows clinical signs. BRD outbreaks mostly occur during the housing period, but also regularly during the pasture period. Dairy heifers affected are mainly older than three months, but younger heifers also might be affected. BRD outbreak cases mostly are caused by a primary viral infection, mainly with *Bovine Respiratory Syncytial Virus*, with or without a secondary bacterial infection.

BRD disease classes:
Three classes were distinguished for severity of (clinical) BRD, being mild, severe and chronic. Each of these three classes was described by its specific symptoms (at the animal level without treatment) shown in Table 4.7.

Age groups
Dairy heifers (0-2 years) were distinguished as to three age classes of 0-3 months, 3-6 months, and 6-24 months.

Table 4.7
Definition of mild, severe and chronic Bovine Respiratory Disease (BRD) in dairy heifers by common and additional (clinical) symptoms seen on animal level without treatment[1]

	Mild BRD	Severe BRD	Chronic BRD
Duration/ start	Duration < 14 days	Duration < 14 days	Starts >14 days after onset of (mild/severe) disease
Common symptoms	*2 or more of:* Nasal discharge Coughing Increased respiratory rate Body temperature < 40° C	*1 or more of:* Nasal discharge Coughing Increased respiratory rate	*1 or more of:* Nasal discharge Coughing Increased respiratory rate
Additional symptoms	Normal level of activity (vital)	*1 or more of:* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing	*1 or more of:* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing

[1]Symptoms that are most characteristic of and distinguishing for the particular disease class are presented only. The symptoms are divided into common and additional symptoms with common symptoms observed in each of the three disease classes and additional symptoms seen in the particular disease class only

Chapter 5

Effects of Bovine Respiratory Disease on the productivity of dairy heifers quantified by experts

Paper by Van der Fels-Klerx, H.J., Saatkamp, H.W., Verhoeff, J., Dijkhuizen, A.A.
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Abstract

The aim of the current study was to obtain expert data on the impact of Bovine Respiratory Disease (BRD) on the productivity of dairy heifers. Expert knowledge on the productivity effects of BRD was elicited because a complete insight into these effects was not available from literature. The experts' assessments were quantified, applying the computerised ELI technique, by means of subjective probability density functions (PDFs). For each parameter assessed, the individual experts' PDFs were aggregated, hereby weighting the experts according to their expertise, to obtain a single weighted distribution per parameter.

Results indicated that mortality following severe pneumonia in heifers between 0-3 months was assessed to be increased by 20 % (range 16-24 %). Body weight of diseased heifers was estimated to be reduced by 10 kg (range 2-18 kg) at three months, up to 29 kg (range 23-36 kg) at 14 months. Furthermore, pneumonia was assessed to delay first calving age with 2 weeks (range 0.1-0.9 months) and to reduce first lactation milk production by about 2 % (150 kg, range 40-250 kg). BRD outbreaks in heifers older than three months were also estimated to reduce body weight at 14 months with approximately 30 kg (range 11-54 kg). The resulting productivity effects following BRD outbreaks were found to be less severe, and only occasionally as detrimental as the productivity effects associated with early pneumonia.

It was concluded that the expert data obtained provide valuable information for economic decision-making in dairy practise.

5.1 Introduction

Bovine Respiratory Disease (BRD) is, besides diarrhoea, the major health problem in dairy heifers. BRD is a broad term that covers a range of clinical signs that can be caused by a variety of infectious agents. The disease complex is caused by one or more primary pathogens, including respiratory viruses and *Mycoplasma spp.*, commonly complicated by a secondary bacterial infection, or by bacteria alone. Although respiratory agents are responsible for the ensuing clinical signs, predisposing factors markedly increase their likelihood and severity, i.e., the disease is multifactorial (Radostits et al., 1994).

Information on the economic consequences of BRD in dairy heifers is scarce. Practical experiences indicate that on individual farms the losses might be substantial. Economic losses caused by BRD include treatment expenditures and losses due to reduced lifetime productivity of cattle affected. Effects on productivity ('productivity effects') associated with BRD in dairy heifers include increased mortality, increased culling, reduced growth, reduced fertility, increased age at first calving, and possibly decreased milk production in first lactation. Only one of these effects, i.e., mortality, has been quantified in various studies (Waltner-Toews et al., 1986a; Waltner-Toews et al., 1986b; Curtis et al., 1988; Curtis et al., 1989; Perez et al., 1990; Curtis et al., 1993; Donovan et al., 1998b). Most productivity effects have been studied less intensively, e.g., growth (Van Donkersgoed et al., 1993; Virtala et al., 1996; Donovan et al., 1998a), premature culling (Waltner-Toews et al., 1986a; Curtis et al., 1989), age at first calving (Waltner-Toews et al., 1986a; Warnick et al., 1994), dystocia at first calving (Warnick et al., 1994), milk production during first lactation (Warnick et al., 1995), and longevity after first calving (Warnick et al., 1997). For most parameters investigated, results of the respective studies were ambiguous or hardly could be compared with each other because of study differences. None of the studies took into account the various productivity effects simultaneously. Hence, comprehensive insight into the impact (ranges) of the productivity effects of BRD is far from complete. The lack of combined quantitative data makes it hard to reliably calculate the economic losses due to BRD in heifers reared on the dairy farm. Consequently, economic sound decision-making on prevention and control of the disease is to a great deal impaired as well.

Experts possess valuable knowledge on parameters related to their field (Goossens et al., 1996). Although expert assessments should not be considered a substitute for field and experimental data, it can be valuable, in particular in case information from the latter sources is incomplete or not available at all (Cooke, 1991; Meyer and Booker, 1991).

Expert data obtained according to a formal protocol is increasingly recognised as a valuable source of scientific data in numerous fields of interest (e.g., Goossens et al., 1996; Goossens and Harper, 1998; Goossens et al., 1998), including the area of animal health economics (Horst et al., 1996; Horst et al., 1998; Van Schaik et al., 1998; Van der Fels-Klerx et al., 2000). In this perspective, quantitative insight into the economic consequences of BRD in dairy heifers could be enhanced using expert assessments of the productivity effects associated with the disease.

This Chapter presents and discusses the results of a formal expert judgement study aimed at the elicitation of expert data on the most important productivity effects of BRD in heifers reared on dairy farms in the Netherlands. An extensive description of the elicitation and analysis techniques applied can be found in Van der Fels-Klerx et al. (2001) (Chapter 4 of this thesis); this Chapter addresses the methodology only briefly.

5.2 Material and methods

5.2.1 The expert elicitation process

The main criteria for expert selection were 1) a DVM degree, 2) working experience related to BRD in dairy heifers, preferably both in science and in practice, and 3) familiarity with dairy heifer rearing practices in the Netherlands. In total 22 persons were selected and approached by postal mail to participate in the expert judgement study on a voluntary and unpaid basis. The selection covered the available community of experts to a large extent. The approached experts responded positively, except for one person, resulting in an expert panel of 21 persons. The experts' background varied from practice to research, with many having recent experiences in both these fields. At the time of the expert judgement study, the experts were employed by the government (3 persons), the Animal Health Service (5 persons), the Institute for Animal Science and Health (3 persons) or by other scientific institutes (2 persons), or were veterinary practitioners (8 persons). The majority of the experts who currently worked in veterinary practice had specialised in BRD, e.g., by co-operation in field trials on the disease. Most of the experts from the scientific field had specialised in one or more specific respiratory micro-organism(s), however, also had knowledge on the other relevant respiratory pathogens. Two experts came from Belgium and the remaining 19 were Dutch.

A schematic overview of the complete expert elicitation process is presented in Figure 5.1. The process started with four stages that each were based on the Delphi technique, a technique to bring together the knowledge of a panel of experts and aggregate their opinion by indirect (expert) interaction (Cooke, 1991; Meyer and Booker, 1991).

Aim	Subject(s)	Method
1) Consensus on qualitative aspects of relevance to the productivity effects of BRD in dairy heifers	*Stage 1* - Definition of BRD	*Delphi (one or more iterations)* consensus ↓ / no consensus ↑

	Stage 2
	- Distinguish BRD to:
	  - type
	  - disease (severity) classes
	  - age classes
	- Definition of disease classes
		Delphi (one or more iterations)
		consensus ↓ / no consensus ↑

	Stage 3 - Definition of BRD types	*Delphi (one or more iterations)* consensus ↓ / no consensus ↑
	Stage 4 - Complete the list of productivity effects of BRD from literature - Identify and rank the most important productivity effects of BRD	*Delphi (one or more iterations)* consensus ↓ / no consensus ↑
2) Quantification of the productivity effects of BRD in dairy heifers	*Stage 5: Group meeting* - Quantify the most important productivity effects of BRD (most likely value with uncertainty)	*ELI method (individually)*

Figure 5.1 Design of the expert elicitation process aimed at the quantification of the productivity effects of Bovine Respiratory Disease (BRD) in dairy heifers

Applying Delphi, each of the first four stages was composed of a series of sequentially mailed questionnaires (i.e., several iterations) administered to the individual experts, hereby assuring the anonymity of their responses. In each iteration, the experts were informed with the results of the previous iteration, including the aggregated or group response (overall response of all experts) and the opinions of their (anonymous) colleagues, and given the opportunity to reassess. The iteration process was repeated until consensus on the subject(s) of the particular Delphi stage was reached.

The four Delphi stages focused on relevant qualitative aspects related to the variables of interest or 'target' variables, i.e., the productivity effects of BRD in dairy heifers. They served as preparation for the final stage (stage 5) of the expert elicitation process which included the actual quantification of these effects. More specially, Delphi stages 1 to 3 focused on the definition of BRD, and classes to be distinguished with respect to BRD type, disease severity and age of heifers affected, as well as the definition of each of these classes. Types of BRD were based on characteristics of occurrence of the disease, e.g., with respect to season. Differentiation of BRD into classes for type, disease severity and age was based on the experts' a priori expectation of variation between the productivity effects and/or their impact (ranges) between one or more of the classes to be considered. In Delphi stage 4, the experts identified and ranked the most important productivity effects, starting with a list reported in literature. They did so for each of three combinations of BRD type, disease class and age class ('BRD combinations') considered relevant based on expert judgement. Stage 5 of the expert elicitation process included a group meeting in which the experts quantified the identified most important productivity effects of each of the three BRD combinations. The experts' assessments of the productivity effects were elicited individually using the ELI ('ELIcitation') technique (Van Lenthe, 1993).

ELI is a graphically-oriented computerised method that facilitates the quantification of subjective knowledge about uncertain continuous quantities (Van Lenthe, 1993; Van Lenthe and Molenaar, 1993), in this case the productivity effects of BRD. The program assists the assessors with the transformation of their estimations as well as their uncertainty about these quantities into unbiased probability density functions (PDFs). The top (modus) of a PDF represents the best guess, and the dispersion corresponds with the uncertainty about this best estimation. ELI's main feature is the application of 'proper scoring rules' in the probability assessment task (Van Lenthe, 1993; Van Lenthe and Molenaar, 1993). A scoring rule is a function that provides a score that reflects the correspondence between a stated PDF and the value that actually occurs. In a training session with ELI, i.e., when the assessor does not know the actual answers or 'true values', the scoring system makes it possible to inform him/her about the quality of his/her answers. Score feedback is given after each training question and the assessor is stimulated to maximise his/her (total) score. In this way, over- and under-confidence bias is minimised enhancing the quality of the PDFs (Van Lenthe, 1993; Van Lenthe and Molenaar, 1993; Hardaker et al., 1997). A training session with feedback also improves the results of new questions for which no feedback is given, such as the questions of interest, and, therefore, in the ELI interview typically precedes these questions (Van Lenthe, 1993). More detail on ELI can be found in Van Lenthe (1993).

The ELI interviews of the group meeting started with an instruction and a few exercises to learn the computer program, followed by a training phase. This training phase consisted of ten questions on quantitative aspects related to BRD in dairy heifers, derived from literature, the answers to which known by the researchers. Feedback about the quality of the experts' PDFs was provided individually, by the computer program, after each training question and the experts were stimulated to maximize their scores. The training phase was followed by the questions on the target variables, which were distributed among the experts such that each expert assessed the productivity effects of two out of the three different BRD combinations considered. The experts quantified each parameter (related to productivity effects of BRD) relative to its pre-set 'reference value', defined as the parameter's value for herd mates not affected by the disease. Reference values were mainly based on advised targets or averages of dairy heifer rearing in the Netherlands, derived from Quigley III et al. (1996) and CR-Delta (1998). Reference values of the parameters that were expressed as rates above rates due to all but BRD were, by definition, zero. The possible range of values for the latter parameters had been cut off at this zero value because negative values were considered not valid. Besides the productivity effects of BRD, each expert also quantified seven 'seed' variables (see section 5.2.2) which were randomly mixed with the target variables. The ultimate outcome of the ELI interviews included the individual experts' PDFs of the target variables and the seed variables, provided by the program by key parameters of their underlying distributions.

The ELI interviews were fully computer-supported and self-explanatory so that they could be completed individually, without interaction between the experts or between the experts and the process facilitators. The ELI interviews had been pre-tested by 19 persons who did not participate in the expert panel. They had a background in veterinary medicine and/or animal science and were at that time working at the Faculty of Veterinary Medicine (Utrecht University, The Netherlands) or the Department of Social Sciences (Wageningen University, The Netherlands).

5.2.2 Analyses

The individual experts' PDFs of the most important productivity effects of BRD, obtained from the ELI interviews, were combined in order to obtain a single aggregated (overall) PDF per parameter. This was done using the Class subsystem of the software package EXCALIBR (Cooke and Solomantine, 1992), which is based on the Classical model (Cooke, 1991). Applying this technique, the individual experts' assessments were weighted, based on the relative expertise of the particular experts indicated by their performance on the seed variables. Seed variables had been included in the ELI interviews (see section 5.2.1) especially for this purpose. Seed variables are uncertain quantities of which, at the time of the elicitation, the true values are not known by the experts but known by the researchers. The performance of the experts on these variables is taken as indicative for their performance on the target variables and, therefore, seed variables must resemble the target variables as much as possible (Cooke, 1991; Goossens et al., 1998; Cooke and Goossens, 1999). The seed variables used were based on parameters related to the impact of BRD on the productivity of heifers raised on dairy farms of the Research Institute for Animal Husbandry in the Netherlands (i.e., experimental and field data). Familiar to the experts, the rearing conditions on these farms are very similar to the rearing conditions on commercial dairy farms in the Netherlands. Hence, the seed variables largely resembled the target variables. At the time of the ELI interviews, the true values of the seed variables were available to the researchers from recent analyses of data from the Research Institute for Animal Husbandry but not (yet) known by the experts.

Applying the Classical model, the individual experts' weights were determined on the basis of two quantitative performance measures: calibration and information. Calibration reflects the degree, in a statistical sense, to which the expert's performance on the seed variables 'supports' the hypothesis that his/her probability statements 'correspond with reality'. The information score represents the degree to which the expert's distribution of a variable is 'concentrated' or 'peaked' (Cooke, 1991; Goossens et al., 1998; Cooke and Goossens, 1999). Weighting assessments of individual experts results in virtual aggregated assessments or the 'virtual expert's' assessments. The aggregated or virtual expert's PDFs were calculated for each target variable, i.e., for each productivity effect of each of the three BRD combinations. More detail on the current expert elicitation process and data analyses can be found in Van der Fels-Klerx et al. (2001) (Chapter 4 of this thesis); more information on the Classical model is presented in Cooke (1991).

5.3 Results

5.3.1 Delphi results: Classes and definitions

The experts defined BRD in dairy heifers as 'a clinical disease of the respiratory tract caused by a viral, bacterial or mycoplasmal infection (parasites excluded) or a combination of these infections'. Heifers affected were divided into the three age classes of 0-3 months, 3-6 months, and 6-24 months. Two types of BRD were distinguished, being calf pneumonia and BRD outbreaks. They were defined as follows:

- *Calf pneumonia:* BRD cases seen one after the other, periodically or whole year around, mostly occurring in heifers < 3 months. Calf pneumonia can be caused by a variety of primary pathogens, but is commonly caused by bacteria, mainly *Pasteurella spp.*, and preceded by an infection with respiratory viruses;
- *BRD outbreak:* A certain number of heifers in a group suddenly shows clinical signs of BRD. BRD outbreaks mostly occur during the housing period, but also regularly during the grazing season. Usually heifers ≥ 3 months are affected, but also regularly heifers < 3 months. BRD outbreaks are mostly caused by a primary viral infection, mainly with *Bovine Respiratory Syncytial Virus*, with or without a secondary bacterial infection.

Three classes of severity of BRD, i.e., mild, severe, and chronic, were considered. These disease classes were defined by symptoms that can be observed at the individual level without treating the animal, and are most characteristic of and distinguishing for the particular disease class, as well as by the duration of the symptoms. Each disease class was defined by the presence of one or more symptoms out of nasal discharge, coughing, and increased respiratory rate. In addition, in case of mild BRD both body temperature and level of activity are normal, whereas in case of both severe and chronic BRD one or more symptoms out of fever (body temperature ≥ 40 °C), 'harsh' breathing sounds and abdominal breathing are observed. The duration of both mild and severe BRD is < 14 days, whereas chronic BRD starts 14 days after the onset of mild or severe BRD.

Table 5.1
Combinations of classes for type of Bovine Respiratory Disease (BRD), disease severity and age (BRD combinations), considered during the last two stages of the expert elicitation process

BRD combination	BRD type	Disease class	Age class
1	Pneumonia	Severe	0-3 months
2	BRD outbreak	Mild	3-6 months
3	BRD outbreak	Severe	6-24 months

The last two stages of the expert elicitation process (i.e., Delphi stage 4 and the ELI interviews) focused on the following three BRD combinations: severe pneumonia in heifers aged 0-3 months (BRD combination 1), mild cases of a BRD outbreak in heifers aged 3-6 months (BRD combination 2), and severe cases of a BRD outbreak in heifers aged 6-24 months (BRD combination 3) (Table 5.1).

