Risk analysis of
classical swine fever introduction

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C.J. de Vos

Risk analysis of classical swine fever introduction

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ABSTRACT

The research described in this thesis aimed to support decision-making on preventing classical swine fever virus (CSFV) introduction into disease-free regions of the European Union (EU). A risk analysis of CSFV introduction was performed. The main objective was to provide quantitative insight into the major risk factors contributing to the probability of CSFV introduction (P_{CSFV}). First, a pathway diagram was constructed presenting an overview of all factors that might possibly contribute to the P_{CSFV}. Then, based on this pathway diagram, a scenario tree model was developed to calculate the annual P_{CSFV} into member states of the EU. The main aim of this model was to analyse quantitatively those pathways that contribute most to the annual $P_{CSFV,}$ and the origin of these pathways. Pathways included in the model were import of pigs and pork products, returning livestock trucks, and contacts with wild boar. All (old) 15 EU member states were included as possible sources of CSFV introduction. Because the model contained many uncertain input parameters, an extensive sensitivity analysis was performed to indicate which of these parameters most influenced model results. The results indicated that only four out of 257 uncertain input parameters changed the ranking of risk factors, viz. the expected number of classical swine fever epidemics in Germany, Belgium, and the United Kingdom, and the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km. Model calculations based on the situation as at 2003 showed that returning livestock trucks contributed most to the annual P_{CSFV} into the Netherlands with 50%. The most likely sources of CSFV introduction were Germany, Belgium and Spain. Finally, a cost-effectiveness analysis was performed for six measures aimed at preventing CSFV introduction into the Netherlands. Results showed that using separate livestock trucks for national and international transport was most cost-effective, especially when a worst-case scenario was assumed (i.e. for 0.95 percentile values of the annual P_{CSFV}).

Keywords: Classical swine fever; Cost-effectiveness; European Union; Pathway diagram; Prevention; Risk analysis; Scenario tree model; Sensitivity analysis; The Netherlands; Virus introduction

VOORWOORD

“Alstublieft, een half proefschrift” ben ik geneigd te zeggen. Nu, bijna zeven jaar na de start van mijn onderzoek, zijn er nog zoveel vragen onbeantwoord en nog zoveel ideeën niet uitgewerkt. Maar toch, mijn boekje is af. En dat geeft een goed gevoel! Veel mensen hebben in meer of mindere mate bijgedragen aan dit onderzoek, waarvoor mijn oprechte dank. Een aantal van hen wil ik hier bij name noemen.

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Clazien de Vos
Ede, januari 2005

CONTENTS

Chapter 1

General introduction

1.1. INTRODUCTION

Classical swine fever (CSF) is a highly contagious viral disease that affects both domestic pigs and wild boar. The virus can be transmitted from infected pigs to susceptible pigs via many routes, including both direct and indirect contacts. Examples of transmission routes are animal movements, transport vehicles, human contacts, swill feeding, genetic material, manure, and air currents (Elbers et al., 1999; Dewulf, 2002; Paton and Greiser-Wilke, 2003). The incubation period of the disease is 7 – 10 days (Moennig, 2000). The diagnosis of CSF based on clinical signs is often difficult as symptoms may vary considerably, depending on the age and/or breed of the affected animals and on the viral strain (Dahle and Liess, 1992; Terpstra, 1997). Young animals are usually affected more severely than older animals. Mortality rates may reach 90% in young pigs. Several countries, including Australia, New Zealand, Canada, United States of America (USA), and some member states of the European Union (EU), have succeeded in eradicating the virus. In most other parts of the world where significant pig production is carried out, the CSF virus (CSFV) is still present, causing substantial economic damage and posing a continuous threat to CSF-free countries (Edwards et al., 2000).

Fig. 1.1 shows a schematic representation of the course of a CSF epidemic over time. An epidemic is started when CSFV is introduced into the pig production sector of a region free of CSF. In general, it takes from a few weeks up to several months before such an introduction is detected (Terpstra, 1996; Horst et al., 1998; Elbers et al., 1999; Sharpe et al., 2001). In the period between introduction and first detection, the so-called high-risk period (HRP), the virus can spread freely to other farms as at this stage no control measures have yet been taken to reduce virus spread and eradicate the disease. A region in the HRP of a CSF epidemic therefore constitutes a considerable threat to its trade partners and neighbouring regions. As soon as the CSFV has been detected, control measures are put in place in the affected region, and other regions take additional measures to prevent the introduction of CSFV into their territory. The end of an epidemic is defined as the moment at which no virus is present any longer, i.e. when all infected herds are depopulated, because by then virus spread is no longer possible. The official CSF-free status is, however, only regained six months later if control is based on stamping out without vaccination (Edwards et al., 2000).

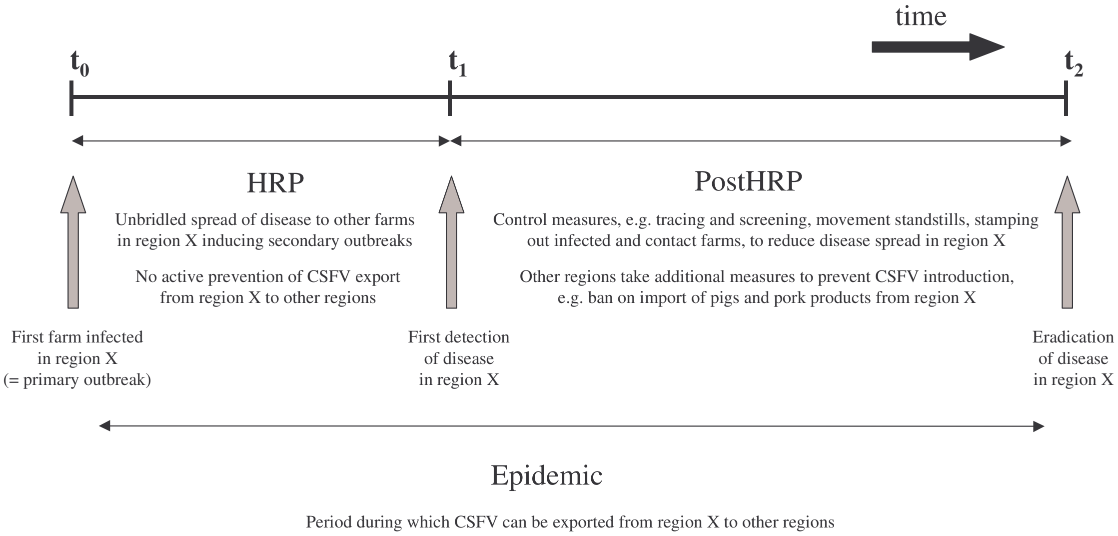

Fig. 1.1. Schematic representation of the course of a CSF epidemic over time.

Since the early 1990s, CSF control in the EU has been based on a strategy of non-vaccination and the stamping-out of infected and contact herds (CEC, 2001). As a consequence of this policy, the whole EU domestic pig population has become fully susceptible to CSFV. This, combined with the existence of areas with dense pig populations, has occasionally led to large epidemics incurring high economic losses (Vanthemsche, 1996; Elbers et al., 1999; Meuwissen et al., 1999; Edwards et al., 2000; Moennig, 2000, Moennig et al., 2003). Table 1.1 shows an overview of all CSF outbreaks in the EU[1] from 1990 onwards. It is evident that sporadic outbreaks of CSF still occur in the domestic pig population of the EU, particularly in Germany and Italy. In addition, CSF is endemic in wild boar populations in some areas of Germany, France, and Italy (Laddomada, 2000), representing a permanent CSFV reservoir. In recent years, infected wild boar have also been found in Austria, Belgium and Luxembourg (Artois et al., 2002; OIE, 2005). The introduction of CSFV therefore remains a continuing risk for the pig production sector of the EU.

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[1] The research described was carried out before the enlargement of the EU by 10 new member states on May 1, 2004.

Table 1.1

CSF infected herds in the EU from 1990 onwards

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Austria	-	-	-	-	-	2	0	0	0	0	0	0	0	0
Belgium	113	0	0	7	48	0	0	8	0	0	0	0	0	0
Denmark	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	-	-	-	-	-	0	0	0	0	0	0	0	0	0
France	4	1	1	1	0	0	0	0	0	0	0	0	1	0
Germany	118	6	13	105	117	54	4	44	11	6	2	5	11	1
Greece	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Italy	15	15	20	12	25	42	46	44	18	9	3	5	0	1
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	12	1
The Netherlands	2	0	5	0	0	0	0	424	5	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	78	21	0	0	33	16	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
United Kingdom	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Total	252	22	39	125	190	98	50	598	55	15	21	43	40	3

Sources: Dewulf, 2002; OIE, 2005.

Risk is defined as the likelihood and magnitude of the occurrence of an adverse event (Ahl et al., 1993). Accordingly, the risk of CSFV introduction comprises: (i) the annual probability of CSFV introduction (P_{CSFV}) and (ii) the epidemiological consequences and economic losses caused by the resulting epidemic, as well as its societal impact. Reducing this risk can thus be achieved both through preventive actions and control measures. In response to the CSF epidemics of the 1990s, much research has been dedicated to analysing spread mechanisms of CSFV in order to define optimum control strategies and minimise epidemiological consequences (see e.g. Jalvingh et al., 1999; Nielen et al., 1999; Mangen, 2002; Dewulf, 2002; Klinkenberg, 2003). Reducing the P_{CSFV} through preventive measures might, however, be a more attractive option to reduce the losses incurred by epidemics in the long term, not in the least place from a socio-ethical point of view. To optimally use resources for prevention of CSFV introduction, more quantitative insight is needed into which factors contribute most to the annual P_{CSFV}. Partial knowledge on this matter is available from both historical outbreaks (e.g. Elbers et al., 1999; De Vos et al., 2000; Fritzemeier et al., 2000) and risk analyses performed (Corso, 1997; Rugbjerg et al., 1998; Horst et al., 1999). However, most import risk analyses focus only on a single pathway for virus introduction. This thesis presents a more comprehensive study based on the principles of quantitative risk analysis (Vose, 2000), taking into account the major pathways responsible for CSFV introduction as well as the main sources from where the virus might be introduced.