In Delphi stage 4, the following productivity effects were selected to be most important for one or more of the three BRD combinations considered:

- Increased risk of mortality;
- Increased risk of culling;
- Reduced weight gain and resulting body weight;
- Increased risk of fertility disorders, particularly foetal losses and abortions;
- Increased age at first insemination and age at first calving; and
- Reduced milk production in first lactation.

The first three productivity effects were defined for various stages of the heifers' rearing period, in particular applying to BRD combinations 1 and 2. Fertility disorders were identified to occur following BRD combination 3 (heifers ≥ 6 months) only. Target variables related to the impact of BRD on risk of culling and age at first insemination were not included in the ELI interviews because these productivity effects usually are too a large extent affected by the farmer's management.

5.3.2 ELI results: Expert data on the productivity effects

The aggregated PDFs, expressed by their 5th, 50th and 95th percentile values, are presented in Tables 5.2 to 5.4 for the productivity effects of BRD combinations 1 to 3 respectively.

Table 5.2
Productivity effects following severe pneumonia in dairy heifers aged 0-3 months (BRD combination 1), expressed by the 5th, 50th and 95th percentiles of the aggregated distributions (based on 13 experts)

Productivity effect	Reference value[1]	Percentiles of aggregated distribution		
		5th	50th	95th
Mortality < 3 months[2] (%)	0	16	20	24
Body weight at 3 months (kg)	100	82	90	98
Body weight at 6 months (kg)	180	164	170	176
Body weight at 14 months (kg)	380	344	351	357
Age at first calving (months)	24	24.1	24.5	24.9
305-d milk production in first lactation (kg)	6800	6550	6650	6760

[1]Value in non-affected herd mates
[2]Above levels due to all but the disease

Table 5.3
Productivity effects following mild outbreaks of Bovine Respiratory Disease (BRD) in dairy heifers aged 3-6 months (BRD combination 2), expressed by the 5th, 50th and 95th percentiles of the aggregated distributions (based on 13 experts)

Productivity effect	Reference value[1]	Percentiles of aggregated distribution		
		5th	50th	95th
Mortality between 3-6 months[2] (%)	0	0.2	0.8	20
Mortality between 6-24 months[2] (%)	0	0.2	0.7	7.4
Body weight at 6 months (kg)	180	167	176	183
Body weight at 14 months (kg)	380	343	356	365
Age at first calving (months)	24	23.4	24.2	25.0
305-d milk production in first lactation (kg)	6800	6600	6790	6890

[1]Value in non-affected herd mates
[2]Above levels due to all but the disease

Table 5.4
Productivity effects following severe outbreaks of Bovine Respiratory Disease (BRD) in dairy heifers aged 6-24 months (BRD combination 3), expressed by the 5th, 50th and 95th percentiles of the aggregated distributions (based on 14 experts)

Productivity effect	Reference value[1]	Percentiles of aggregated distribution		
		5th	50th	95th
Mortality between 6-24 months[2] (%)	0	0.1	3.2	27
Body weight at 14 months (kg)	380	326	348	369
Foetal losses[2,3] (%)	0	0.2	5.1	30
Abortions[2,4] (%)	0	0.2	2.7	29
Age at first calving (months)	24	23.6	24.1	27.1
305-d milk production in first lactation (kg)	6800	6370	6720	6890

[1]Value in non-affected herd mates
[2]Above levels due to all but the disease
[3]< 4 months pregnant
[4]≥4 months pregnant

5.3.2.1 Mortality

The increase of mortality following pneumonia during the first three months of life was assessed to be large; the median (50th percentile) of the aggregated PDF was 20 %, ranging from 16 to 24 % (Table 5.2). The increase of mortality due to BRD outbreaks in heifers ≥ 3 months was much lower, i.e., 0.7 to 3.2 % (median of aggregated PDFs), but on occasion could be as high (Tables 5.3 and 5.4). In both BRD combination 2 and 3, the assessed lower confidence bound of the PDF for mortality, indicated by its 5th percentile value, was very close to this parameter's reference value of zero. Because the possible range of values for this parameter had been cut off at zero in the assessment task, mortality following BRD outbreaks might, according to the experts, not be considerably increased.

5.3.2.2 Body weight

Body weight at three months following pneumonia before this period was assessed to be 90 kg (median of aggregated PDF), i.e., 10 kg less than this parameter's reference value of 100 kg (Table 5.2). As the reference value fell outside the estimated confidence interval, indicated by the 5th and 95th percentile values (i.e., 82 to 98 kg), the reducing effect of early pneumonia on body weight at three months was found to be considerable. Body weight was still reduced at later stages of the rearing period. At the age of six months, the reduction was found to be comparable with the reduction at three months, however, at the age of 14 months the reduction was more severe, namely 29 kg, ranging from 23 to 36 kg (Table 5.2). BRD outbreaks in heifers ≥ 3 months, mainly occurring in the first rearing year, were also perceived to considerably reduce body weight at 14 months (Tables 5.3 and 5.4). As with pneumonia, this reduction was assessed to be approximately 30 kg, but its variation was higher, in particular for heifers ≥ 6 months.

5.3.2.3 Fertility and milk production

BRD outbreaks in heifers ≥ 6 months were assessed to increase the occurrence of foetal losses and abortions by 5.1 and 2.7 % respectively, both ranging up to 30 % (Table 5.4). Both fertility disorders may, however, not be considerably increased because the estimated lower confidence bounds of the distributions of these parameters were close to their reference value of zero, and these distributions had been cut off at this value in the assessment task.

Pneumonia in early life was found to increase age at first calving by half a month (range 0.1-0.9 months) and to reduce first lactation milk production by 150 kg (i.e., 2.2 %), ranging from 40 to 250 kg (Table 5.2). In case of BRD outbreaks in heifers ≥ 6 months, both these parameters were perceived not to differ considerably from their pre-set reference values (Tables 5.3 and 5.4).

5.4 Discussion and conclusion

Expert assessments are frequently used in on-farm advice given and as such are implicitly used in decision-making processes in dairy practise. In the current study, this 'underlying' expert data was quantified, i.e., made explicit, applying a formal expert elicitation process so that it could be used for further analyses (e.g., aggregation).

The consulted experts all were specialised in the current interest field of BRD in dairy heifers, however, varied with respect to disciplinary background and level of specialisation as well as years of experience and geographic working environment. Due to this variation, the performance of the experts in assessing the productivity effects of BRD, was expected to vary as well. Therefore, the expertise of the individual experts was accounted for in composing aggregated distributions, applying the Classical model, by down-weighting the assessments of the lower-performing experts. Due to the variability present within the panel, the experts' assessments were considered as independent as possible, justifying application of the Classical model approach.

For most of the parameters considered, the experts were reasonably consistent on the expected most likely value; differences particularly were found in the indicated ranges, reflecting their uncertainties about their best estimations. The final aggregated PDFs of the productivity effects covered the total variation in the experts' assessments on both the perceived most likely values and uncertainties of the particular parameters.

Previous findings on mortality following pneumonia during early life are ambiguous, and range from no direct (significant) effect (Perez et al., 1990; Donovan et al., 1998b) to an odds of 6.5 (Curtis et al., 1988). The experts' assessment of this parameter, in terms of its aggregated PDF, indicates this effect to be more detrimental which might be due to the fact that it applies to severe cases only whereas the previous studies refer to pneumonia cases of all severities.

The experts' assessment of body weight at the age of three months following severe pneumonia before this period is somewhat higher but in the order of magnitude of findings from Virtala et al. (1996). The latter study reported that early pneumonia reduced body weight at three months by almost 4 kg. Correspondingly, pneumonia between 0-6 months of age was found to reduce weight gain during this period by almost 11 kg (Donovan et al., 1998a). In addition, pneumonia before the age of six months reduced weight gain during the consecutive period up to 14 months with an additional 3 kg (Donovan et al., 1998a), which is less detrimental than the assessed median reduction in body weight at this age of almost 30 kg. Donovan et al. (1998a) probably have underestimated the effect of pneumonia on body weight as they dealt with the problem of selective follow-up; 40 percent of the heifers that were culled from their study herds before the age of six months did so because of the detrimental effect of BRD on growth (Donovan et al., 1998a).

Although a direct effect of BRD on the occurrence of fertility disorders during the rearing period was not quantified previously, several studies investigated the indirect effect on age at first calving, determined by growth and fertility during the rearing period as well as by the farmer's breeding management. Results of these studies, dealing with pneumonia in early life, include no (significant) effect (Waltner-Toews et al., 1986a) and a delay of 3 months (Warnick et al., 1994). The aggregated PDF of age at first calving following early pneumonia is within the range of these findings. As pneumonia was not expected to increase the occurrence of fertility disorders, the extended rearing period was perceived to be caused by diminished growth delaying age at first breeding.

The decrease in first lactation milk production following pneumonia before the age of three months was assessed to be small, and in the same order of magnitude as findings from Warnick et al. (1995). However, the latter study found the reduction to be non-significant, which is not surprising given the high number of observations needed to detect an effect of only few percent to be significant in the field.

In conclusion, the most detrimental productivity effects associated with BRD in dairy heifers were assessed to occur following severe pneumonia during early life. Consequently, the economic losses caused by the disease might be large. BRD outbreaks in heifers older than three months were estimated to have less high an impact on the productivity of affected cattle, however, the productivity effects were perceived to be detrimental on occasion, and so might be their associated economic consequences. The experts' assessments of the identified most important productivity effects of early pneumonia were either in the same order of magnitude as findings from earlier field studies, as far as these are available, or there was a reasonable explanation for their differences. A similar comparison for the productivity effects associated with BRD outbreaks was not possible because previous research on these parameters is (too) scarce.

When consulting experts to provide their assessments, they will weight all relevant information available to them, originating, e.g., from literature or databases, add their own experiences, and use it for the actual quantification task. In this perspective, the expert data obtained in the current study can be viewed as embracing many 'pieces' of the existing information. Another advantage of this study is that it provided assessments of parameters for which data from other sources is lacking or incomplete. Furthermore, the various parameters were considered simultaneously, and their impact ranges, rather than their averages only, were estimated. Given the above-mentioned perspectives, the experts' assessments obtained in this study provide a comprehensive insight into the impact (ranges) of the productivity effects of BRD.

Like any other expert judgement study, the current study made use of human subjects and, consequently, the results entail, by definition, a certain degree of subjectivity. However, the formal elicitation process was designed such that this inherent subjectivity was reduced as much as possible. Hence, the expert data obtained can be considered to provide valuable information for economic decision-making and farm advice in dairy practise. This data can, however, never replace objective or 'hard' data from well-designed field studies, if available. But, as long as such studies provide insufficient information, it is considered to be useful.

The expert data obtained in the current study could be used for evaluation of the economic losses caused by BRD in dairy heifers. Moreover, inclusion of the aggregated PDFs of the productivity effects of BRD in such calculations will enhance the overall quantitative insight into these losses, including their ranges. This insight will support on-farm decision-making processes with regard to the control and prevention of BRD.

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Chapter 6

An economic model to calculate farm-specific losses due to Bovine Respiratory Disease in dairy heifers

Paper by Van der Fels-Klerx, H.J., Sørensen, J.T., Jalvingh, A.W., Huirne, R.B.M.
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Abstract

This Chapter describes a personal-computer-based model estimating the economic losses associated with (clinical) Bovine Respiratory Disease (BRD) in replacement heifers raised on individual dairy farms. The model is based on the partial-budgeting technique, and calculates the losses for two types of the disease separately: calf pneumonia and a seasonal outbreak. Model input includes farm-specific data such as the incidence of BRD, prices, and effects of the disease on the heifers' productivity. The input database was linked directly with the economic model. For all input parameters, default values used are available to the user and can be modified easily.

Losses considered by the model include treatment expenditures and costs associated with increased mortality, increased premature culling, reduced growth, reduced fertility and reduced milk production in first lactation. Uncertainty is taken into account for parameters related to disease incidence, mortality and culling.

Basic calculations for a typical Dutch dairy farm with 60 % of the heifers affected, indicated total annual losses due to pneumonia (< 3 months) average € 31.2 per heifer present on the farm (range € 18.4 – 57.1). The estimated losses for one seasonal outbreak with heifers up to 15-months old affected were € 27.0 per heifer present (range € 17.2 – 43.1). For both BRD types, the model's outcome was most sensitive to the number of heifers affected. Most of the resulting parameters that had a major impact on the total losses were related to treatment or to the effects on the heifers' productivity.

The model is user-friendly and flexible, and can be used as an interactive tool by farmers and veterinarians in the (economic) decision-making process regarding on-farm prevention and control of BRD.

6.1 Introduction

Bovine Respiratory Disease (BRD) is a broad term used for a range of clinical signs caused by a variety of infectious agents (essentially viruses and bacteria) (Appendix 6.1). Clinical signs of the disease include increased respiratory rate, coughing, serous and nasal discharge, fever, and decreased appetite. Although infectious agents are primarily responsible for the clinical signs, host factors as well as environmental and management factors markedly increase their likelihood and severity (i.e., the disease is multifactorial). Dairy cattle of all ages can be affected, but calves and yearlings are most susceptible (Radostits et al., 1994).

Estimations of the economic consequences of BRD in dairy heifers are scarce; reliable insight into the losses is lacking. Practical experiences indicated that losses associated with BRD can be important for the individual-farm economy. Variation between farms seems to be large; hence, there is potential to improve farm profitability. Economic losses associated with BRD in dairy heifers occur due to treatment and reduced lifetime productivity of the animals affected. Treatment expenditures include drugs (e.g., antibiotics) and veterinary services. Effects on productivity ('productivity effects') following BRD in dairy heifers include increased mortality, increased premature culling (i.e., reduced lifetime), reduced weight gain, reduced fertility and increased age at first calving, and possibly reduced milk production in first lactation (Waltner-Toews et al., 1986; Curtis et al., 1988; Warnick et al., 1994; Warnick et al., 1995; Sivula et al., 1996; Virtala et al., 1996; Donovan et al., 1998). Information on the impact of these productivity effects is scarce and, if available, is often conflicting and uncertain. In addition, at herd level the productivity effects of BRD are complex because of their interrelationships. This complicates an accurate evaluation of the economic losses associated with BRD in dairy heifers. Despite this lack of knowledge, farmers and veterinarians frequently have to make (management) decisions on prevention and control of BRD. To improve this decision-making process, more insight into the on-farm economic impact of the disease is required, and a personal-computer (PC)-based decision support system might be useful (Dijkhuizen and Morris, 1997). Simulation approaches to cattle diseases and to their economic evaluation provide useful information (Nyamusika et al., 1994; Pasman et al., 1994; Sørensen et al., 1995). The economics of BRD in a dairy-cattle herd have been modelled by a stochastic distributed-delay simulation model (Hurd et al., 1995). The major shortcoming of this approach is that it cannot easily be applied and accepted in the field, because it is difficult to explain and has limited flexibility. A more user-friendly and flexible model is needed for use in dairy practice as well as for investigation of the uncertain information on the productivity effects of BRD.

This Chapter describes a PC-based model that calculates the economic losses associated with clinical BRD in dairy heifers, and which was developed especially for on-farm decision support.

6.2 Model description

6.2.1 Basic model assumptions

The model evaluates the economic consequences of BRD in Holstein-Friesian heifers that are raised on a Dutch dairy farm; particular characteristic is the use of home-raised heifers to replace milking cows. The losses are calculated at the individual-farm level, relative to the same farm not having BRD ('reference situation'). BRD affects only some of the parameters of the dairy herd. Therefore, partial-budgeting (considering only those items of costs and returns that actually change) is used (Dijkhuizen and Morris, 1997). Consequently, the model only includes the (variable) costs and returns influenced by BRD. Fixed costs, such as interest and depreciation on investments, are assumed not to change and are not considered.

Following expert judgement elicited by Van der Fels-Klerx and Dijkhuizen (2000), the model distinguishes two types of clinical BRD: calf pneumonia and a seasonal outbreak. In short, pneumonia is assumed to occur all-year-round in younger heifers (< 3 months) only, whereas an outbreak is assumed to occur in the winter season with heifers up to a certain age at risk. For both BRD types, three classes of severity of (clinical) disease are distinguished: mild, severe and chronic. Definitions formulated by Van der Fels-Klerx and Dijkhuizen (2000) were used (Appendix 6.1). The model assumes heifers can be affected (clinically) by BRD during their rearing period only once. The economic consequences were evaluated for the two BRD types separately.

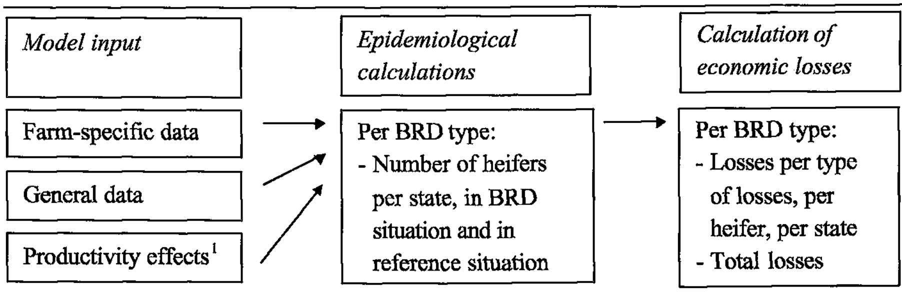
The model was divided into three parts: 1) input, 2) epidemiological calculations, and 3) evaluation of the economic losses. The three steps are illustrated in Figure 6.1, and explained in more detail in the following three sections.

6.2.2 Model input

Input of the model includes: 1) farm-specific data, 2) general data, and 3) data on the productivity effects following BRD in dairy heifers (Figure 6.1). Farm-specific data describe the particular herd by several key figures including the number of milking cows in the herd, annual replacement percentage and calving interval. By default, the model uses averages of all Dutch dairy farms for the farm characteristics derived from Research Institute for Animal Husbandry (1997), CR-Delta/NRS division (1998) and Agricultural Information and Knowledge Centre and Research Institute for Animal Husbandry (1999) (Table 6.1). Figures on the incidence of BRD and treatment refer to the specific herd in question and can be set by the user. Incidence of BRD is expressed as proportion of heifers affected, and specified both per BRD type and disease class. Optionally, these figures can be specified further to season and age for pneumonia and outbreaks respectively (section 6.2.3). By default, the same values are used for each season or each age class.