1.2. OBJECTIVE OF THE THESIS

The main objective of this thesis was to provide quantitative insight into the major risk factors contributing to the P_{CSFV} to provide support for decision-making on the prevention of CSFV introduction. This objective was subdivided into three parts:

1) overview of all factors possibly contributing to the P_{CSFV} into the domestic pig population of a region free of disease;
2) development of a model to quantitatively estimate the relative contribution of risk factors to the annual P_{CSFV};
3) cost-effectiveness analysis of tactical measures aimed at prevention of CSFV introduction.

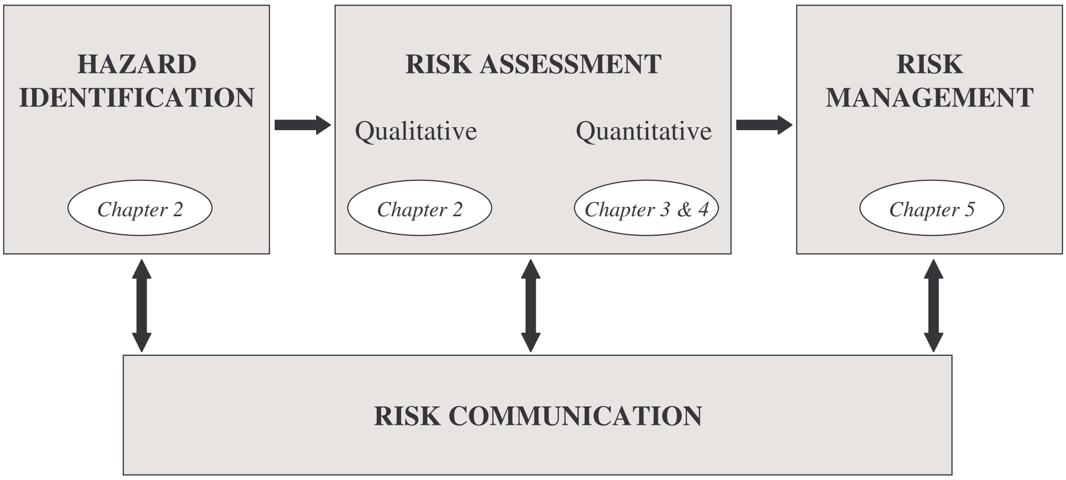

Fig. 1.2. The four components of risk analysis and their place in this thesis.

1.3. OUTLINE OF THE THESIS

The outline of this thesis follows the four steps of a risk analysis study as presented in Fig. 1.2: (a) hazard identification, (b) risk assessment, (c) risk management, and (d) risk communication (Zepeda et al., 2001; Murray, 2002; OIE, 2004). The hazard identified in this study was CSFV introduction into a region free of disease. A pathway diagram was constructed to identify all risk factors possibly contributing to the P_{CSFV} (Chapter 2). This pathway diagram formed the basis for a qualitative risk assessment of CSFV introduction at regional level in the EU (Chapter 2). A scenario tree model was developed to perform a quantitative risk assessment of CSFV introduction into member states of the EU (Chapter 3). Data availability, or rather the lack of data, was one of the major constraints in building the model. Therefore, an extensive sensitivity analysis was performed to investigate the effect of uncertain parameters on model outcome (Chapter 4). To manage the risk of CSFV introduction, tactical preventive measures can be implemented. The scenario tree model was used to calculate the effectiveness of such measures for the Netherlands. To support decision-making, the extra annual costs required to implement these measures were also estimated and cost-effectiveness ratios calculated (Chapter 5). Risk communication as such was not a research objective of this study and is therefore not addressed explicitly in this thesis. Nevertheless, it has been an integral part of this study. Examples include consultation with experts on model parameters and preventive actions, oral presentations for both scientific and political audiences, written papers, and last but not least, this thesis. In the general discussion (Chapter 6) the two critical steps of this risk analysis study – quantitative risk assessment and risk management – are discussed in more detail.

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Chapter 2

The risk of the introduction of classical swine fever virus at regional level in the European Union: a conceptual framework

Paper by De Vos, C.J., Saatkamp, H.W., Huirne, R.B.M., Dijkhuizen, A.A., 2003. Revue Scientifique et Technique de Office International des Epizooties 22 (3), 795-810.

Abstract

Recent classical swine fever (CSF) epidemics in the European Union (EU) have clearly shown that preventing the introduction of CSF virus (CSFV) deserves high priority. Insight into all the factors contributing to the risk of CSFV introduction is a prerequisite for deciding which preventive actions are cost-effective. The relations between virus introduction and spread, prevention and control, and economic losses have been described using the conceptual framework presented in this paper. A pathway diagram provides insight into all the pathways contributing to the likelihood of CSFV introduction (LVI_CSF) into regions of the EU. A qualitative assessment based on this pathway diagram shows that regions with high pig densities generally have a higher LVI_CSF, although this cannot be attributed to pig density only. The pathway diagram was also used to qualitatively assess the reduction in LVI_CSF achieved by restructuring the pig production sector. Especially integrated chains of industrialised pig farming reduce the LVI_CSF considerably, but are also difficult and costly to implement. Quantitative assessment of the LVI_CSF on the basis of the pathway diagram is needed to support the results of the qualitative assessments described.