Table 6.1
Characteristics of a typical dairy herd in the Netherlands (1997)

Milking cows (no.)	55
Replacement (%/year)	32
Calving pattern (all-year-round/autumn calving)	autumn calving
Calving interval (days)	401
First-lactation milk production (kg)	6800
Age at first insemination (months)	15
Body weight at first insemination (kg)	360
Oestrus detection (%)	70
Pregnancy risk per service (%)	70
Growth pattern (g/day):	
Month 1	500
Month 2	700
Month 3 to 8	850
Month 9 to 15	700
Month 16 to 21	625
Month 22, 23	500
Month 24, higher	350



[1]Data on effects of Bovine Respiratory Disease (BRD) on the productivity of dairy heifers; stored in underlying database

Figure 6.1 Outline of the model

Table 6.2
Default prices (€)[1] used to estimate the economic losses due to Bovine Respiratory Disease in heifers raised on a dairy farm in the Netherlands

Expenditures	
Veterinary expenditures:	
Visit	20.0
Consultation	5.7
General during 1st rearing year	39.0
General during 2nd rearing year	17.2
Feed (per kg DM):	
Milk powder	1.18
Concentrates	0.13
Silage	0.11
Grass	0.07
Insemination	13.6
General rearing costs (per day)	0.08
Calving heifer[2]	699
Difference in farm's net return to labour and management at decreased milk production (per kg)	-0.09
Revenues	
Calving heifer[2]	663
Heifers that aborted[2]	436
Culled heifer[2]:	
0-<3 months	0
3-<6 months	0
6-<9 months	45
9-<12 months	91
12-<15 months	136
15-<18 months	182
18-<21 months	272
21-<24 months	318

[1]1 Euro = 0.861 US Dollar
[2]Variable costs only

General data include prices, composition of feedstuffs, and the growth pattern of dairy heifers, defined by their average daily gain per month. Prices used represent, by default, the current Dutch prices (Agricultural Information and Knowledge Centre and Research Institute for Animal Husbandry, 1999) (Table 6.2). Default values for feed composition and the heifers' growth pattern are based on Central Bureau for Livestock Feeding (1998) and Quigley III et al. (1996), respectively. Information on the productivity effects is based on literature complemented with expert data, which was elicited especially for this purpose (Van der Fels-Klerx and Dijkhuizen, 2000). Quantitative data (from literature and experts) obtained was stored in a separate PC-based database, which was linked directly with the economic model. Based on the information stored, a default value for each productivity effect was constructed, both per BRD type and per disease class (Tables 6.3 and 6.4). Defaults of all input parameters are shown to the user using Excel worksheets and -- because no intermediate calculations are made in the program's worksheet cells -- can be modified easily. The model itself was built using the Visual Basic language, and output is reported to Excel worksheets.

Table 6.3
Default parameter values, per disease class, for proportion of animals affected and effects on productivity associated with pneumonia in dairy heifers in the Netherlands

Parameter	Disease class		
	Mild	Severe	Chronic
Proportion affected (%)	25	25	10
Mortality (%)[1]	2.8	5.5	5.5
Culling (%)[1]	1.0	1.3	1.5
Treatment:			
Drugs (no. doses/case)	2.0	5.0	7.0
Costs drugs (€/dose)[2]	5.5	5.5	5.5
Veterinary visits (no./case)	0.0	0.1	0.3
Veterinary consultations (no./case)	0.10	0.12	0.15
Extra labour by farmer (h/case/day)			
Growth:			
Growth standstill (no. days)	3.0	7.0	10.0
Growth in month of disease (% of normal)	100	90	80
Growth in next month (% of normal)	100	90	80
Growth in rest rearing period (% of normal)	100	100	90
Fertility disorders[1]:			
Return to oestrus (%)	0.5	1.0	1.5
Early abortion (%)	0.5	0.8	1.0
Late abortion (%)	0.0	0.5	0.8

[1]Above rates due to all but BRD
[2]1 Euro = 0.861 US Dollar

Table 6.4
Default parameter values, per disease class, for proportion of animals affected and effects on productivity associated with an outbreak of Bovine Respiratory Disease (BRD) in dairy heifers

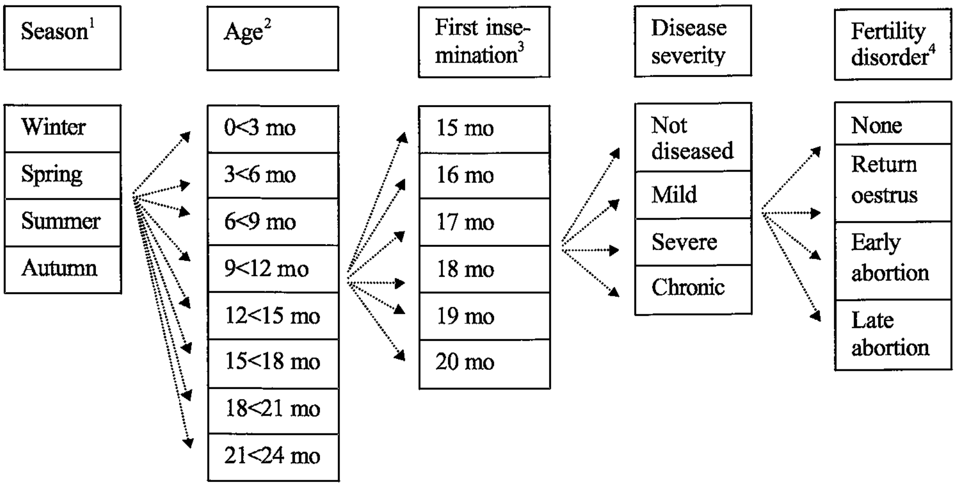
Parameter		Disease class		
		Mild	Severe	Chronic
Proportion affected (%)		25	25	10
Mortality (%)[1]		1.7	3.4	5.1
Culling (%)[1]		1.8	3.5	4.2
Treatment:				
Drugs (no. doses/case)		2.0	3.0	4.0
Costs drugs (€/dose)[2]		4.5	5.0	5.5
Veterinary visits (no./herd)	3			
Extra labour by farmer (h/day/herd)	1			
Growth:				
Growth standstill (no. days)		6.3	7.0	7.7
Growth in month of disease (% of normal)		77	70	63
Growth in next month (% of normal)		88	80	72
Growth in rest rearing period (% of normal)		100	100	90
Fertility disorders[1]:				
Return to oestrus (%)		11.1	12.3	13.5
Early abortion (%)		8.8	9.8	10.8
Late abortion (%)		9.8	10.3	11.3

[1]Above rates due to all but BRD
[2]1 Euro = 0.861 US Dollar

6.2.3 Epidemiological calculations

Epidemiological calculations on the disease and the evaluation of the economic consequences (section 6.2.4) are comparable for both BRD types, and, therefore, described in general with special reference to differences between types as appropriate.

In the model, heifers are defined by five state variables: season of birth, age, (future) age at insemination, severity of BRD and fertility disorders (Figure 6.2). A year is divided into four seasons (quarters) of three months each, with the winter defined as November 1st to January 31st. Heifers (0-2 years) are divided into eight age classes of three months each. Insemination classes (six at the maximum) indicate the heifer's (future) age, by month, in which the (latest) successful insemination occurs. Furthermore, four classes for both disease severity and fertility disorders are considered (Figure 6.2). Return to oestrus indicated the heifer's return to (future) latest insemination, early abortion was defined as embryonic/foetal deaths occurring in the first seven months of gestation, and late abortion was defined to occur during the last two months of gestation. In total, 3072 states are considered at the maximum. Both in the reference situation and the BRD situation, the



[1]Periods of three months each, with winter defined from November 1st to January 31st. For outbreaks, the winter season is considered only

[2]For pneumonia, the first age class (0-<3 months) is considered only

[3]Age at first insemination given the heifer's body weight is not restricted; the model's default of 15 months can be increased by the user

[4]Fertility disorders due to Bovine Respiratory Disease (BRD), above rates due to all but BRD

Figure 6.2 Illustration of calculation of heifers per state

(continuous) numbers of heifers present in each state are calculated for each 3-month time step (Figure 6.2).

The model begins by calculating the farm's starting situation, defined as the number of heifers present in each state at the first time step (winter season), for both the reference and the BRD situation. In the reference starting situation, heifers are not diseased and hence have no (extra) fertility disorders. The BRD starting situation is calculated by dividing the number of heifers present in each state in the reference starting situation to one of the four classes for severity of disease by probabilities[i]. Next, these numbers are further distinguished, by probabilities, to classes for fertility disorders following BRD. Assumptions made about heifers at risk for BRD follow the definition of the particular BRD type (Appendix 6.1). In case of pneumonia, heifers at risk are 0-<3 months old and present on the farm in each of the four seasons. With an outbreak, heifers aged up to the user-defined maximum age (class) present at the farm in the winter season are at risk. Next, for both situations (reference and BRD), the number of heifers present in each state

[i]In the model, heifers that become chronically affected are assigned directly to this disease class, and not to the mild or severe disease class first

in each 3-month time step is calculated given normal culling risks (culling due to all but BRD) per age class and the number of heifers in the particular state in the previous time step.

6.2.4 Evaluation of economic losses

6.2.4.1 General

The economic losses following BRD are calculated per year (four seasons) in case of pneumonia, and for one outbreak occurring during the winter season in case of an outbreak. In both cases, total losses are expressed per heifer present on the farm. The total time span considered by the model equals the period from the starting situation until the (future) moment the last heifer in the BRD situation present at this (starting) situation calves. Besides treatment expenditures and (opportunity) costs for labour by the farmer, the model takes into account the costs associated with effects of BRD on the productivity of the heifers during their remaining rearing period. More specifically, the types of losses considered in the model are associated with:

- Treatment and extra labour by the farmer;
- Increased mortality and increased premature culling;
- Reduced growth and reduced fertility;
- Reduced milk production in first lactation.

Culling refers to involuntary culling directly after the disease and to voluntary culling of calving heifers (surplus). Culling of heifers in the period between the disease and calving was not considered, because it is generally not done on Dutch dairy farms. Furthermore, BRD was assumed to have no effect on culling of heifers once in the milking herd (Warnick et al., 1997).

First, for each type of losses, the economic consequences are calculated at the animal level for each relevant state separately (Figure 6.1). Second, total losses per type as well as overall losses are calculated, per BRD type, from the losses per heifer per state and the number of heifers present in each state. For each of the various types of losses, calculation of the economic consequences is described in detail below.

6.2.4.2 Treatment and labour

Treatment costs are composed of expenditures for drugs and veterinary services (visits and consultations). Drugs are assumed to be administered by the veterinarian at the time of service(s). Follow-up doses, if necessary, are administered by the farmer. Opportunity costs for the farmer's labour (e.g., for extra handling of the affected heifers) are included. Diseased heifers that die due to BRD and diseased heifers that are culled directly due to BRD are assumed to receive a quarter and a half, respectively, of the doses of drugs administered to diseased heifers that do not die or are culled. In case of pneumonia, diseased heifers that die due to BRD and diseased heifers that are directly culled due to the disease also receive a quarter and a half, respectively, of both veterinary services (visits and consultations) and labour of the farmer given to diseased heifers that do not die or are culled due to BRD. Total costs for treatment and labour are calculated as follows:

$$T = \sum_{i=1}^{3} \{NDOS_i * PDOS_i * (NDIS_i + \tfrac{1}{4} * NDE_i + \tfrac{1}{2} * NCUL_i)\}$$
$$+ NVISH * PVIS + NDAYS * NLABH * PLAB \quad \text{for an outbreak, and}$$

$$T = \sum_{i=1}^{3} \{CCASE_i * (NDIS_i + \tfrac{1}{4} * NDE_i + \tfrac{1}{2} * NCUL_i)\} \quad \text{for pneumonia}$$

where,

T: treatment costs

i: disease class (1: mild, 2: severe, 3: chronic)

$PDOS_i$: price per dose of drugs per disease class (i)

$NDOS_i$: number of doses of drugs per case per disease class (i)

$NDIS_i$: number of diseased heifers (that do not die or are culled due to BRD) per disease class (i)

NDE_i: number of diseased heifers that die due to BRD per disease class (i)

$NCUL_i$: number of diseased heifers that are culled due to BRD per disease class (i)

NVISH: number of veterinary visits per herd

PVIS: price per veterinary visit

NDAYS: acute disease period in days

NLABH: labour by farmer in hours per day of acute disease in the herd

PLAB: price of labour by farmer per hour

$CCASE_i$: costs per case of pneumonia per disease class (i)

with

$$CCASE_i = NDOS_i * PDOS_i + NCON_i * PCON + NVIS_i * PVIS + NLAB_i * PLAB$$

where,

$NCON_i$: number of veterinary consultations per case per disease class (i)

PCON: price per veterinary consultation

$NVIS_i$: number of veterinary visits per case per disease class (i)

$NLAB_i$: labour by farmer, in hours per day per case per disease class (i)

6.2.4.3 Mortality and culling

BRD is assumed to occur halfway through the age class of the particular heifer affected. Both mortality and culling lead to savings for rearing expenditures during the remaining period (i.e., to calving) and to expenditures for the purchase of a calving heifer. In addition, culling leads to revenues for the culled heifer. Savings for rearing expenditures are outlined below; expenditures for the purchase of calving heifers (to replace heifers that died or were culled due to BRD) as well as revenues for heifers that are culled are dealt with in section 6.2.4.5.

The savings for the remaining rearing period of heifers that died or were culled are calculated as the rearing expenditures from birth to calving should the particular heifer have calved (i.e., reference heifer: same state but not diseased and no fertility disorder) minus the rearing expenditures from birth to the day of mortality or direct culling. Only variable rearing expenditures are considered, including expenditures for feeding, general veterinary expenditures for drugs and veterinary services, and some general minor expenditures (e.g., for bedding material). Variable rearing expenditures from birth until event (either mortality due to BRD, culling due to BRD, or calving) are calculated per heifer per state according to the following formula:

$$REAR = FEED + \sum_{j=1}^{2}(NRDAYS_j * EVET_j) + \sum_{j=1}^{2}(NRDAYS_j * EGEN)$$

where,

REAR: rearing expenditures until event (mortality, culling, or calving)

FEED: total feed expenditures until event (mortality, culling, or calving)

j: heifer's rearing year (j=1,2)

$NRDAYS_j$: number of days until event (mortality, culling, or calving) per rearing year (j)

$EVET_j$: general daily veterinary expenditures per rearing year (j)

EGEN: general minor expenditures (e.g., for bedding material) per rearing day

Total feed expenditures for the particular raising period (birth until mortality, culling, or calving) are retrieved by summation of the feed expenditures per month. In the pre-weaning period (< 2 months), heifers are assumed to receive a certain amount of each of three different feedstuffs, i.e., milk replacer, silage, and concentrates, independently of their growth. The monthly feed expenditures during this period are derived from the total amount of each feedstuff given per month and its particular price. Monthly feed expenditures during the post-weaning period are based on the least-cost ration formulation for the given growth pattern assuming a controlled feeding system, which are calculated on a monthly basis. The composition of the monthly feed intake depends on feed quality, energy requirements, and capacity for dry-matter intake. Protein requirements are not considered, because they generally are less restricting than energy requirements (Mourits et al.. 2000). Feedstuffs given represent the ones fed in Dutch dairy practice, including grass in summer and autumn, and silage in winter and spring, both supplemented with concentrates. The heifer's energy need includes requirements for maintenance, growth and pregnancy (Van Vliet, 1997), and is calculated using the heifer's body weight (BW), average daily gain and pregnancy status in each particular month. Breeding is assumed to commence when the heifer has reached a farm-specified minimum for both BW and age. The heifer's monthly pregnancy status follows from its actual BW, age and farm-specific breeding efficiency, determined by specification of farm-specific oestrus detection percentage and pregnancy risk per service.

6.2.4.4 Growth and fertility

Parameter values on reduction in weight gain and reduced fertility are related to disease classes. Growth rate decrease is specified by four parameters: 1) the number of days of non-growth during the acute disease period, 2) the decrease (expressed by proportion of normal growth) during the rest of the month in which the disease occurred, 3) the decrease during the following month, and 4) the decrease during the remainder of the total rearing period. Because the heifer's feed intake depends on its actual BW and growth rate (section 6.2.4.3), reduced growth results in a reduced feed intake. Reduced fertility is indicated by increased probability of one of the fertility disorders after the heifer's (future) last insemination. With an outbreak, these disorders are assumed only to occur in heifers older than one year at the outbreak. Return to oestrus and early abortion are assumed to increase time of successful breeding by one month and four months, respectively. Both these fertility disorders and growth reduction (either in combination or alone) lead to an increased (expected) age at first calving. Consequently, the resulting losses include the expenditures for the increased rearing period supplemented with expenditures for extra insemination in case of both fertility disorders. Late abortion is assumed to occur at eight months of pregnancy on average. The heifer that aborted is culled from the herd and replaced by a calving heifer at its initial calving time. The resulting losses are composed of the rearing expenditures from birth until moment of abortion plus the expenditures for the purchase of a calving heifer (section 6.2.4.5) subtracted by both revenues for the culled heifer (section 6.2.4.5) and savings of rearing expenditures for the remaining period until calving. Rearing expenditures (until abortion or calving) are calculated in a similar manner as described in section 6.2.4.3.

The losses due to the increased (decreased in case of abortion) rearing period of the heifer affected (per state) (caused by reduced weight gain and/or reduced fertility) follow from the total rearing expenditures until abortion or calving minus this total for the same heifer in the reference situation. The total net difference in rearing expenditures for all heifers in the reference and the BRD situation (including expenditures for extra inseminations) the 'growth and fertility' type of losses, can be either positive or negative.