Keywords: Classical swine fever; European Union; Pathway diagram; Prevention; Qualitative risk assessment; Risk; Virus introduction

2.1. INTRODUCTION

Recent classical swine fever (CSF) epidemics in the European Union (EU) resulted in high economic losses. In 1993 and 1994, Germany and Belgium were severely affected by a CSF epidemic with 217 farms infected in Germany (Kramer et al., 1995; Pittler et al., 1995) and 55 in Belgium (Koenen et al., 1996; Vanthemsche, 1996; Laevens et al., 1998). Even more disastrous was the 1997/1998 CSF epidemic in the Netherlands which affected 429 farms and led to the destruction of more than 10 million pigs for preventive and welfare reasons (Anonymous, 1998a). The costs of this epidemic (i.e. direct costs and consequential losses to farms and related industries) were estimated at US$2.3 billion (Meuwissen et al., 1999). The importation of infected piglets from the Netherlands also resulted in a major epidemic in Spain, with 99 farms being infected in 1997 and 1998 (Edwards et al., 2000; Greiser-Wilke et al., 2000).

The introduction of CSF is a continuing threat to the pig production sector of the EU. The disease is still present in some countries of central and eastern Europe (Edwards et al., 2000). Moreover, CSF occurs in an endemic form in wild boar populations in some areas of Germany, France and Italy (Laddomada, 2000), representing a permanent CSF virus (CSFV) reservoir. Prevention of CSFV introduction should therefore be attributed the highest priority possible.

Most outbreaks in the major CSF epidemics mentioned above occurred in what is referred to as densely populated livestock areas (DPLAs) with an average pig density of more than 300 pigs/km^2 (Michel and De Vos, 2000). These areas developed due to economic factors, such as the availability of cheap feedstuff and reasonably priced land and the vicinity of urban markets (Dijkhuizen and Davies, 1995; Huirne et al., 1995). The concentration of pig production in these areas is supposed to be correlated with the risk of introduction and spread of epidemic diseases (Dijkhuizen and Davies, 1995). Pig and pig farm density are, however, not the only determinants in the risk of virus introduction. Insight into all factors contributing to the risk of virus introduction is a prerequisite for taking preventive actions that are both epidemiologically effective and economically sensible, and is therefore of utmost importance in supporting policy-making. The main aims of this paper were to present a conceptual framework for estimating the overall risk of CSFV introduction into regions within the EU and to explore opportunities to reduce this risk.

Risk of virus introduction is assessed at regional level because operating on a country-by-country basis to prevent disease introduction is no longer in accordance with official EU policy following the establishment of the free internal market in 1993 (Anonymous, 1993). In that year, veterinary controls at the borders between member states were abolished, resulting in free movement of livestock and livestock products. In cases of occurrence of certain animal diseases, including CSF, the principle of regionalisation is applied, which consists of implementing disease control measures and restrictions to trade only in the area where the disease occurs (Anonymous, 1993; Edwards et al., 2000). The Office International des Epizooties (OIE: World organisation for animal health) also recommends this regionalisation principle for the prevention and control of contagious animal diseases (OIE, 1998). A further argument for the use of regions instead of countries for risk assessments lies in the important differences between regions of the EU, even within the same member state, with regard to pig and pig farm densities and the structure of the pig industry (Moennig, 2000).

The paper commences with an overview of definitions and transmission routes for CSFV. A conceptual framework for the risk of CSFV introduction is then presented. In the remainder of the paper, emphasis is placed on the likelihood of CSFV introduction (LVI_CSF). Results of a qualitative assessment of the LVI_CSF for several regions in the EU are presented, after which the possible reduction in the LVI_CSF by structural changes in the pig production sector is explored. The paper concludes with a discussion and prospects for future research.

2.2. DEFINITIONS

A brief overview of definitions is provided for key terms used throughout this paper in order to avoid possible confusion.

A generally accepted definition of risk is given by Ahl et al. (1993) as the likelihood and magnitude of the occurrence of an adverse event. Accordingly, risk of virus introduction takes into account (i) the likelihood that a virus be introduced into a region and (ii) the resulting epidemiological consequences and economic losses caused by the primary outbreak and subsequent spread of the disease (Zepeda et al., 2001).

Virus introduction is defined as entrance of virus into the livestock production sector of a region free of the disease, causing a primary outbreak[2]. Virus spread is defined as dissemination of virus from one farm to another within the affected region, resulting in secondary outbreaks. The distinction between introduction and spread thus depends on the regional level used, i.e. dissemination of virus between provinces is referred to as spread at country level, but as introduction at the provincial level.

The regional level used in this study was determined by the definition of a primary outbreak derived from EU Council Directive 82/894/EEC: ‘an outbreak not epizootiologically linked with a previous outbreak in the same region of a member state, or the first outbreak in a different region of the same member state’ (CEC, 1982).

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[2] This article focuses on CSFV introduction into the domestic pig population of a region. Virus introduction into the wild boar population has not been considered because the prevention and control strategies used are different (CEC, 1980), as are the economic consequences of such an introduction.

The regions referred to in the above definition are areas with a surface of at least 2 000 km^2, controlled by competent authorities and at least comprising one of a certain, member state-dependent, administrative area, e.g. provinces in Belgium, Italy and Spain, counties in the United Kingdom and Ireland and departments in France (CEC, 1964). Based on the EU definition of a primary outbreak, further primary outbreaks can occur within one epidemic if virus is spread from one region to another. This was the case, for example, during the 1997/1998 CSF epidemic in the Netherlands, in which four primary outbreaks were recorded.

Both introduction and spread of virus occur by so-called transmission routes (TRs). These are the carriers and mechanisms which may lead to virus transmission from infected to susceptible animals. In this paper, TRs for virus introduction will be referred to as pathways and TRs for virus spread as spread mechanisms.

2.3. TRANSMISSION ROUTES FOR CLASSICAL SWINE FEVER VIRUS

2.3.1. General overview

Table 2.1 presents an overview of the most important TRs for CSFV, based on published scientific literature. Movement of pigs which are incubating the disease or are persistently infected is the most common mode of CSFV transmission (Terpstra, 1991; Elbers et al., 1999). Other important TRs are indirect spread of virus through transport vehicles and human contacts (Elbers et al., 1999) and feeding of swill without proper heat-treatment (Van Oirschot, 1992). Classical swine fever virus can survive in pork and pork products beyond processing (Blackwell, 1984; Farez and Morley, 1997). Survival can be prolonged for months if the meat is stored at a cool temperature, or even years if stored frozen (Van Oirschot and Terpstra, 1989; Terpstra, 1991). Furthermore, presence of virus in infected wild boar constitutes an important TR, either by direct or indirect contact, for example, through the food chain (Terpstra, 1991; Moennig, 2000). Other TRs include airborne transmission through air currents (Terpstra, 1987; Dewulf et al., 2000), mechanical transmission by arthropod vectors, birds, pet animals and rodents (Tersptra, 1987; Elbers et al., 1999), transmission by manure (Elbers et al., 1999) and transmission by genetic material, i.e. artificial insemination (De Smit et al., 1999; Elbers et al., 1999).

So-called neighbourhood infection has been ascribed an important role in the spread of CSFV, especially during recent CSF epidemics in the EU (Pittler et al., 1995; Stärk et al., 1997; Elbers et al., 1999). Neighbourhood infection is considered as the TR for those farms for which the origin of infection is unknown and which are situated in the immediate vicinity of another herd, infected at an earlier date. Neighbourhood infection is not a TR in itself, but refers to a number of possible TRs that account for virus spread over a short distance, including spread by human contacts, air currents, rodents and birds, all of which having already been included in Table 2.1.

Table 2.1

Transmission routes for CSF virus

	Importance for		
Transmission route	Introduction	Spread	References[a]
Animal movements	++	++	Harkness, 1985; Edwards, 1989; Terpstra, 1991; Van Oirschot, 1992; Davies, 1994; Kramer et al., 1995; Elbers et al., 1999; Fritzemeier et al., 2000
Transport vehicles	+	++	Harkness, 1985; Edwards, 1989; Van Oirschot, 1992; Kramer et al., 1995; Elbers et al., 1999; Fritzemeier et al., 2000
Human contacts	+/–	++	Harkness, 1985; Terpstra, 1991; Van Oirschot, 1992; Kramer et al., 1995; Edwards, 1989; Elbers et al., 1999; Fritzemeier et al., 2000
Swill-feeding	++	+/–	Harkness, 1985; Williams and Matthews, 1988; Edwards, 1989; Terpstra, 1991; Van Oirschot, 1992; Davies, 1994; Kramer et al., 1995; Fritzemeier et al., 2000
Wild boar	++	–	Terpstra, 1991; Van Oirschot, 1992; Davies, 1994; Laddomada et al., 1994; Kramer et al., 1995; Laddomada, 2000; Moennig, 2000; Fritzemeier et al., 2000
Air currents	–	+/–	Terpstra, 1991; Van Oirschot, 1992; Elbers et al., 1999; Dewulf et al., 2000
Rodents, birds, arthropods, pets	–	+/–	Harkness, 1985; Terpstra, 1987; Terpstra, 1988; Van Oirschot, 1992; Elbers et al., 1999
Manure	–	+/–	Terpstra, 1988; Elbers et al., 1999
Genetic material	+/–	+	De Smit et al., 1999; Elbers et al., 1999

– : unimportant
+/– : might be important
\+ : important
++ : very important

[a] A selection of references has been made. An extensive overview of references is available on request.

2.3.2. Indication of importance

Information from historical outbreaks was used to classify TRs according to their importance for introduction and spread (Table 2.1). Only a qualitative classification can be provided, because the ultimate importance of a specific TR depends on the extent of presence (e.g. number of animal contacts) and its specific risk (e.g. probability of virus transmission per animal contact) and can therefore differ per region.