6.2.4.5 Purchase/selling of heifers

The previously mentioned productivity effects of BRD (mortality, culling, reduced weight gain and reduced fertility) result in a decreased total number of calving heifers raised at the farm and/or an increased age of first calving, compared to the reference situation. Moreover, the number of calving heifers present on the farm might be changed (either increased or decreased) in various periods of the total time span considered. The resulting losses are calculated by comparing (in both the reference and the BRD situation) the number of calving heifers available at the farm with the number required (calculated from farm characteristics) in each of the 3-month time steps of the total time span. In each time step and in both situations, calving heifers are bought in case the number required exceeds the number available at the farm; otherwise the surplus is sold. By default, both purchase price and selling price of a calving heifer include variable rearing expenditures only, supplemented with a margin in case of purchase. Losses for the number of calving heifers available follow the formula below:

$$\text{NHEIF} = P_{ref} - S_{ref} - (P_{BRD} - S_{BRD})$$

where,

NHEIF: losses for number of calving heifers available

P_{ref}: expenditures for purchase of calving heifers in the reference situation

S_{ref}: revenues for selling of calving heifers in the reference situation

P_{BRD}: expenditures for purchase of calving heifers in the BRD situation

S_{BRD}: revenues for selling of calving heifers in the BRD situation

with S and P defined, both in the reference and the BRD situation, as:

$$S = \sum_{k=1}^{max} \{\text{SHEIF} * (\text{NPRES}_k - \text{NREQ}_k)\} \text{ for } (\text{NPRES}_k - \text{NREQ}_k) > 0$$

$$P = \sum_{k=1}^{max} \{\text{PHEIF} * (\text{NREQ}_k - \text{NPRES}_k)\} \text{ for } (\text{NPRES}_k - \text{NREQ}_k) < 0$$

where,

k: time period of 3 months, 1 to maximum (derived from total time span)

SHEIF: selling price per calving heifer (variable costs)

PHEIF: purchase price per calving heifer (variable costs + margin)

$NPRES_k$: number of calving heifers present in period k

$NREQ_k$: number of calving heifers required in period k

Total losses for purchase and selling of heifers include the losses for calving heifers available subtracted with revenues for heifers that are culled directly after the disease and heifers that aborted. These revenues are based on the number of heifers culled per age class and the number of heifers that aborted, respectively, and their specific revenues.

6.2.4.6 Milk production

The heifer's first-lactation milk production is related to its BW at calving, based on the following function derived from Mourits et al. (1999):

$$EMP = SMP * (1 + 0.001 * (BW - 525)) \quad \text{for BW} \leq 570 \text{ kg}$$

$$EMP = SMP * (1 + 0.001 * (570 - 525)) \quad \text{for BW} > 570 \text{ kg}$$

where,

EMP: expected milk production in first lactation

SMP: standard milk production in first lactation, i.e., EMP for a standard heifer that calves at a BW of 525 kg, set to be 6800 kg

The first lactation milk production of heifers that experienced BRD during their raising period might be either increased or decreased, depending on the effects of the disease on growth and fertility. Due to the change in milk production of the heifers that had BRD, the total number of milking cows required to produce the farm milk quota might also be changed. The difference is calculated between total first-lactation milk production of (all) heifers in the reference situation and this total in the BRD situation. The resulting losses (or savings) are derived from this difference in milk production and the difference between both situations in the farm's net return to labour and management per kg of milk, which arises from the number of milking cows in the herd necessary to produce the milk quota.

6.2.4.7 Uncertainty and output

Uncertainty in model input has been taken into account for three input parameters that were expected to have a major impact on the model's outcome. The uncertainty of these parameters (disease occurrence, mortality and (direct) culling) is reflected by the 10^{th} and 90^{th} percentiles of their particular distributions. The underlying distribution assumed is Normal for disease occurrence parameters, and Beta for mortality and culling parameters. The distributions were established (both per BRD type and disease class) using information from literature and experts (Van der Fels-Klerx and Dijkhuizen, 2000) on variation in the outcome of the particular parameter.

The model calculates the median losses (median scenario) based on the 50th-percentile values for the three key parameters. In addition, both the best- and worst-case scenario outcome are calculated based on the 10th and 90th percentiles, respectively, of these parameters. Percentiles of key parameters and values used for the resulting input parameters are either default or user-defined. Per BRD type, the total losses as well as the losses per type are presented to the user for each of the three possible outcome scenarios (best, median, worst). For the median scenario, losses per type also are presented in detail.

6.2.4.8 Basic calculations

The economic losses of BRD in heifers were calculated (per BRD type and per scenario) for a so-called typical Dutch dairy farm using the model's default input parameter values. For both BRD types, total proportion of heifers affected was set to be 60 % (25 % mild, 25 % severe, and 10 % chronically diseased). In case of the outbreak, maximum age of heifers at risk was set at 15 months.

To explore the sensitivity of the model's outcome in the median scenario to variation in input, values of all input parameters (except for parameters related to growth) were varied systematically –20 %, -10 %, 10 % and 20 % relative to the level in the default situation. For each parameter, a value also was considered from both its lower and upper range observed in practice (biological range). Furthermore, in case of an outbreak, the maximum age of heifers affected was varied. Only one parameter was changed at a time (assuming default values for all other parameters). Sensitivity analyses as to input parameters related to growth decrease following BRD were performed by considering several realistic profiles, by varying one or more of the four parameters (at the same time) that describe the effect on growth. Several of these profiles included compensatory growth effects.

6.3 Results

Results from the basic calculations, i.e., the losses due to (clinical) BRD in heifers (60 % affected) on a typical Dutch dairy farm, are shown in Table 6.5 for pneumonia and in Table 6.6 for a BRD outbreak (for each of the three scenarios considered).

The total annual losses due to pneumonia are to a great extent associated with treatment costs (including labour by the farmer); treatment costs vary from over 40 % of the total losses in the worst case to up to almost 90 % of this total in the best case (Table 6.5).

Table 6.5
Losses (€)[1], per type and in total, due to pneumonia in dairy heifers (60% affected) on a typical Dutch farm, estimated for each of the three scenarios

	Scenario		
Type of losses	Best	Median	Worst
Treatment and labour by farmer	437.9	584.9	682.4
Mortality and culling	5.0	118.0	508.6
Growth and fertility	-1.5	-421.8	-1888.4
Purchase/selling heifers	29.9	523.6	2215.1
Milk production	43.9	69.6	83.2
Total:			
Per year	515.1	874.2	1600.9
Per heifer present	18.4	31.2	57.1

[1] 1 Euro = 0.861 US Dollar

Table 6.6
Losses (€)[1], per type and in total, due to an outbreak of Bovine Respiratory Disease in dairy heifers (60 % affected) on a typical Dutch farm, estimated for each of the three scenarios

	Scenario		
Type of losses	Best	Median	Worst
Treatment and labour by farmer	340.4	401.6	448.6
Mortality and culling	7.8	166.4	535.9
Growth and fertility	186.5	-236.3	-1314.3
Purchase/selling heifers	312.0	995.8	2469.2
Milk production	33.5	53.7	67.0
Total:			
Per outbreak	880.2	1381.2	2206.5
Per heifer present	17.2	27.0	43.1

[1] 1 Euro = 0.861 US Dollar

In case of an outbreak, the impact of treatment is much lower and varies from 20 % to 40 % of the total losses. In the worst-case scenarios of both BRD types, total losses are mainly associated with the purchase and selling type of losses and the growth and fertility type of losses (Tables 6.5 and 6.6). Both these types of losses also have high impacts on the total losses in the median-case scenarios -- and in the outbreak, also in the best-case scenario. Except for the latter scenario, the growth and fertility losses result in profits. This is mainly due to reduced rearing costs in the situation with BRD as compared to the reference situation caused by less heifers reared on the farm. Note that losses associated with reduced growth and reduced fertility (as well as with increased mortality and increased culling) are much related to the losses associated with the purchase and selling of heifers; therefore, these types of losses should be considered at the same time.

For both BRD types, sensitivity analyses with ± 10 %, ± 20 %, or variation seen in practice, resulted in the same parameters having a high impact on the model's outcome. Results from sensitivity analyses are presented in Tables 6.7 and 6.8 for those input parameters that had the highest impact on the model's outcome as far as their variation observed in practice (low and high value) was concerned.

Table 6.7
Effect of variation in input parameters on the economic losses (median scenario) due to pneumonia in heifers on a typical Dutch dairy farm

	Lowest value	Losses (€)[1]	Relative to default[2] (%)	Highest value	Losses (€)[1]	Relative to default[2] (%)
Default		874			874	
Farm specific input:						
Milking cows (no.)	40	635	-27.4	70	1114	+27.4
Replacement (%/year)	26	835	-4.5	38	926	+6.0
Calving interval (days)	365	961	+9.9	435	811	-7.2
Revenues (€)[1]*:*						
Calving heifer[3]	549	786	-10.1	776	962	+10.1
Prices (€)[1]*:*						
Silage (per kg DM)	0.07	943	+7.9	0.016	806	-7.8
Grass (per kg DM)	0.02	924	+5.7	0.11	825	-5.6
Drugs (per dose)	4.54	815	-6.8	6.35	934	+6.8
Occurrence and treatment[4]*:*						
Heifers affected (%)	times 0.7	585	-33.1	times 1.5	1312	+50.1
Drugs (no. doses/case)	-1.5	743	-15.1	+1.5	1006	+15.1
Veterinary visits (no./case)	-0.1	856	-2.1	+0.1	907	+3.7
Extra labour by farmer (h/day/case)	0	694	-20.6	times 2	1055	+20.7
Productivity effects[4]*:*						
Mortality (%)[5]	times 0.5	820	-6.2	times 2	984	+12.5
Culling (%)[5]	times 0.5	856	-2.1	times 2	912	+4.3
Growth standstill (no. days)	-2	854	-2.4	+2	913	+4.5
No decrease in growth		791	-9.5			
Growth in rest rearing period (% of normal)	+10 %	851	-2.6			

[1]1 Euro = 0.861 US Dollar
[2]See Tables 6.1-6.4 for default values
[3]Variable costs only
[4]Account for each disease class
[5]Above rates due to all but BRD

Table 6.8
Effect of variation in input parameters on the economic losses (median scenario) due to an outbreak of Bovine Respiratory Disease (BRD) in heifers on a typical Dutch dairy farm

	Lowest value	Losses (€)[1]	Relative to default[2] (%)	Highest value	Losses (€)[1]	Relative to default[2] (%)
Default		1381			1381	
Farm specific input:						
Milking cows (no.)	40	1046	-24.3	70	1717	+24.3
Replacement (%/year)	26	1315	-4.8	38	1469	+6.3
Calving interval (days)	365	1491	+8.0	435	1306	-5.4
Revenues (€)[1]:						
Calving heifer[3]	549	1302	-5.7	776	1460	+5.7
Heifer that aborted[3]	345	1525	+10.4	526	1238	-10.4
Occurrence and treatment:						
Heifers affected (%)[4]	times 0.7	969	-29.9	times 1.5	2015	+45.9
Drugs (no. doses/case)[4]	-1.5	1249	-9.6	+1.5	1530	+10.8
Extra labour by farmer (h/day/herd)	0	1286	-6.9	+1	1477	+6.9
Productivity effects[4]:						
Mortality (%)[5]	times 0.5	1314	-4.9	times 2	1516	+9.8
Culling (%)[5]	times 0.5	1325	-4.1	times 2	1494	+8.2
No decrease in growth		1246	-9.8			
Growth in rest rearing period (% of normal)	+10 %	1292	-6.5			
Return to oestrus (%)[5]	times 0.5	1347	-2.5	times 2	1450	+5.0
Early abortion (%)[5]	times 0.5	1291	-6.5	times 2	1565	+13.3
Late abortion (%)[5]	times 0.5	1236	-10.5	times 2	1675	+21.3

[1]1 Euro = 0.861 US Dollar
[2]See Tables 6.1-6.4 for default values
[3]Variable costs only
[4]Account for each disease class
[5]Above rates due to all but BRD

As an example, it can be read from Table 6.7 that in case of pneumonia, a two-times increase of the farmer's labour results in an increase of the total losses following the disease of 20.7 %, whereas zero extra labour reduces these losses by about the same percentage.

Parameters that affected the number of heifers diseased most (the number of milking cows as well as the proportion of animals affected) had the highest impacts on the model's outcome for both BRD types (Tables 6.7 and 6.8). Other farm-specific parameters (including replacement rate and calving interval) also had high an influence on the results. In addition, for both BRD types, the model was sensitive to the number of doses of drugs administered and extra labour by the farmer as well as for the heifers' selling prices and, in case of pneumonia, also for price of drugs administered and number of veterinary visits. Furthermore, effects of BRD on the heifers' productivity (including mortality, culling and growth for both BRD types, and fertility in case of the outbreak) determined the losses to a large extent. The various profiles of compensatory growth, results of one presented (Tables 6.7 and 6.8), led to a decrease of the total losses of up to 7 %. Varying the maximum age up to which heifers get clinically affected in case of an outbreak resulted in losses of € 938 (-32.1 %), 1170 (-15.3 %) and 1835 (+32.8 %) for 9, 12 and 18 months, respectively.

6.4 Discussion

In the current model, the losses associated with a BRD outbreak in dairy heifers are estimated for such an outbreak occurring during the winter season. Depending on the frequency of outbreaks in the succeeding years, the losses due to one or more consecutive outbreaks also can be expressed per year. On many Dutch dairy farms, BRD outbreaks are observed yearly. Most of these outbreaks are caused primarily by the BRS-virus and/or the PI_3-virus; both are endemic on almost every dairy farm in the Netherlands (Verhoeff, 2000, pers. comm.). If an outbreak is observed on the farm every winter, heifers affected are assumed to be younger than one year. This is because older animals have experienced the disease in their first rearing year and, therefore, will not get affected clinically in their second rearing year. With an outbreak occurring every second year or less, all heifers (0-2 years) present on the farm are at risk of getting clinically diseased. However, heifers of 15 months and older raised on Dutch dairy farms generally do not get clinically affected by the pathogens present on these farms (Verhoeff, 2000, pers. comm.). Total annual losses associated with an outbreak with heifers aged up to 12 months were more than 1.5-times higher than the yearly losses following an outbreak with heifers up to 15 months affected. These (annual) losses due to outbreaks with heifers affected aged up to 12 and 15 months comprised, respectively, 3.9 % (2.6 to 6.0 %) and 2.3 % (1.5 to 3.7 %) of the farm's net return to labour and management of 1997-1998 of a typical Dutch (specialised) dairy farm (Agricultural Economics Research Institute, 2000). Total annual losses associated with pneumonia were 2.9 % of this amount and vary from 1.7 % to 5.4 % in the best and worst case, respectively.

Total annual losses associated with a BRD outbreak in heifers raised on a typical Dutch dairy farm calculated in the present study were much lower than the yearly losses associated with epidemic respiratory disease in an 'average' Michigan dairy herd as calculated by Hurd et al. (1995). This can be explained partly by differences in prices and the fact that in the model by Hurd et al. (1995) the disease was assumed to occur in milking cows as well. A major difference between the two models is that ours is aimed at detailed evaluation of the economic consequences of BRD, whereas Hurd et al. (1995) placed a greater emphasis on modelling the spread of disease to get the number of animals in any given disease state. In the current model, these numbers can be calculated from farm-specific figures directly indicated by the user. The user being able to modify these and all other (default) input data as well as its open structure results in maximal user-confidence in this model and, consequently, its outcome. The model is also flexible in the sense that new information becoming available can be added easily to the underlying database. The default value of the particular parameter(s) can be updated with the latest information available, and by a new run the model's outcome is also updated.

Farmers together with their veterinarians can use the present model as an interactive tool to get more insight into the farm-specific losses associated with BRD. The model's outcome supports them to make economically sound decisions with regard to the on-farm prevention and control of the disease. Losses due to BRD have been shown to be most sensitive to disease incidence -- and, therefore, measures to decrease this incidence, including vaccination and reduction or elimination of one or more risk factors of the disease from the farm -- will reduce these losses greatly. A disease-free situation is unlikely to exist and, therefore, prevention-and-control measures will not eliminate the disease totally from the farm. The model calculates the farm-specific losses due to BRD relative to the same farm without BRD (reference situation) so that results from different scenarios regarding disease incidence (intervention strategies) can be compared. Most prevention-and-control measures for BRD affect farm management in the longer term, and costs associated are amortised over the same (longer) time period. Therefore, for appropriate cost-benefit analyses of these measures, either the yearly costs of the particular intervention strategy should be considered or the losses due to BRD should be recalculated for a period as long as the pay-off period of the particular strategy.

In addition to its application in dairy practice, this model also could be useful to indicate priorities for future research. The model's outcome was sensitive to disease incidence and productivity effects. Future research, therefore, should focus on the effectiveness of measures to reduce the on-farm risk of BRD as well as on precise quantification of the effects of the disease on the heifers' productivity.

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Appendix 6.1: Definition of Bovine Respiratory Disease, classes considered with respect to disease type, disease severity and age of heifers affected, and definitions of these classes

Bovine Respiratory Disease (BRD):
A clinical disease of the respiratory tract caused by a viral, bacterial or mycoplasmal infection (parasites excluded) or by a combination of these infections.

BRD types:
Calf pneumonia: BRD cases seen one after the other, periodically or whole year round, mostly occurring in the first three months of life. These cases can be caused by a variety of primary pathogens, but commonly are caused by bacteria, mainly *Pasteurella spp*., and preceded by an infection with respiratory viruses.
BRD outbreak: A certain number of heifers in a group suddenly shows clinical signs of BRD. BRD outbreaks mostly occur during the housing period, but also regularly during the pasture period. Dairy heifers affected are mainly older than three months, but younger heifers also might be affected. BRD outbreak cases are mostly caused by a primary viral infection, mainly with *Bovine Respiratory Syncytial Virus*, with or without a secondary bacterial infection.

BRD disease classes:
Three classes were distinguished for severity of (clinical) BRD, being mild, severe and chronic. Each of these three classes was described by its specific symptoms (at the animal level without treatment) shown in Table 6.9.

Age groups
Dairy heifers (0-2 years) were distinguished as to three age classes of 0-3 months, 3-6 months, and 6-24 months.