The major routes for CSFV introduction into regions of the EU since the prohibition of mass vaccination in 1992 include feeding of improperly heated swill, direct or indirect contact with wild boar and animal movements (De Vos et al., 2000; Fritzemeier et al., 2000). These TRs were therefore considered of great importance in CSFV introduction. The most important TRs for virus spread during recent epidemics were animal movements, transport vehicles, human contacts and neighbourhood infections (Kramer et al., 1995; Pittler et al., 1995; Winkenwerder and Rassow, 1998; Elbers et al., 1999; Fritzemeier et al., 2000). These TRs were therefore considered as very important in CSFV spread.

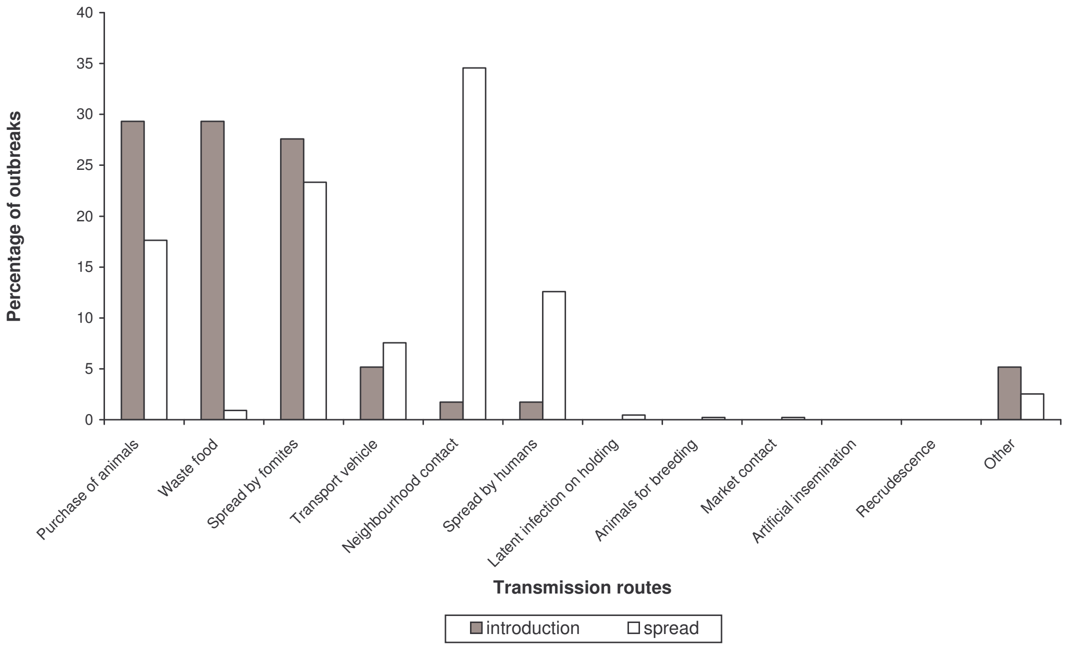

Fig. 2.1. Transmission routes responsible for CSF outbreaks in the EU between January 1990 and April 1999, for which the origin of disease is registered in the Animal Disease Notification System, i.e. about 34% of all outbreaks.

The origin of disease was obtained from the Animal Disease Notification System (ADNS) of the EU for 28.2% of all primary CSF outbreaks (n = 206) and 35.0% of all secondary CSF outbreaks (n = 1 247) between January 1990 and April 1999 (Fig. 2.1). Although the classification of TRs used in the ADNS differs from that used in Table 2.1, the main TRs responsible for the outbreaks in the ADNS correspond to a large extent to those derived from scientific literature. Most primary CSF outbreaks (about 85%) were caused by purchase of animals, feeding of waste food and spread by fomites[3]. More than 95% of all secondary outbreaks for which the origin of disease is provided by the ADNS were caused by neighbourhood contacts, purchase of animals, spread by fomites, humans and transport vehicles.

2.4. CONCEPTUAL FRAMEWORK FOR ASSESSING THE RISK OF CLASSICAL SWINE FEVER VIRUS INTRODUCTION

Although the use of import risk analysis has increased significantly in recent years, most analyses focused only on a single pathway for virus introduction (Heng and Wilson, 1993; Astudillo et al., 1997; Sutmoller and Wrathall, 1997). However, comprehensive understanding of all the factors which contribute to the risk of virus introduction, including their interactions, is required to support epidemiologically and economically sound decisions concerning preventive actions. This is illustrated in Fig. 2.2. Pathways determine the likelihood of virus introduction (LVI), whereas spread mechanisms determine the extent of virus spread. Long-term economic losses due to virus introduction in a region are determined by both the likelihood of introduction and the extent of virus spread. The presence of both pathways and spread mechanisms are, to a large extent, determined by the structure of the livestock production sector in a given region, e.g. farm and animal densities, farm types (mixed or specialised, open or closed, extensive or intensive), and contact patterns. Preventive measures aim at reducing the LVI, whereas control measures are applied to decrease disease spread and eventually eradicate the virus. Both types of measures aim at reducing the economic losses of virus introduction, although their implementation also results in expenses. From an economic point of view, measures should only be taken if the reduction in economic losses outweighs the cost of disease prevention and control.

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[3] Spread by fomites is all virus spread caused by objects contaminated with the disease agent and, hence, covers those indirect contacts between animals that are not included in other TRs distinguished by the ADNS (A. Laddomada, personal communication), including spread by wild boar (Pittler et al., 1995).

Preventive measures are usually taken to reduce the impact of pathways, e.g. by quarantine of imported animals. Most control measures aim at reducing the presence of spread mechanisms, e.g. by movement standstills and stamping out of infected premises. These types of measures are of a technical character and can be implemented and lifted rapidly, hence providing ad-hoc solutions. An alternative approach to prevention is restructuring the livestock production sector of a region. This is an irreversible and often expensive process which impacts the risk of virus introduction in the long term, not only changing the LVI, but also the opportunities for disease spread once the virus has been introduced. The Netherlands provides an example of how the livestock production sector can be restructured at regional level. In an attempt to solve two major problems of DPLAs, i.e. manure surpluses and contagious animal disease epidemics (Dijkhuizen and Davies, 1995), the legislation aims at reducing total pig populations (Anonymous, 1998b) and to relocate the national pig production in clustered areas, separated by so-called pig-free corridors (Anonymous, 2002).

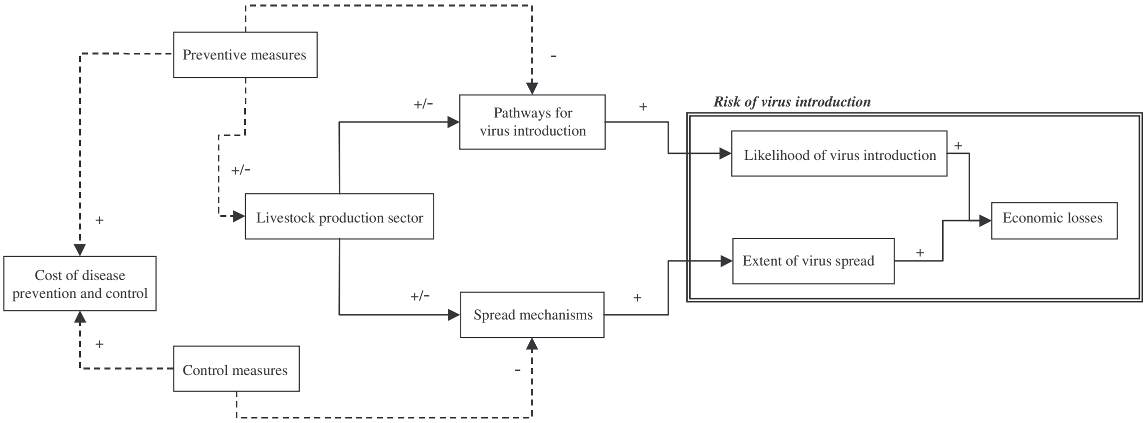

Fig. 2.2. Relation between the risk of virus introduction and preventive and control measures.

\+ : positive connection (e.g. if more pathways for virus introduction are present, the likelihood of virus introduction will increase)

– : negative connection (e.g. if more preventive measures are installed, the (risk of) pathways for virus introduction will decrease)

+/– : unpredictable connection (e.g. a change in the livestock production sector might either increase or decrease the spread mechanisms present)

2.4.1. Pathway diagram to estimate the likelihood of classical swine fever virus introduction

To obtain more insight into the regional LVI_CSF in the EU, a pathway diagram was designed to show all the possible pathways for CSFV introduction, including their main events and inter-relations (Fig. 2.3). A pathway diagram uses a tree-like approach to provide insight into all the possible causes of an adverse event. For the adverse event to occur, all the events of a certain pathway have to take place. Estimating the probability of occurrence of the adverse event is made possible by adding probabilities to all the events in the diagram.

The pathway diagram comprises four levels. At the top of the diagram, the first level shows the pathways for virus introduction into a region, including both exogenous and endogenous pathways. Exogenous pathways are linked with virus sources outside the region where they might cause a primary outbreak, whereas endogenous pathways reside within the affected region. The pathways were derived from the TRs presented in Table 2.1. Some TRs were, however, broken down into more specific sub-TRs to account for all the possible routes of virus introduction at regional level.

A pathway can only contribute to the LVI if present. The extent of presence is expressed in pathway-units. These are the logical units in which a pathway is usually measured, e.g. an animal, one kilogram of animal product or a returning livestock truck. Exogenous pathways only constitute a risk if they originate from an area where the disease is prevalent, whereas endogenous pathways only pose a risk if they contain a virus reservoir. Some exogenous pathways only contribute to the LVI if they originate in a neighbouring area, e.g. air currents and birds, pets, arthropods and rodents. These pathways play a minor role in virus introduction because they transport the virus over only short distances.

At the second level, it is determined whether any infected or contaminated pathway-units are present. Only in such cases will a pathway contribute to the overall LVI.

The third level is used to evaluate whether preventive actions may detect and/or inactivate the virus. Only a selection of preventive measures is given in the diagram, but most additional measures that can be taken by a region, e.g. testing or quarantine, can be introduced at this level.