Table 6.9
Definition of mild, severe and chronic Bovine Respiratory Disease (BRD) in dairy heifers by common and additional (clinical) symptoms seen on animal level without treatment[1]

	Mild BRD	Severe BRD	Chronic BRD
Duration/ start	Duration < 14 days	Duration < 14 days	Starts >14 days after onset of (mild/severe) disease
Common symptoms	*2 or more of;* Nasal discharge Coughing Increased respiratory rate Body temperature < 40° C	*1 or more of;* Nasal discharge Coughing Increased respiratory rate	*1 or more of;* Nasal discharge Coughing Increased respiratory rate
Additional symptoms	Normal level of activity (vital)	*1 or more of;* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing	*1 or more of;* Body temperature ≥ 40 °C 'Harsh' breath sounds Abdominal breathing

[1]Symptoms that are most characteristic of and distinguishing for the particular disease class are presented only. The symptoms are divided into common and additional symptoms with common symptoms observed in each of the three disease classes and additional symptoms seen in the particular disease class only

Chapter 7

General discussion

7.1 Introduction

In modern dairy farming, control of the costs of production has become increasingly important to maintain farm income and to ensure continuity of the business (Dijkhuizen and Morris, 1997). The costs of raising replacement heifers represent one of the largest costs within the dairy farming system (Mourits, 2000). Hence, reduction of these costs will substantially increase the farm's net return to labour and management. A major aspect of dairy heifer management concerns health optimisation (Quigley III et al., 1996).

Bovine Respiratory Disease (BRD) can be a serious health problem in dairy heifers. Rough estimations and practical experiences indicate that the economic losses due to BRD might be considerable, particularly on farms that experience high levels of frequency of the disease. However, at present an exact quantification of these losses is not available.

To decrease the on-farm losses due to BRD, dairy farmers need to improve their management regarding prevention and control of the disease. Prevention of BRD usually focuses on eliminating risk factors for the disease from the farm, such to reduce the disease frequency. In order to make economically sound decisions on the prevention of BRD, dairy farmers need to have more accurate insight into the on-farm economic consequences of the disease including its prevention.

The main objective of the research project described in this thesis was to obtain insight into the economic consequences of BRD in dairy heifers by means of a PC-based simulation model. The model was aimed at calculating the economic losses due to BRD in dairy heifers and evaluating the cost-effectiveness of prevention actions against the disease for individual dairy farm conditions in the Netherlands. It was aimed to be user-friendly and flexible so that it that it could be used as a tool to support decision-making in dairy practice. The second objective of the research project was to obtain the necessary underlying information on the epidemiological consequences of BRD in dairy heifers to be used as model input, in particular referring to 1) effects of BRD on the productivity ('productivity effects') of dairy heifers and 2) risk factors of the disease. This data was obtained from literature and an expert judgement study.

This general discussion focuses on perspectives of the simulation model developed, in particular its use for evaluation of the economic consequences of BRD and its characteristics. Furthermore, the quality of data from literature is dealt with and the expert judgement study, including its design and the techniques applied, is discussed. Finally, the main conclusions of this research project are presented.

7.2 Perspectives of the BRD-simulation model

7.2.1 Economic consequences of BRD

The simulation model developed aims to be used by veterinarians or other farm consultants as a tool to advice dairy farmers in the decision-making process with regard to the prevention of BRD. Therefore, as a first goal, the model calculates the economic losses caused by the disease for specific dairy farm conditions. Second, it was aimed at being used for evaluation of the on-farm economic consequences of managerial actions that reduce BRD frequency. To illustrate the principles of such an evaluation by the simulation model, the cost-effectiveness of various prevention actions against BRD was calculated for several individual dairy farms in practice. The farms considered were selected from a national survey on dairy heifer management on nearly 1000 farms in the Netherlands (Mourits et al., 2000). The farms that participated in this survey were considered representative of all commercial Dutch dairy farms. For the actual illustration purpose in this Chapter, herds that did not treat heifers preventively for BRD were selected from the survey referred to, such that almost the entire range of BRD frequency on the participating farms was covered. Information on important farm-related model input parameters was based on the survey data, including number of milking cows, replacement rate, calving pattern, frequency of BRD and, in case of BRD outbreaks, also the maximum age of heifers affected.

The prevention actions considered were based on elimination of important risk factors for BRD, as defined by experts (Chapter 3), from the farm. Information on the presence of these risk factors was based on the survey data. Information on their relative impacts was based on the expert data, i.e., on the medians of the importance values estimated by the individual experts (Chapter 3). Insight into variation in the model's outcome resulting from variation in the experts' judgements on the risk factors' impacts could be obtained by sensitivity analyses, i.e., by running the simulation model using the separate sets of inputs of the individual experts' estimates. For the current illustration purposes, however, the use of medians was thought to be satisfying.

The model results, in terms of the on-farm economic consequences of BRD for the case farms selected, are presented in Tables 7.1 and 7.2 for pneumonia and BRD outbreaks, respectively. More specifically, these Tables show the overall economic losses due to BRD as well as the remaining losses for scenarios with regard to the elimination of specific risk factors.

Table 7.1
Economic consequences of pneumonia in dairy heifers for various farm characteristics based on selected case farms

Case farm	A	B	C	D	E	F
Farm characteristics:						
Milking cows (no.)	125	55	80	110	97	58
Replacement (%/year)	40	25	35	29	29	30
Calving pattern (year round/autumn)	autumn	year round	autumn	year round	year round	year round
Pneumonia (%)	4	5	20	25	59	68
Model calculations:						
Overall losses (€/herd per year)	154	73	452	750	1539	1089
Remaining losses (€/herd per year) after elimination specified risk factor[1]:						
- Colostrum management	-[2]	-	291	445	-	446
- Housing system	63	-	290	444	-	-
- Purchase of cattle	-	28	-	-	-	-
- Season of calving	82	-	322	-	-	-
- Bedding condition	-	-	-	616	1187	-
- Animal density	-	-	-	-	913	-
- Group size	-	45	-	-	982	643

[1]See Chapter 3 (Appendix 3.1) for a description of the risk factors; the risk factors 'grazing in summer' and 'air circulation' were not present on the case farms selected
[2]The risk factor was not present on the farm

The frequency of pneumonia ranged between the selected farms from 4 to 68 % of heifers affected per year, and the associated overall economic losses ranged from € 73 per year for farm B to € 1539 per year for farm E (Table 7.1). The cost-effectiveness of eliminating a specific risk factor from the farm depends on the particular farm characteristics. For example, improvement of the risk factor 'colostrum management' reduced the economic losses on farm C from € 452 to 291 per year (i.e., a decrease of € 161 per year). The decrease of the losses on the other two farms on which this risk factor had been present amounted to € 305 per year for farm D and € 643 per year for farm F (Table 7.1).

The economic losses associated with BRD outbreaks ranged between the selected farms from € 407 per outbreak for farm A to € 2785 per outbreak for farm F (Table 7.2). Again, the expected reduction of the overall on-farm losses by eliminating a specific risk factor from the farm depends on the particular farm conditions. For farm A, for example, the highest reduction in the economic losses due to a BRD outbreak will be achieved by not purchasing and/or introducing cattle on the farm anymore (remaining losses the

Table 7.2
Economic consequences of outbreaks of Bovine Respiratory Disease (BRD) for various farm characteristics based on selected case farms

Case farm	A	B	C	D	E	F
Farm characteristics:						
Milking cows (no.)	50	55	72	48	55	83
Replacement (%/year)	24	36	28	27	27	42
Calving pattern (year round/autumn)	year round	year round	year round	year round	year round	year round
BRD outbreak cases 0-1 years (%)	16	25	6	33	38	0
BRD outbreak cases 1-2 years (%)	5	5	71	40	23	98
Maximum age affected (months)	15	15	18	15	15	21
Model calculations:						
Overall losses (€/herd per outbreak)	407	615	758	794	884	2785
Remaining losses (€/herd per outbreak) after elimination specified risk factor[1]:						
- Previous BRD	-[2]	-	664	-	-	1999
- Cattle flow through pens	-	-	642	-	-	1967
- Housing system	-	477	-	591	653	2007
- Air circulation	-	-	613	-	-	-
- Animal density	-	-	-	587	646	-
- Purchase/introduction cattle	275	477	612	-	-	-
- House type	331	520	678	655	722	-
- Grazing in summer	362	557	741	709	787	2459

[1]See Chapter 3 (Appendix) for a description of the risk factors; the risk factors 'group size' and 'bedding condition' were not present on the selected farms
[2]The risk factor was not present on the farm

lowest, i.e., € 275 per herd per outbreak), whereas for farm D, the highest reduction will be achieved by decreasing animal density (remaining losses € 587 per herd per outbreak)

Evidently, the costs associated with the implementation of a specific prevention measure should also be considered in the decision-making process on the prevention of BRD. After all, for any prevention action to be economically sound, its associated costs should not exceed the expected reduction in losses. For example, farms D and E presented in Table 7.1 both consider improvement of bedding condition in order to reduce the on-farm pneumonia frequency and its associated economic losses. Elimination of the risk factor 'poor bedding condition' results in a reduction of the yearly losses, calculated by the simulation model, of € 134 (from € 750 to 616) for farm D and € 352 (from € 1539 to 1187) for farm E. If the costs of improvement of bedding amount to, say, € 200 per year for both farms, elimination of this risk factor is attractive, from an economic perspective, for farm E only.

Evaluation of the economic consequences of BRD for selected case farms (Tables 7.1 and 7.2) showed that the farm-specific cost-effectiveness of prevention actions against BRD can be determined from the reducing impact of these actions on the on-farm economic losses due to the disease. Hence, the model can be used for evaluation of alternative actions aimed at reducing BRD frequency on individual dairy farms, hereby supporting farmers to make economically sound decisions on the prevention of the disease. As its results aim to be directive in economic decision-making processes, the model in particular will be valuable for dairy farms for which the optimal decision on the prevention of BRD is not straightforward. In most cases BRD frequency on these farms will be intermediate, i.e., between the extreme high and low levels.

Table 7.3
Losses (€/herd per year) due to pneumonia in dairy heifers for various scenarios with regard to dairy farm characteristics (including best and worst case[1])

Milking cows (no.)	Calving pattern (year round/autumn)	Replacement rate (%/year)	Pneumonia (%)		
			10	50	90
40	Year round	25	105	527	971
			(0-393)	(293-994)	(673-1615)
		35	114	569	1049
			(0-425)	(316-1074)	(728-1757)
	Autumn	25	104	519	955
			(0-388)	(288-982)	(661-1595)
		35	113	564	1039
			(0-426)	(311-1087)	(715-1781)
80	Year round	25	211	1057	1947
			(1-789)	(587-1194)	(1350-3238)
		35	228	1141	2103
			(1-852)	(634-2154)	(1459-3520)
	Autumn	25	208	1040	1916
			(1-778)	(577-1969)	(1326-3198)
		35	226	1131	2082
			(1-853)	(624-2179)	(1434-3569)
120	Year round	25	317	1586	2922
			(1-1184)	(881-2993)	(2027-4862)
		35	343	1713	3157
			(1-1279)	(951-3233)	(2190-5284)
	Autumn	25	312	1562	2876
			(1-1169)	(866-2956)	(1991-4801)
		35	340	1698	3126
			(1-1281)	(936-3270)	(2152-5357)

[1]Based on 10^{th} and 90^{th} percentiles of parameters related to BRD frequency, mortality and culling (see Chapter 6)

Table 7.4
Losses (€/per herd per outbreak) due to outbreaks of Bovine Respiratory Disease in dairy heifers for various scenarios with regard to dairy farm characteristics (including best and worst case)[1]

Milking cows (no.)	Calving pattern (autumn/ year round)	Replacement rate (%/year)	Heifers affected (%) 50, Maximum age affected (months) 12	Heifers affected (%) 50, Maximum age affected (months) 18	Heifers affected (%) 90, Maximum age affected (months) 12	Heifers affected (%) 90, Maximum age affected (months) 18
40	Year round	25	733 (486-1116)	1078 (644-1821)	1218 (887-1733)	1852 (1235-2890)
		35	788 (513-1214)	1165 (683-1984)	1336 (974-1921)	2018 (1351-3173)
	Autumn	25	722 (480-1099)	1131 (662-1948)	1205 (882-1726)	1932 (1272-3078)
		35	806 (529-1229)	1219 (707-2121)	1359 (988-1938)	2122 (1370-3417)
80	Year round	25	1315 (819-2081)	2005 (1135-3494)	2285 (1622-3319)	3558 (2320-6538)
		35	1424 (873-2276)	2180 (1214-3820)	2521 (1795-3693)	3889 (2551-6202)
	Autumn	25	1291 (807-2047)	2112 (1172-3749)	2260 (1612-3304)	3717 (2394-6014)
		35	1459 (904-2307)	2287 (1261-4094)	2568 (1824-3729)	4097 (2591-6692)
120	Year round	25	1896 (1152-3046)	2933 (1627-5168)	3353 (2358-4905)	5263 (3405-8387)
		35	2059 (1232-3339)	3194 (1744-5656)	3706 (2617-5465)	5759 (3752-9231)
	Autumn	25	1861 (1133-2996)	3093 (1681-5550)	3314 (2342-4882)	5502 (3516-8949)
		35	2112 (1280-3385)	3355 (1816-6067)	3777 (2660-5519)	6071 (3812-9967)

[1]Based on 10^{th} and 90^{th} percentiles of parameters related to BRD frequency, mortality and culling (see Chapter 6)

To explore the potential range of economic losses due to BRD, these losses were calculated by the simulation model for several scenarios with regard to Dutch dairy farm characteristics. The scenarios were defined by combinations of extreme levels for important farm-related model input parameters. The losses were calculated per BRD type; in case of BRD outbreaks for heifers affected up to 12 months as well as up to 18 months. The results are presented in Table 7.3 for pneumonia and in Table 7.4 for BRD outbreaks.

For the farm scenarios calculated, the (median) economic losses due to pneumonia ranged from approximately € 100 to 3200 per herd per year (Table 7.3). The losses depended to a large extent on pneumonia frequency and the number of milking cows. For the scenarios calculated, the range of losses between the best and worst case was approximately € 0-1300 per herd per year for a pneumonia frequency of 10 %, through € 300-3300 per herd per year for a frequency of 50 %, up to € 700-5400 per herd per year for a frequency of 90 %. The median losses associated with one BRD outbreak ranged from approximately € 700 to 6100 per herd for the farm scenarios calculated (Table 7.4). Again, the losses were mainly determined by frequency of heifers affected and the number of milking cows in the herd, as well as the age up to which heifers were affected. With a morbidity level of 50 %, the losses in the best and worst cases ranged between approximately € 500 and 3400 per herd per outbreak in case the maximum age was 12 months, and between € 600 and 6100 per herd per outbreak in case this age was 18 months. With 90 % of the heifers affected, these figures were € 900-5500 and € 1200-10,000, respectively.

Data of the national survey on dairy heifer rearing management (Mourits et al., 2000) showed that BRD frequency on Dutch dairy farms averaged nearly 10 %. For pneumonia, the economic losses associated with this frequency level, calculated for typical Dutch dairy farms with 55 milking cows, were approximately € 130 per herd per year (range best-worst case: € 0-530), whereas for BRD outbreaks with heifers up to 15 months affected these losses amounted to € 330 per herd per outbreak (range best-worst case: € 156-805). On more than 40 % of the surveyed farms BRD was not observed, but on about 4 % of the farms over 50 % of the heifers were affected. For pneumonia, the losses associated with this morbidity level were calculated to amount approximately € 750 per herd per year (range € 420-1440); for BRD outbreaks with heifers up to 15 months affected the losses amounted to € 1190 per herd per outbreak (range € 730-1950).

In conclusion, on most commercial dairy farms in the Netherlands, the economic losses due to BRD will be relatively small, i.e., around 1 % of the farm's net return to labour and management (Agricultural Economics Research Institute, 2001), increasing up to 3-4 % at worst. However, for individual farms that experience a high level of BRD frequency, the associated losses can be as high as 10-15 % of the farm's net return to labour and management, up to 25 % on large farms.

Irrespective of the economic losses due to BRD on the individual dairy farm, any net savings of these losses are worthwhile, as they improve the farm's income. In addition, improvement of farm management to reduce the frequency of BRD is likely to reduce the frequency of other diseases in dairy heifers as well, particularly diarrhoea (Chapter 2), because of the similarities between many of their risk factors, e.g., season of birth and other birth circumstances, colostrum management and housing (Waltner-Toews et al., 1986; Curtis et al., 1988; Perez et al., 1990; Frank and Kaneene, 1992; Curtis et al., 1993). Thus, besides its direct benefits on the frequency of BRD and the associated economic losses, prevention of BRD will have indirect benefits related to other diseases. Consequently, the potential profits of BRD prevention are likely to be higher than based on the model's outcome only. In general, the use of the model will increase the farmer's notion of animal health, motivating him/her to prevent and control diseases affecting the dairy cattle herd.

7.2.2 Model characteristics

7.2.2.1 Uncertainty analysis

In addition to median outcomes, the simulation model also provides results for worst and best case scenarios, defined by values of, respectively, the 10^{th} and 90^{th} percentiles of the distributions for parameters related to BRD frequency, mortality and culling, and defaults for the resulting parameters (Chapter 6). Although such an uncertainty analysis oversimplifies the existing variation and uncertainty, it provides a good indication of the expected outcome ranges on commercial dairy farms, in accordance with the model's goal, i.e., decision-support in dairy practice. Moreover, the current uncertainty analysis results in only a slight increase of the model's running time. As a possible extension of the current model, the entire probability distributions of these and other critical model parameters could be included, and used by means of random sampling. Multiple runs of such a stochastic model with random elements then will provide a more precise distribution of the model outcomes. In addition, the available information on the expected standard deviation of the results allows for statistical tests and risk-aversion analysis. One disadvantage is the high number of iterations needed to obtain reliable output parameter estimates, which could substantially increase the model's running time (Jalvingh, 1993; Dijkhuizen and Morris, 1997). Moreover, the use of entire probability distributions of model input parameters is of additional value, only in case accurate information on these distributions is available.

7.2.2.2 Underlying database

Data on the productivity effects of BRD, obtained from literature and experts, was stored into a PC-based database which was directly linked to the simulation model developed (Chapter 6). The advantage of such an underlying database is that it gives an up-to-date overview of all relevant information available. Technically, additional findings, e.g., from future research, can easily be added to the database, weighted with the information already stored, and used to update the model's default input. However, determining the weights of new findings by judgement of their quality is a difficult task (see section 7.3), and one should be aware of creating any false sense of reliability.

7.2.2.3 Flexibility

For the majority of the model input parameters, default values, representing the typical or 'average' Dutch dairy farm, are presented clearly to the user and can easily be modified to fit specific farm conditions (Chapter 6). The insight into the model's input and the possibility of modifying its defaults enhances the user's confidence in the model and its outcome and, hence, the application of the model results. Obviously, the more farm-specific data is available, the higher the accuracy of the results for the particular farm in question. Therefore, farm-specific information should preferably be obtained on as many model input parameters as possible. As the model showed to be sensitive to input on parameters that determine the number of heifers affected, such as BRD frequency, number of milking cows in the herd, replacement rate, and calving interval, as well as mortality, drug use, and several prices and revenues, and these parameters are relatively easy to record, it is important to obtain farm-specific input on these critical model parameters.

Due to its high flexibility, the model is also valuable for dairy farms in foreign countries having a dairy farming system that is comparable to the Dutch one, e.g., for Danish dairy farms (Van der Fels-Klerx et al., 2000). The model might also be easily convertible for application to other diseases in replacement heifers, such as diarrhoea.

7.3 Data from literature

The reliability of the model's outcome largely depends on the availability of accurate data on its input parameters. Therefore, considerable emphasis was placed on the collection of input data, in particular focusing on the productivity effects and risk factors of BRD in dairy heifers. From an extensive literature review, quantitative information on the majority of the variables of interest was found to be incomplete and, if available, often ambiguous (Chapter 2). Findings originated from different studies, varying in their design with regard to e.g., sample size, geographic area, and parameters studied. Often too little information was provided to reconstruct or relate the differences in output to the underlying input factors. Consequently, the studies and their findings were expected to vary in their reliability and relevance to the current research project. Therefore, the quality of the various studies (and their findings) was evaluated and ranked. The various findings on a particular parameter were weighted, based on the evaluation results, to obtain a single overall (weighted) value per parameter for use in the simulation model. To make the evaluation of the studies' quality as objective as possible, a set of relevant pre-defined criteria was used, referring to, among other things, study design and data analysis. Each study was evaluated by giving credits on a scale of 1 to 10 to each criteria as well as an overall credit taking into account all criteria at the same time.

Prior to the actual evaluation process, the implication of judgement of the quality of research was explored by means of a pilot experiment. For this purpose, 12 well-known researchers in the current field were selected and asked to evaluate the quality of in total 36 studies published in peer-reviewed journals. The publications included 12 papers from each of three groups of studies ('study groups') related to BRD in dairy heifers, including studies on 1) the productivity effects and/or risk factors of BRD (not specified to agent), 2) the productivity effects of a specific respiratory disease, such as BRSV infections, and 3) vaccination against a specific respiratory disease. The papers were distributed among the researchers such that each person judged the quality of six papers, including two papers from each of the three study groups, and each paper was evaluated by two different researchers. Judgement of the study quality was based on the set of evaluation criteria (as described above).

Results of this experiment showed that the variation between the judgements of researchers was quite large for most of the studies. For example, the difference between the individual researchers' judgements of the overall quality of studies from the first (study) group averaged 1.5 credits (range 0-5). The researchers experienced evaluating the quality of research to be a difficult task, which was mainly because the publications often described the studies not precisely enough and/or understandably enough.

It was concluded that judgement of the quality of published research entails much variation, even if objective evaluation criteria are applied. The variation may to a large extent have been caused by the publications describing the studies in too little detail and/or too little clarity, hereby enabling different interpretations. In addition, the use of various researchers entails some subjectivity, e.g., due to different backgrounds. Therefore, the literature used in this research project was evaluated by one and the same person, although this person's judgement may not have reflected the true study quality perfectly. However, bias due to the use of various human subjects was eliminated.

From the experiment it was learned that elicitation of expert assessments should be limited to cases for which the problem in question is well-defined and clearly stated. Furthermore, much attention should be paid to ensuring that experts know and agree upon the qualitative aspects of concern, e.g., definition of the problem area and variables of interest, prior to the actual quantification task.

7.4 Expert judgement study

7.4.1 Study design

The expert judgement study (Chapters 3-5) used a relatively large number of experts (21 persons), including the nearly entire community of scientific-oriented experts, with or without having practical experience, as well as eight veterinary practitioners. All experts fulfilled the selection criteria applied, among other things, of being specialised in BRD, but varied in disciplinary background and level of specialisation. Hence, the panel was heterogeneous in nature within the boundaries set by the selection criteria (Chapter 4). Elicitation and analysis technique were used that accounted for the expertise level of the individual experts, in order to obtain high quality expert data.

Because of the broad field of interest, the expert elicitation process was divided into various (five) stages, each of which using methods appropriate to the actual question of interest. In each stage it was ensured that expert judgement was elicited anonymously and individually such to avoid bias associated with group interaction, e.g., due to domination of the discussion by one or more individuals.

The first phase of the expert elicitation process, including the first four stages, was aimed at obtaining consensus on qualitative aspects of relevance to the variables of interest, such as definitions to be used. This was done in order to ensure that the experts hold and work from the same understanding on these aspects prior to the elicitation of their assessments on the variables of interest. As expert interaction is considered valuable for this task (Clemen and Winkler, 1999), but direct personal interaction was not desired, this phase was based on the Delphi technique (Cooke, 1991; Meyer and Booker, 1991). For most of the aspects considered, consensus was reached after a few iterations, but in some cases a few experts had to compromise for sake of the group opinion. This, for instance, applied to the differentiation of affected heifers to age. Thus, the consensus reflected the group opinion, rather than the individual experts' thoughts. However, the experts indicated that they could 'live' with the group opinion, and use this opinion in providing their quantitative assessments.

The second phase of the expert elicitation process (last stage) consisted of a group meeting, in which the experts assembled to fulfil the quantitative assessment task. The advantage of such a group meeting is that the experts meet each other and have the opportunity for discussions, increasing their motivation to participate. The experts' assessments were elicited individually by means of self-explicable PC-based methods. The application of highly-structured individual computerised interviews during a group meeting has the advantage that a large quantity of information can be obtained from a panel of experts in a relatively short time span (Horst, 1998).

7.4.2 Elicitation and aggregation of expert data

7.4.2.1 Risk factors

Adaptive Conjoint Analysis (ACA) was used to quantify the risk factors of BRD because this technique can handle relatively large numbers of attributes (risk factors) and levels, hereby minimising interview time and, hence, avoiding fatigue bias. Another advantage of the ACA technique is that it provides a check for the internal consistency of the individual experts' assessments (Metenagro, 1994). Inconsistency may arise from a shortage of motivation, lack of relevant knowledge and/or misunderstanding of the questions. As answers of inconsistent experts are of inferior quality they should be excluded from further analyses, regardless of whether they are outliers or not. In the current study, experts were very consistent, both absolutely and relatively to other studies (Stärk et al., 1997; Van Schaik et al., 1998), so only little data had to be excluded.

A limitation of ACA is that the technique assumes no interaction among attributes and, consequently, attribute levels have to be chosen such that they are independent. Other conjoint analysis techniques are available that can allow for interaction, e.g., the full profile approach (Hair et al., 1995). However, with these techniques either the number of attributes that can be considered is restricted and/or much more interview time is required. Because current knowledge on the risk factors of BRD is scarce (Chapter 2), let alone on their interactions, this study dealt with interaction in a limited way (i.e., by defining composite variables). Moreover, the additive ('main effects') model has been argued to be very robust and valid in most cases (Steenkamp, 1987; Hair et al., 1995).

The accurateness of the experts' judgements could be further increased if, besides the internal validity (consistency) of the experts' answers, the external validity is accounted for. The best way to determine the predictive performance of experts' assessments is to compare these assessments with observational data. However, like in most cases, if not all, in which expert judgement is required, such data was unavailable. Alternatively, measures assessing the correspondence between estimated and actual choices of respondents, e.g., hitrates, could be used (Huber et al., 1993; Hair et al., 1995). However, these measures still do not provide information on the correspondence between respondents' assessments with reality.

In general, the current research project experienced ACA to be an easy-to-understand and user-friendly program to elicit expert judgement on the relative importance of risk factors of an animal disease, supporting findings from previous studies that dealt with a comparable task (Horst et al., 1996; Stärk et al., 1997; Van Schaik et al., 1998). Thus, besides in its originating area of marketing and consumer research, the program is also attractive for application to comparable types of problems in other fields of interest.

7.4.2.2 Productivity effects

Expert judgement on the productivity effects was quantified using ELI because this technique, being self-explicable and providing a simple-to-use graphical working environment, minimises the demand for normative expertise. Moreover, ELI results in more reliable and accurate probability density functions as compared to other direct and indirect elicitation methods (Van Lenthe, 1993).

A drawback of the ELI method is that the choice of underlying distributions is limited, which might reduce the reliability of the results (Van Lenthe, 1993; Hardaker et al., 1997). Furthermore, the consequent limitations on the shapes of the score curves to be manipulated might frustrate the experts and de-motivate them from further participation. The experts' faith in the ELI program might increase, if they were able to indicate the form of the score curves by themselves.

The majority of the parameters to be assessed was reflected best by the so-called user-defined quantity, a continuous quantity to be pre-defined by the researcher by entering its range of values. Obviously, a good choice of the parameters' value ranges is important in obtaining reliable and accurate assessments. With a range being too wide, small differences are hard to observe, whereas if too small, it could reflect an expert's opinion on the particular parameter imperfectly. As the latter factor was considered more important than the former, pre-set ranges were chosen such that they covered the parameters' potential value ranges.

For use in the simulation model, the individual experts' probability density functions obtained were aggregated into a single distribution per parameter. Alternatively, the separate distributions of each parameter could have been used, their ranges studied through sensitivity analyses. Both approaches are known to result in approximately the same model outcomes (Goossens, pers. comm. 2001), however, aggregation of the individual experts' distributions provided more manageable model input.

To formalise the weighting procedure, hereby reducing subjectivity, in aggregating the experts' assessments, the individual experts were weighted based on their actual performance on seed variables. As a self-evident consequence of differentiating between the individual experts' performance on the basis of seeds, the application of this procedure is restricted to cases in which a *proper* set of seed variables is available. Fortunately, an adequate set of domain seeds, quite well reflecting the variables of interest, was available to the current research project. For cases in which appropriate domain seeds are unavailable, adjacent seeds have been claimed to also provide good results (Goossens et al., 1996). However, this statement was based on the experts' performance on the adjacent variables, mainly indicated by the experts' calibration score, and it could not automatically be assumed that extensive knowledge on these variables implicates a thorough knowledge on the variables of interest.

Both the ELI method and the Classical model have been widely used in other fields of interest. However, in the current field of animal health economics they have been applied only once, in case of ELI (Horst et al., 1998), or not yet, in case of the Classical model. The expert judgement study experienced both techniques to be attractive, supporting their wider use in the current field and comparable fields of interest. Moreover, inclusion of the Classical model approach into software of the ELI program would make both techniques even more attractive for quantification of subjective knowledge on continuous quantities. Aggregated (weighted) distributions then could directly be obtained from individual respondents' distributions stored. Moreover, the aggregated distributions could be updated with the assessments of an additional respondent directly after he/she has completed the ELI interview.

7.4.3 Final note

The expert judgement study has increased quantitative knowledge on the input variables of the simulation model developed, in particular on risk factors affecting BRD frequency and productivity effects of the disease. However, insight into these variables is still not unambiguous and complete. For instance, information on the most important risk factors differed between literature and expert opinion.

More accurate information on its input will further increase the realness of the model and its outcome. In this perspective, future research should focus on further identification and quantification of the productivity effects of BRD in dairy heifers and risk factors of the disease. As the most objective information on these variables can probably be obtained from well-designed field studies, they should preferably be investigated by means of this type of research. Moreover, the various factors should be considered at the same time, both in case of disease impact and risk factor research, to account for possible interacting and confounding effects. However, large all-embracing field studies will take many resources and are hard to complete successfully. A series of clinical field trials may be used to at least obtain insight into the upper ranges of the impacts of individual parameters. Although further research by means of these types of studies is theoretically interesting from both the economic and veterinary perspective, it may not be recommendable in practice from the current economic point of view.

7.5 Main conclusions

1. Quantitative information from peer-reviewed literature on epidemiological aspects of BRD in dairy heifers is in most cases ambiguous and far from complete. This applies in particular to associations and their impacts of risk factors for the disease and the disease effects on productivity.
2. The literature review revealed that BRD in dairy heifers increases the risk of mortality directly after the disease episode by approximately 6 times and reduces body weight in the short term with up to 10 kg. Effects of BRD on other production parameters were less clear.
3. The literature findings showed that herd size and other diseases, especially diarrhoea, are associated with the on-farm risk of BRD in dairy heifers, and both season and colostrum feeding management presumably affect this risk. Quantitative information on these factors and on other potential risk factors was less clear.
4. The quality of expert data can be assured, if elicited by means of a formal procedure, including accurate elicitation techniques. In this perspective, the PC-based interview techniques ACA and ELI have proven to be attractive.
5. Taking into account the level of expertise of individual experts in aggregating their assessments results in better estimates as compared to equal weighting. Seed variables provide a formal basis to determine the individual experts' weights, and the Classical model provides a framework for the aggregation procedure.
6. According to expert judgement, both pneumonia and BRD outbreaks in dairy heifers reduced body weight at 14 months by 30 kg. Furthermore, pneumonia was estimated to increase mortality risk by 20 %, to delay age at first calving by 2 weeks and to reduce first lactation milk production by 2 %. BRD outbreaks possibly also increase risk of mortality by 1-3 % and risk of fertility disorders by 3-5 % (all figures are medians of their probability density functions).
7. The expert study found '(poor) air circulation' and 'purchase of cattle' to be the most important risk factors for both pneumonia and BRD outbreaks in dairy heifers, complemented with 'previous BRD' in case of the outbreaks. 'Colostrum feeding management' and 'housing system' were also considered to be important determinants for pneumonia frequency.
8. The simulation model developed provides a valuable tool in improving quantitative insight into the economic losses due to BRD in dairy heifers and the cost-effectiveness of prevention actions against the disease for individual dairy farm conditions, hence, to support the on-farm decision-making process with regard to the prevention of BRD.

9. For most dairy farms in the Netherlands, the economic losses due to BRD will be small: approximately 1 % of the farm's net return to labour and management. For individual farms that experience high levels of BRD frequency, the associated losses can be as high as 10-15 % of the farm's net return to labour and management, or even higher on large farms.
10. The economic losses due to BRD in dairy heifers are most sensitive to parameters that determine the number of heifers affected, the impact of the disease on the heifers' productivity, drug use, extra labour requirements by the farmer, and several prices and revenues.

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Summary

Introduction

In modern dairy farming, control of the production costs has become critically important to maintain farm profit and to guarantee the continuity of the business enterprise. The costs of raising replacement heifers represent one of the largest costs within the dairy farming system. Hence, improvement of the dairy heifer rearing process has a profound effect on the profitability of the farm as a whole. A major aspect of dairy heifer raising management concerns health control.

Bovine Respiratory Disease (BRD) can be a serious health problem in dairy heifers. The economic losses due to BRD might be considerable, in particular on farms that experience high levels of frequency of the disease. However, an exact quantification of these losses was not available yet.

The on-farm economic losses due to BRD can be reduced by improvement of farm management such to decrease the disease frequency. Dairy farmers often need to make decisions with regard to the prevention of BRD. To support this decision-making process, more accurate insight is necessary into the economic consequences of BRD in dairy heifers for individual dairy farm conditions.

The main objective of the research project described in this thesis was to obtain insight into the economic consequences of BRD in dairy heifers by means of a PC-based simulation model. The model developed calculates the economic losses due to BRD in dairy heifers and evaluates the cost-effectiveness of prevention actions against the disease for individual dairy farms in the Netherlands. A second objective of the research project was to obtain information on the epidemiological consequences of BRD in dairy heifers to be used as model input, in particular referring to 1) effects of BRD on the productivity ('productivity effects') of dairy heifers and 2) risk factors of the disease.

Literature review

The research started with a literature review aimed at obtaining the necessary qualitative and quantitative information on 1) productivity effects of BRD in dairy heifers, and 2) risk factors for the disease, relevant to dairy heifer raising conditions in the Netherlands. To obtain data of a high quality and of relevance for decision-making in dairy practice, the literature study focused on peer-reviewed publications of research that quantified the variables of interest under conditions relevant to commercial dairy farms.

The majority of the studies that met these selection criteria focused on dairy farm conditions in the USA. Results are presented and discussed for their relevance to the Dutch dairy heifer raising system (Chapter 2).

From the study findings, it was evident that BRD in dairy heifers increases the risk of mortality directly after the disease episode by approximately 6 times and reduces growth in the short term with up to 10 kg. The impact of BRD on other production parameters was less clear. The disease may increase both mortality in later stages of the rearing period and age at first calving, although findings were not conclusive, as well as the likelihood of dystocia at first calving. BRD does not seem to affect culling and/or selling during the rearing period and performance after first calving.

Field studies that focused on the risk factors of BRD in dairy heifers often varied in their findings, however, several tendencies were seen. Herd size and other diseases in dairy heifers, especially diarrhoea, are evidently associated with the on-farm risk of BRD, and both season and colostrum feeding management presumably affect this risk. Effects of birth circumstances, housing and prophylactic administration of antimicrobials are less clear, as are effects of region, genetics, herd milk production level and prophylactic vaccination against *Bovine Respiratory Syncytial Virus.* Navel-disinfection, preventive treatment of the dam prior to calving and the basis for weaning heifers do not seem to affect BRD frequency. Although several risk factors were found to be more or less likely associated with BRD, their impacts remain uncertain.

From the literature review, it was concluded that the findings on the productivity effects and risk factors of BRD in dairy heifers were often ambiguous or incomplete. Moreover, several factors that are presumably associated with the disease were not investigated, nor were potential interacting and confouding effects. Hence, despite the knowledge obtained from the literature review, an overall insight into the productivity effects and risk factors of BRD in dairy heifers, including their impact and variation, is lacking to date. Thus, qualitative and quantitative information for accurate and precise evaluation of the economic consequence of BRD in dairy heifers could not fully be obtained.

Expert elicitation study

A formal expert judgement study was conducted in order to obtain additional information on the risk factors (Chapter 3) and the productivity effects (Chapters 4 and 5) associated with BRD in heifers raised under Dutch dairy farm conditions. For this purpose, a panel of 21 experts was composed, fulfilling the criteria of having 1) a DVM degree, 2) relevant working experience related to BRD in dairy heifers, preferably in both the scientific and practical field, and 3) familiarity with dairy heifer rearing practices in the Netherlands.

The total expert elicitation process consisted of five stages. Each of the first four stages was based on the Delphi technique and, as typical for this technique, used a series of sequentially mailed questionnaires (i.e., several iterations). The last stage (stage 5) included a one-day group meeting with the experts to finalise the elicitation process. The Delphi stages were aimed at obtaining consensus on qualitative aspects of relevance to the variables of interest (i.e., the productivity effects and risk factors of BRD in dairy heifers), such as definitions to be used. In fact, the Delphi stages served as preparation for the last stage of the expert elicitation process (i.e., the group meeting) in which these variables were quantified.

Delphi stages 1 to 3 focused on the definition of BRD, and classes to be distinguished with respect to type of BRD, disease severity and age of heifers affected, as well as the definitions of the classes considered. Agreement among the experts on these aspects often was reached after a few iterations (per Delphi stage). The experts defined BRD in dairy heifers as 'a clinical disease of the respiratory tract caused by a viral, bacterial or mycoplasmal infection (parasites were excluded), or a combination of these infections'. BRD distinguished between two types, being calf pneumonia and a seasonal outbreak, and three classes for disease severity, i.e., mild, severe, and chronic. Heifers affected were divided into the three age classes of 0-3 months, 3-6 months, and 6-24 months. In Delphi stage 4, the experts identified the most important risk factors[1] and the most important productivity effects for each of the following three combinations of BRD type, disease severity class and age class ('BRD combinations'): 1) severe pneumonia in heifers aged 0-3 months, 2) mild cases of a BRD outbreak in heifers aged 3-6 months, and 3) severe cases of a BRD outbreak in heifers aged 6-24 months. For each of the three BRD combinations considered, the selected set of risk factors was perceived not to differ between the mild and severe disease class. Consequently, the most important risk factors were actually identified for six BRD combinations. During the group meeting, the experts' assessments on the selected risk factors (Chapter 3) and productivity effects (Chapters 4 and 5) were elicited individually applying PC-based interviews.

Quantification of the risk factors was based on Adapted Conjoint Analysis (ACA) (Chapter 3). One of the advantages of this technique is that a large number of risk factors and their levels can be handled within a relatively short period of time. Using ACA, the

[1]Prophylactic vaccination against BRD was not considered in the expert study

most important risk factors for each of the six BRD combinations, identified in Delphi stage 4, were quantified in terms of their expected relative impacts on the on-farm BRD frequency.

The ACA results showed that '(poor) air circulation' and 'purchase of cattle' were perceived to be the most important risk factor for, respectively, mild and severe pneumonia between 0-3 months. Additional important risk factors included 'housing system' for mild cases, and 'colostrum management' for severe cases of the disease. 'Purchase of cattle' was also assessed to have the highest impact on the frequency of BRD outbreak cases between 3-6 months (severe cases only), whereas 'air circulation' was also expected to affect frequency of BRD outbreak cases between 6-24 months (mild and severe cases) most. 'Previous BRD' was perceived to have the highest impact on mild cases of BRD outbreaks between 3-6 months.

The experts' assessments on the most important productivity effects, identified in Delphi stage 4, were elicited using the graphically-oriented ELI('citation') technique (Chapters 4 and 5). ELI facilitates the quantification of subjective knowledge about uncertain continuous quantities into unbiased probability density functions (PDFs). The mode (most likely value) of a PDF represents the 'best guess', according to the expert, and the dispersion corresponds with his/her uncertainty about this best estimation. The outcome of the ELI session included the individual experts' PDFs for the most important productivity effects of each of the three BRD combinations considered. For each parameter, the separate PDFs were combined in order to obtain a single aggregated distribution (per parameter). This was done applying the so-called Classical model, a linear pooling or weighted averaging model. The individual experts' PDFs were weighted based on the relative expertise of the particular experts, indicated by their performance on the seed variables. The latter variables had been included in the ELI interview especially for this purpose.

The results showed that mortality following severe pneumonia before the age of three months was estimated to be increased by 20 % (range 16-24 %). Body weight of pneumotic heifers was assessed to be reduced by 10 kg (range 2-18 kg) at three months, up to 29 kg (range 23-36 kg) at 14 months. Furthermore, early pneumonia was estimated to delay age at first calving by 2 weeks (range 0.1-0.9 months), and to reduce first lactation milk production by 2 % (150 kg, range 40-250 kg). BRD outbreaks in heifers older than three months were also assessed to reduce body weight at 14 months by approximately 30 kg (range 15-54 kg). Furthermore, BRD outbreaks possibly increased mortality by 1-3 % and, in case of heifers aged over six months, fertility disorders by 3-5 %, both increasing up to 30 %.

Simulation model

A simulation model was developed that calculates the economic losses due to BRD in dairy heifers for individual dairy farm conditions in the Netherlands (Chapter 6). The model is based on the partial-budgeting technique and, following the results of the expert judgement study, calculates the losses for the two BRD types (i.e., calf pneumonia and a seasonal outbreak) separately. Model input includes 1) farm-specific data such as figures on the frequency of BRD and the number of milking cows, 2) prices, and 3) data on the productivity effects of BRD. Defaults on the model input parameters are available to the user and can easily be modified to fit specific farm conditions. Losses considered by the model include treatment costs and losses associated with the following productivity effects: increased mortality, increased premature culling, reduced growth, reduced fertility and reduced milk production in first lactation. Uncertainty is taken into account for parameters related to BRD frequency, mortality and culling.

Calculations of the simulation model for a typical Dutch dairy farm with 55 milking cows and nearly 10 % heifers affected by BRD (Chapter 7) indicated the total economic losses due to pneumonia (< 3 months) to be approximately € 130 per herd per year (range € 0-530). The losses due to one seasonal outbreak with heifers up to 15 months affected amounted to € 330 per herd (range € 160-800). For individual farms that experience high levels of BRD frequency, i.e., over 50 %, the calculated losses due to pneumonia were approximately € 750 per herd per year (range € 420-1440), whereas for BRD outbreaks with heifers up to 15 months affected the losses amounted to € 1190 per herd per outbreak (range € 730-1950).

The potential range of economic losses due to BRD on Dutch dairy farms was explored by the simulation model for several scenarios with regard to farm characteristics. The scenarios were defined by combinations of extreme levels for important farm-related model input parameters. Results showed that the losses due to pneumonia ranged from approximately € 100 to 3200 per herd per year, up to nearly € 5500 at worst. The losses due to BRD outbreaks ranged from approximately € 700 to 6100 per herd per outbreak, up to nearly € 10,000 at worst.

Sensitivity analyses (Chapter 6) found the model's outcome to be most sensitive to (farm-specific) input parameters that determine the number of heifers affected, including BRD frequency, the number of milking cows, the maximum age of heifers affected (for BRD outbreaks only) and, to a lesser extent, calving interval and replacement rate. Other critical input parameters were related to the productivity effects of BRD, drug use, extra labour requirements by the farmer, and several prices and revenues.

From the model calculations it was concluded that for most commercial dairy farms in the Netherlands, the economic losses due to BRD will be small: around 1 % of the farm's net return to labour and management, increasing up to 3-4 % at worst. For individual farms that experience a high level of BRD frequency, the associated losses can be as high as 10-15 % of the farm's net return to labour and management, up to 25 % for large farms.

Application of the model for evaluation of the cost-effectiveness of prevention actions against BRD was demonstrated for several cases based on selected real farms (Chapter 7). The cost-effectiveness of eliminating a specific risk factor of BRD from the farm was determined by its reducing impact on the on-farm economic losses caused by the disease. Estimates used on the relative impacts of the risk factors were based on the expert data obtained (Chapter 3). The application showed that the simulation model developed is useful for economic evaluation of alternative managerial actions aimed at reducing BRD frequency on individual dairy farms. Moreover, the model proved to be user-friendly and flexible. Hence, it can be used as an interactive tool to enhance quantitative insight into the economic consequences of BRD, hereby supporting the decision-making process with regard to prevention of the disease on the individual dairy farm.

Main conclusions

The main conclusions of the thesis are:

1. Quantitative information from peer-reviewed literature on epidemiological aspects of BRD in dairy heifers is in most cases ambiguous and far from complete. This applies in particular to associations and their impacts of risk factors for the disease and the disease effects on productivity.
2. The literature review revealed that BRD in dairy heifers increases the risk of mortality directly after the disease episode by approximately 6 times and reduces body weight in the short term with up to 10 kg. Effects of BRD on other production parameters were less clear.
3. The literature findings showed that herd size and other diseases, especially diarrhoea, are associated with the on-farm risk of BRD in dairy heifers, and both season and colostrum feeding management presumably affect this risk. Quantitative information on these factors and on other potential risk factors was less clear.

4. The quality of expert data can be assured, if elicited by means of a formal procedure, including accurate elicitation techniques. In this perspective, the PC-based interview techniques ACA and ELI have proven to be attractive.
5. Taking into account the level of expertise of individual experts in aggregating their assessments results in better estimates as compared to equal weighting. Seed variables provide a formal basis to determine the experts' weights, and the Classical model provides a framework for the aggregation procedure.
6. According to expert judgement, both pneumonia and BRD outbreaks in dairy heifers reduced body weight at 14 months by 30 kg. Furthermore, pneumonia was estimated to increase mortality risk by 20 %, to delay age at first calving by 2 weeks and to reduce first lactation milk production by 2 %. BRD outbreaks possibly also increase risk of mortality by 1-3 % and risk of fertility disorders by 3-5 % (all figures are medians of their probability density functions).
7. The expert study found '(poor) air circulation' and 'purchase of cattle' to be the most important risk factors for both pneumonia and BRD outbreaks in dairy heifers, complemented with 'previous BRD' in case of the outbreaks. 'Colostrum feeding management' and 'housing system' were also considered to be important determinants for pneumonia frequency.
8. The simulation model developed provides a valuable tool in improving quantitative insight into the economic losses due to BRD in dairy heifers and the cost-effectiveness of prevention actions against the disease on individual dairy farms, hence, to support the on-farm decision-making process with regard to the prevention of BRD.
9. For most dairy farms in the Netherlands, the economic losses due to BRD will be small: approximately 1 % of the farm's net return to labour and management. For individual farms that experience high levels of BRD frequency, the associated losses can be as high as 10-15 %, or even higher on large farms.
10. The economic losses due to BRD in dairy heifers are most sensitive to parameters that determine the number of heifers affected, the impact of the disease on the heifers' productivity, drug use, extra labour requirements by the farmer, and several prices and revenues.

Samenvatting

Inleiding

In de huidige melkveehouderij is het terugdringen van de productiekosten van essentieel belang om een voldoende inkomen uit het bedrijf te kunnen halen en de continuïteit van het bedrijf te kunnen waarborgen. Eén van de grootste kostenposten op een melkveebedrijf betreft de opfok van jongvee. In veel gevallen kan de winstgevendheid van het bedrijf dan ook aanzienlijk worden verbeterd door optimalisatie van de jongveeopfok. Een belangrijk aspect hierbij is preventie en controle van gezondheidsaandoeningen.

Op veel bedrijven vormt Bovine Respiratory Disease (BRD), oftewel luchtwegaandoeningen, een belangrijke gezondheidsprobleem bij het jongvee. BRD kan tot aanzienlijke economische schade leiden. Een nauwkeurig kwantitatief inzicht in deze schade is echter niet voorhanden.

De economische schade als gevolg van BRD kan worden teruggedrongen door verbetering van het bedrijfsmanagement gericht op preventie van de ziekte. Ten einde beslissingen omtrent preventieve maatregelingen tegen BRD te kunnen ondersteunen en verbeteren is een nauwkeuriger inzicht nodig in de economische gevolgen van de aandoening op het individuele melkveebedrijf.

Het belangrijkste doel van het dit proefschrift beschreven onderzoek was het verkrijgen van inzicht in de economische consequenties van BRD bij jongvee door middel van een simulatiemodel. Het ontwikkelde model berekent de economische schade als gevolg van BRD en evalueert de kosten-effectiviteit van preventieve maatregelingen tegen de aandoening voor individuele melkveebedrijven in Nederland. Een tweede doel van het onderzoek was het verkrijgen van informatie met betrekking tot de epidemiologische gevolgen van BRD bij jongvee op melkveebedrijven, te gebruiken als input voor het model, met name over 1) effecten van BRD op de productiviteit ('productie-effecten') van jongvee, en 2) risicio-factoren van de ziekte.

Literatuurstudie

Het onderzoeksproject startte met een literatuurstudie gericht op het verkrijgen van informatie met betrekking tot de productie-effecten en risico-factoren van BRD bij jongvee, voor zover relevant voor Nederlandse melkveebedrijven (hoofdstuk 2). De literatuurstudie was gebaseerd op wetenschappelijke publicaties gericht op het kwantificeren van deze doelvariabelen (i.e., productie-effecten en risico-factoren van BRD bij jongvee) onder voor de praktijk relevante omstandigheden. Op deze manier werden hoog kwalitatieve gegevens verkregen die relevant zijn voor besluitvormingsprocessen op Nederlandse melkveebedrijven. De meeste publicaties die voldeden aan de toegepaste selectie criteria waren gericht op de melkveehouderij in de USA. In hoofdstuk 2 zijn de resultaten gepresenteerd en bediscussieerd.

Uit de resultaten van de literatuurstudie bleek dat BRD de kans op sterfte tijdens of direct na het optreden van de ziekte ongeveer 6 maal vergroot, en de groei van het jongvee op de korte termijn met ten hoogste 10 kg vermindert. Het effect van BRD op andere productieparameters was minder duidelijk. De ziekte lijkt zowel de kans op sterfte later in de opfokperiode als de leeftijd bij eerste afkalving te verhogen, alhoewel de bevindingen omtrent deze effecten niet eenduidig waren. Ook lijkt BRD de kans op dystocia bij eerste afkalving te verhogen. BRD heeft waarschijnlijk geen invloed op vrijwillige en/of onvrijwillige afvoer gedurende de opfokperiode en productiviteit na eerste afkalving.

Ook de resultaten van onderzoek gericht op de risico-factoren van BRD bij jongvee waren in de meeste gevallen niet eenduidig. Wel waren enkele tendensen te zien. Bedrijfsgrootte en andere ziekten in het jongvee, met name diarree, bleken duidelijk gerelateerd te zijn aan de kans op BRD, en seizoen en biestgift beïnvloedden deze kans eveneens. Effecten van geboorteomstandigheden, huisvesting en het preventief toedienen van anti-microbiële middelen zijn minder duidelijk, evenals effecten van regio, genetische achtergrond, melkproductie niveau op het bedrijf en preventieve vaccinatie tegen *Bovine Respiratory Syncytial Virus*. Desinfectie van de navel direct na de geboorte, preventieve behandeling van de moeder vlak voor afkalven, en de basis waarop het jongvee gespeend wordt lijken het optreden van BRD niet te beïnvloeden. De impact van genoemde factoren die in meer of mindere mate met BRD zijn geassocieerd is onduidelijk.

De conclusie was dat informatie uit de literatuur met betrekking tot de meeste productie-effecten en de meeste risico-factoren van BRD bij jongvee, dan wel onvolledig dan wel niet eenduidig was. Bovendien zijn een aantal factoren die waarschijnlijk aan de ziekte zijn gerelateerd niet onderzocht, evenals potentiële interacties en 'confounding' effecten. De literatuurstudie heeft dus, ondanks de verkregen kennis, niet geleid tot een volledig kwantitatief inzicht in de productie-effecten en risico-factoren van BRD bij jongvee. Een compleet beeld van de factoren die van belang zijn voor nauwkeurige evaluatie van de economische gevolgen van BRD bij jongvee op melkveebedrijven was derhalve niet voorhanden.

Expertstudie

Aansluitend op de literatuurstudie werd een protocollaire studie gehouden naar de meningen van deskundigen. Het doel van deze expertstudie was het verkrijgen van aanvullende informatie over de risico-factoren (hoofdstuk 3) en de productie-effecten (hoofdstukken 4 en 5) van BRD bij jongvee op Nederlandse melkveebedrijven. Ten behoeve van de expertstudie was een panel samengesteld van 21 deskundigen, die geselecteerd waren op basis van de volgende criteria: 1) universitaire diergeneeskundige opleiding, 2) relevante werkervaring met betrekking tot BRD bij jongvee, bij voorkeur zowel op wetenschappelijk gebied als in de praktijk, en 3) aantoonbare kennis van de jongveeopfok in Nederland.

De totale expertstudie bestond uit vijf achtereenvolgende fasen. De eerste vier fasen bestonden uit enquêtes die per post werden gehouden en de laatste fase bestond uit een (groeps)bijeenkomst van één dag waarin de experts bij elkaar kwamen. Elk van de eerste vier fasen was gebaseerd op de Delphi-techniek en bestond uit een serie opeenvolgende enquêtes (i.e., enkele iteraties). Het doel van deze Delphi-fasen was het verkrijgen van consensus onder de deskundigen over relevante kwalitatieve aspecten met betrekking tot de doelvariabelen (i.e., productie-effecten en risico-factoren), bijvoorbeeld te gebruiken definities. In feite waren de Delphi-fasen bedoeld als voorbereiding op de laatste fase van de expertstudie (fase 5) waarin de deskundigen werd gevraagd kwantitatieve inschattingen van de doelvariabelen te maken.

De eerste drie Delphi-fasen richtten zich op de definitie van BRD, te onderscheidden klassen voor het type van BRD, de ernst van de ziekte, en de leeftijd van het jongvee, als wel de definitie van elk van de te onderscheiden klasse. Voor elk van deze aspecten gold dat overeenstemming werd bereikt na een aantal iteraties (per Delphi-fase). De deskundigen definieerden BRD als "een klinische ziekte van het luchtwegapparaat die veroorzaakt wordt door een virale, bacteriële of mycoplasmale infectie (parasieten zijn buiten beschouwing gelaten), of een combinatie van deze infecties". De deskundigen verdeelden BRD in twee types, te weten pneumonie en een seizoensgebonden uitbraak, en in drie klassen voor de ernst van de aandoening, te weten mild, ernstig en chronisch. Het jongvee werd verdeeld in de volgende drie leeftijdsklassen: 0-3 maanden, 3-6 maanden, en 6-24 maanden. In de vierde Delphi-fase selecteerden de deskundigen de belangrijkste risico-factoren en de belangrijkste productie-effecten voor elk van de volgende drie combinaties van BRD type, ziekteklasse en leeftijdsklasse ('BRD-combinaties'): 1) ernstige pneumonie tussen 0-3 maanden, 2) milde gevallen van een BRD uitbraak tussen 3-6 maanden, en 3) ernstige gevallen van een BRD uitbraak tussen 6-24 maanden.

Volgens de deskundigen was er geen verschil tussen de belangrijkste risico-factoren voor de milde en de ernstige ziekteklasse van elk van de drie BRD-combinaties, zodat de risico-factoren in feite bekend waren voor elk van zes BRD-combinaties.

Gedurende de groepsbijeenkomst gaven de individuele deskundigen hun kwantitatieve inschattingen van de geselecteerde risico-factoren (hoofdstuk 3) en productie-effecten (hoofdstukken 4 en 5) middels het voltooiden van enquêteprogramma's op de PC.

De PC-enquêtes over de risico-factoren waren gebaseerd op 'Adapted Conjoint Analysis (ACA)' (hoofdstuk 3). Met behulp van deze techniek kon een groot aantal risico-factoren en hun componenten behandeld worden in een relatief kort tijdsbestek. Voor elk van de zes BRD-combinaties was een aparte ACA-enquête opgesteld, waarin de belangrijkste risico-factoren van de betreffende BRD-combinatie behandeld werden. Hierbij werden de risico-factoren meegenomen die in de vierde Delphi-fase waren geselecteerd. De deskundigen gaven hun schattingen omtrent het relatieve belang van elk van de risico-factoren (per BRD-combinatie) op het optreden van BRD op melkveebedrijven.

Volgens de deskundigen waren 'luchtventilatie' en 'aankoop van vee' de belangrijkste risico-factoren voor, respectievelijk, milde en ernstige pneumonie tussen 0-3 maanden. De daaropvolgende belangrijkste risico-factor voor milde en ernstige gevallen van de aandoening was, respectievelijk, 'huisvesting systeem' en 'biestgift'. Volgens de deskundigen was 'aankoop van vee' ook de belangrijkste risico-factor voor het optreden van BRD-uitbraken in jongvee tussen 3-6 maanden (alleen ernstige gevallen), en 'luchtventilatie' ook de belangrijkste factor voor BRD-uitbraken in de leeftijd tussen 6-24 maanden (milde en ernstige gevallen). 'BRD-historie' had de grootste invloed op het optreden van milde gevallen van BRD-uitbraken tussen 3-6 maanden.

De PC-enquêtes over de productie-effecten van BRD waren gebaseerd op de ELI-techniek (hoofdstukken 4 en 5). ELI is een grafisch georiënteerd, interactief programma voor het afleiden ('eliciteren') van onzekere kennis over continue variabelen. Het helpt respondenten hun kennis weer te geven in goede ('unbiased') subjectieve kansverdelingen. In de interactie met de respondent gebruikt ELI eenvoudig te hanteren score-curven in plaats van kansdichtheden. De top van de curve komt overeen met de waarde die de respondent het meest waarschijnlijk acht voor de gevraagde variabele ('beste' schatting). De spreiding of 'breedte' van de curve weerspiegelt de onzekerheid die de respondent heeft over de juistheid van de beste schatting. Hoe breder de curve des te onzekerder de respondent.

Middels de ELI-enquêtes gaven de deskundigen hun schattingen van de belangrijkste productie-effecten van elk van de drie BRD-combinaties, zoals geselecteerd in de vierde Delphi-fase. Dit resulteerde in subjectieve kansverdelingen van de individuele deskundigen voor elk van de betreffende parameters. Voor elke parameter werden de afzonderlijke verdelingen gecombineerd ten einde een enkele, geaggregeerde verdeling (per parameter) te verkrijgen. De combinatie van de verdelingen vond plaats op basis van het 'Classical model', een lineair aggregatie ofwel gewogen-gemiddelde model. De kansverdelingen van de individuele deskundigen werden gewogen op basis van de expertise van de betreffende personen. Het expertise niveau was hierbij gebaseerd op de inschattingen van de individuele deskundigen van 'wegingsvariabelen'. Wegingsvariabelen lijken veel op doelvariabelen (in dit geval de productie-effecten), maar hun werkelijke waarde is bekend (onbekend voor deskundigen). Des te beter een expert de wegingsvariabelen inschat, des te hoger zijn schattingen van de doelvariabelen worden ingewogen.

Uit de schattingen van de experts bleek dat ernstige pneumonie voor de leeftijd van drie maanden de kans op sterfte verhoogt met 20 % (range 15-24 %). De groei van jongvee met pneumonie tussen 0-3 maanden was verminderd met 10 kg in deze periode (range 2-18 kg), oplopend tot een reductie van 29 kg op 14 maanden (range 23-36 kg). Pneumonie verhoogt de leeftijd bij eerste afkalving met twee weken (range 0.1-0.9 maanden), en vermindert de melkproductie in eerste lactatie met 2 % (150 kg, range 40-250 kg). Volgens de experts leiden uitbraken van BRD bij jongvee dat ouder is dan drie maanden ook tot een verminderd lichaamsgewicht van bijna 30 kg op 14 maanden (range 15-54 kg). Verder verhogen BRD-uitbraken mogelijk de kans op sterfte met 1 à 3 % en, in geval van jongvee ouder dan 6 maanden, vruchtbaarheidsstoornissen met 3 à 5 %, beide oplopend tot 30 %.

Simulatiemodel

Na het verkrijgen van de benodigde input gegevens werd een simulatie model ontwikkeld voor het berekenen van de economische schade van BRD bij jongvee. Het model berekent deze schade voor individuele melkveebedrijven in Nederland en, in navolging van de resultaten van de expertstudie, voor elk van de twee BRD types (i.e., pneumonie en BRD-uitbraken) afzonderlijk (hoofdstuk 6). De input van het model bestaat uit 1) bedrijfsspecifieke gegevens zoals het optreden van BRD en het aantal melkkoeien op het bedrijf, 2) prijzen, en 3) gegevens over de effecten van BRD op de productiviteit van het jongvee. In het simulatiemodel worden standaardwaarden van deze input parameters getoond aan de gebruiker. De gebruiker kan deze waarden eenvoudig aanpassen voor specifieke bedrijfsomstandigheden. De schadeposten die in de modelberekeningen worden meegenomen bestaan uit de kosten voor de behandeling van BRD en schade als gevolg van een verminderde productiviteit door de ziekte, te weten verhoogde sterfte, verhoogde voortijdige afvoer, verminderde groei, verminderde vruchtbaarheid, en verminderde melkproductie in eerste lactatie. Onzekerheid omtrent de input van het model wordt meegenomen voor zover het parameters betreft die gerelateerd zijn aan het optreden van BRD, de kans op sterfte en de kans op afvoer.

In hoofdstuk 7 zijn berekeningen gedaan met het simulatiemodel voor een typisch Nederlands melkveebedrijf met 55 melkkoeien en BRD in bijna 10 % van het jongvee. De totale economische schade als gevolg van pneumonie (0-3 maanden) was voor dit bedrijf ongeveer € 130 per jaar (range € 0-530). De schade als gevolg van één BRD-uitbraak in jongvee tot de leeftijd van 15 maanden bedroeg bij benadering € 330 (range € 160-800). Voor bedrijven waarop BRD veelvuldig voorkomt, i.e., bij méér dan 50 % van het jongvee, bedroeg de berekende schade ongeveer € 750 per bedrijf per jaar (range € 420-1440) in geval van pneumonie en € 1190 per bedrijf per uitbraak (range € 730-1950) voor BRD-uitbraken in jongvee tot 15 maanden.

Met behulp van het simulatiemodel is de potentiële range onderzocht van de economische schade als gevolg van BRD op Nederlandse melkveebedrijven (hoofdstuk 7). Dit is gedaan door de schade te berekenen voor verschillende scenario's met betrekking tot bedrijfsspecifieke kenmerken. De scenario's waren gedefinieerd door combinaties van extreme waarden van belangrijke bedrijfsgerelateerde input parameters van het model. De economische schade als gevolg van pneumonie varieerde van ongeveer € 100-3200 per bedrijf per jaar, oplopend tot bijna € 5500 in het ergste geval. De schade als gevolg van BRD-uitbraken lag bij benadering tussen de € 700-6100 per bedrijf per uitbraak, oplopend tot bijna € 10.000 in het ergste geval.

In hoofdstuk 6 zijn gevoeligheidsanalyses uitgevoerd om inzicht te verkrijgen in kritische factoren van de schade van BRD. Hieruit bleek dat de uitkomsten van het model het meest afhangen van input parameters die in meer of mindere mate gerelateerd zijn aan het aantal stuks jongvee dat aan BRD lijdt, zoals het optreden van BRD, het aantal melkkoeien op het bedrijf, de leeftijd tot waarop het jongvee symptomen van BRD vertoont (alleen in geval van BRD-uitbraken), de tussenkalftijd en het vervangingspercentage. Andere kritische input parameters waren gerelateerd aan de productie-effecten van BRD, medicijngebruik, extra benodigde arbeid van de veehouder, en prijzen van enkele kosten- en opbrengstposten.

De conclusie van de modelberekeningen was dat voor de meeste melkveebedrijven in Nederland de economische schade als gevolg van BRD gering is, namelijk ongeveer 1 % van de arbeidsopbrengst, oplopend tot 3 à 4 % in het ergste geval. Op bedrijven waarop

BRD veel voorkomt bedraagt de schade ongeveer 10 à 15 % van de arbeidsopbrengst, of nog hoger voor grote bedrijven

Het simulatiemodel kan worden gebruikt voor evaluatie van de kosten-effectiveit van preventieve maatregelingen tegen BRD. In hoofdstuk 7 is het principe van deze toepassing van het model gedemonstreerd aan de hand van enkele cases gebaseerd op bestaande Nederlandse melkveebedrijven. In deze berekeningen was de kosten-effectiviteit van het terugdringen van een bepaalde risico-factor van BRD bepaald door het (reducerende) effect ervan op de economische schade als gevolg van de aandoening. Schattingen met betrekking tot de relatieve invloed van de risico-factoren van BRD waren gebaseerd op de meningen van de deskundigen (hoofdstuk 3). Het model bleek een bruikbaar hulpmiddel te zijn voor economische evaluatie van verschillende managementmaatregelingen gericht op het terugdringen van het optreden van BRD op individuele melkveebedrijven. Het model is bovendien gebruikersvriendelijk en flexibel. Het kan derhalve worden gebruikt als interactief hulmiddel voor het verkrijgen van kwantitatief inzicht in de economische gevolgen van BRD, en het ondersteunen van de besluitvorming omtrent preventie van de aandoening op individuele melkveebedrijven.

Belangrijkste conclusies

1. Kwantitatieve informatie uit de wetenschappelijke literatuur over epidemiologische aspecten van BRD bij jongvee op melkveebedrijven is in de meeste gevallen niet eenduidig en verre van compleet. Dit geldt met name voor de risico-factoren van BRD en de gevolgen van de aandoening op de productiviteit van het jongvee.
2. Uit het literatuuronderzoek bleek dat BRD bij jongvee op melkveebedrijven de kans op sterfte tijdens of direct na het optreden van de ziekte ongeveer 6 maal vergroot en de groei op de korte termijn met ten hoogste 10 kilogram vermindert. Informatie over de invloed van BRD op andere productieparameters was niet eenduidig.
3. Uit de wetenschappelijke literatuur blijkt dat het optreden van BRD bij jongvee op melkveebedrijven beïnvloed wordt door de grootte van het bedrijf en door het optreden van andere ziekten, met name diarree, in het jongvee. Seizoen en biestgift hebben zeer waarschijnlijk ook invloed op het optreden van BRD. Informatie over de kwantitatieve invloed van deze en andere potentiële risico-factoren was niet eenduidig.
4. De kwaliteit van 'expert'-informatie kan worden gewaarborgd door het gebruik van een protocollaire procedure voor het afleiden van deze informatie. Dit houdt onder

andere in dat goede 'elicitatie'-technieken gebruikt dienen te worden, zoals bijvoorbeeld de PC-programma's ACA en ELI.

5. Indien bij het combineren van schattingen van individuele deskundigen rekening wordt gehouden met het expertise-niveau van de betreffende personen worden betere resultaten verkregen dan wanneer de schattingen van de verschillende deskundigen gelijk worden ingewogen. Het expertise-niveau kan op een formele manier worden vastgesteld door het gebruik van 'wegingsvariabelen'; het Classical model vormt een protocollaire aanpak voor het combineren van schattingen.
6. Volgens deskundigen verminderen zowel pneumonie als BRD-uitbraken het lichaamsgewicht van jongvee op melkveebedrijven met ongeveer 30 kilogram op 14 maanden. Tevens leidt pneumonie tot een verhoging van de kans op sterfte van 20 %, een verhoging van de leeftijd bij eerste afkalving van 2 weken en een vermindering van de melkproductie in de eerste lactatie van 2 %. Uitbraken van BRD verhogen mogelijk de kans op sterfte met 1-3 % en de kans op vruchtbaarheidsstoornissen met 3-5 % (alle getallen zijn medianen van de afgeleide kansverdelingen).
7. Uit de expertstudie bleek dat 'luchtventilatie' en 'aankoop van vee' de belangrijkste risico-factoren zijn voor pneumonie en BRD-uitbraken bij jongvee op melkveebedrijven. 'Historie van BRD' was tevens een belangrijke risico-factor voor het optreden van BRD-uitbraken, en 'biestgift' en 'huisvesting systeem' belangrijke risico-factoren voor pneumonie.
8. Het ontwikkelde simulatiemodel is een waardevol hulpmiddel voor het verkrijgen van kwantitatief inzicht in de economische schade als gevolg van BRD bij jongvee en de kosten-effectiviteit van preventieve maatregelingen tegen de aandoening op individuele melkveebedrijven. Het kan derhalve de besluitvorming omtrent de preventie van BRD op het individuele melkveebedrijf ondersteunen.
9. Op de meeste melkveebedrijven in Nederland is de economische schade als gevolg van BRD gering: ongeveer 1 % van de arbeidsopbrengst, oplopend tot 3-4 % in het ergste geval. Op bedrijven waarop BRD veel voorkomt bedraagt de schade ongeveer 10-15 % van de arbeidsopbrengst, of nog hoger voor grote bedrijven.
10. De economische schade als gevolg van BRD bij jongvee op melkveebedrijven wordt het sterkst bepaald door parameters die gerelateerd zijn aan het aantal stuks jongvee dat lijdt aan de aandoening, de invloed van BRD op de productiviteit van het jongvee, medicijngebruik, extra benodigde arbeid van de veehouder en prijzen.

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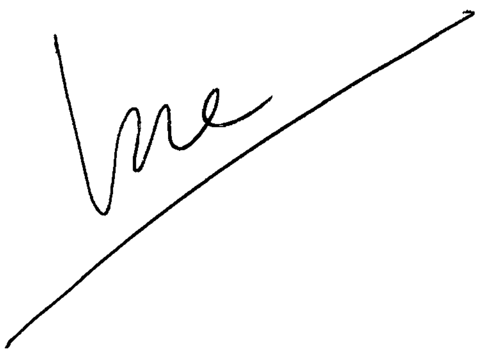

Ine van der Fels-Klerx
Wageningen, november 2001

Curriculum vitae

Huberdina Johanna (Ine) Klerx werd op 3 februari 1971 geboren te Waalwijk. In 1989 behaalde zijn het diploma Atheneum-B aan het Mollercollege te Waalwijk. In september van dat jaar maakte zij een start met de studie Levensmiddelentechnologie van de toenmalige Landbouwuniversiteit Wageningen. In maart 1990 maakte zij de overstap naar de toenmalige studie Zoötechniek. Deze studie werd in november 1994 afgerond met twee afstudeervakken Veehouderij. Het eerste afstudeervak werd gedeeltelijk uitgevoerd in samenwerking met de Faculteit Diergeneeskunde van de Universiteit Utrecht. Het tweede afstudeervak werd uitgevoerd bij de Department of Veterinary Clinical Science, Massey University te Palmerston North in Nieuw Zeeland.

Van september 1994 tot februari 1997 werkte zij als wetenschappelijk onderzoeker bij de afdeling Veehouderij van het toenmalige Praktijkonderzoek Rundveehouderij te Lelystad; tot april 1996 binnen de sectie Management en Diergezondheid, en vervolgens binnen de sectie Paarden. In de periode van februari 1997 tot en met oktober 2001 werkte zij als Assistent in Opleiding (AIO) bij de Leerstoelgroep Agrarische Bedrijfseconomie van de Wageningen Universiteit aan haar promotieonderzoek, hetgeen geleid heeft tot dit proefschrift. Het onderzoek werd mede gefinancierd door Pfizer Animal Health BV. Een deel van het onderzoek is uitgevoerd bij de Department of Animal Health and Welfare, Research Centre Foulum in Denemarken.

Vanaf november 2001 is zij als onderzoeker werkzaam bij het Microbiologisch laboratorium voor Gezondheidsbescherming (MGB) van het Rijksinstituut voor Volksgezondheid en Milieu te Bilthoven. Zij werkt daar aan een project getiteld "Kwantitatieve analyse van productstromen in de dierlijke productieketens als basis voor potentiële aanpassingen in monitoring en surveillance".

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