If the virus is still present after passing the third level, virus transfer to susceptible domestic animals can occur by two main routes, i.e. swill-feeding to or direct or indirect contact with susceptible animals. Which route is relevant depends on the pathway for virus introduction. Virus transfer will only result in an outbreak if the virus conveyed constitutes an infective dose. There is, however, one exception to this general pattern, i.e. the legal or illegal import of an infected live animal will always lead to an outbreak if the animal survives and infection is not detected sufficiently early. In such cases, swill-feeding or contact with susceptible animals is not needed to cause a primary outbreak since the imported animals become part of the livestock population.

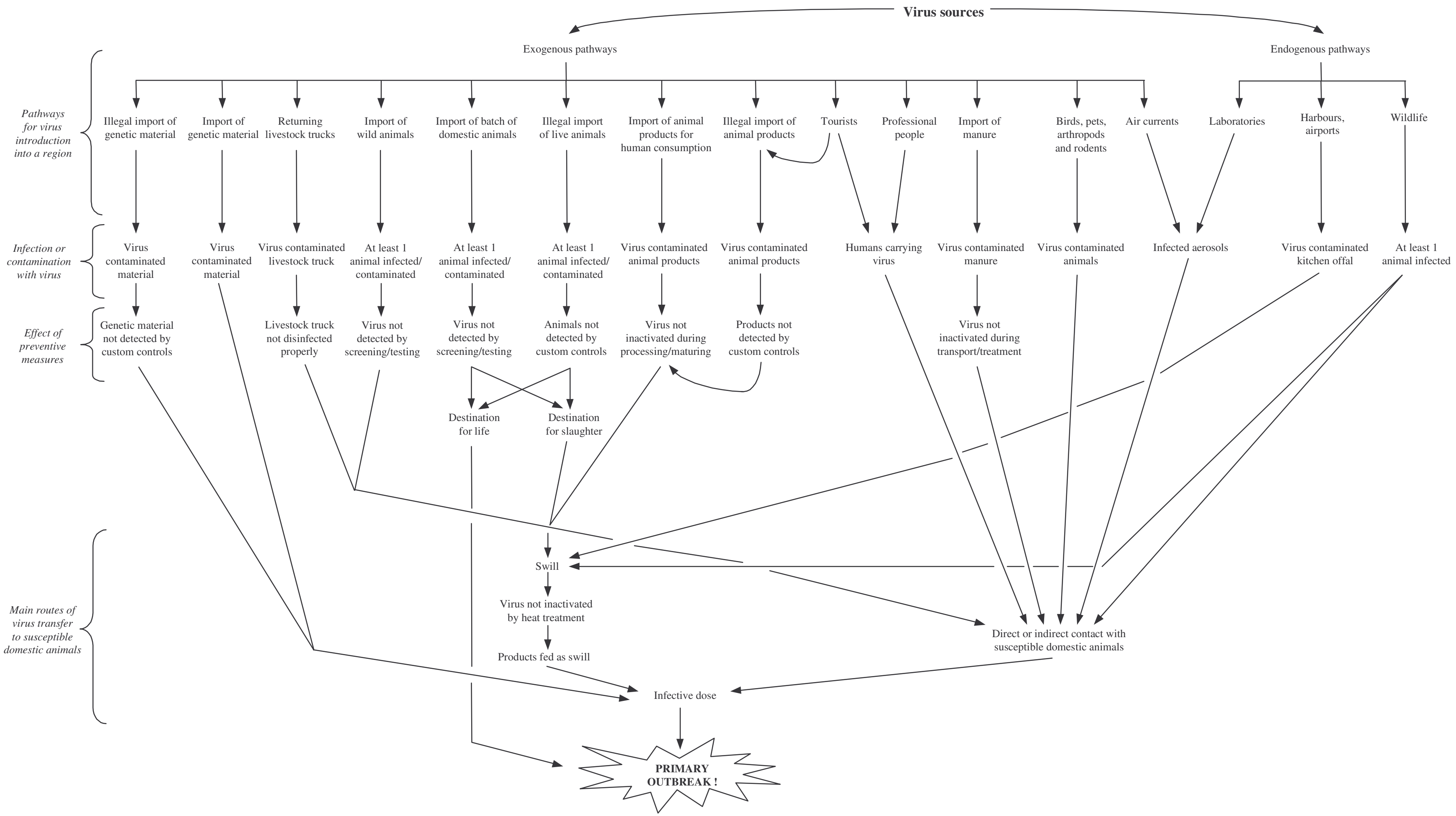

Fig. 2.3. Pathway diagram containing all pathways that contribute to the likelihood of regional CSFV introduction in the EU.

For each pathway, the main events leading to a primary outbreak of CSF are shown in the pathway diagram. Theoretically, each event in the diagram can be assigned a probability that the event will occur. These are all conditional probabilities, i.e. the probability of occurrence of a certain event given that all previous events have occurred. For example, virus introduction by the pathway 'returning livestock trucks' will only occur if a livestock truck returns to the region after visiting an infected region, if this truck is contaminated with virus, if the truck is not disinfected properly, if the truck comes into contact with susceptible animals and if the virus dose conveyed is at least the minimum infective dose.

2.4.2. Interventions to reduce the likelihood of classical swine fever virus introduction

The pathway diagram can be used to explore opportunities for reducing the LVI_CSF for regions in the EU. Interventions can take place at all levels of the diagram, except the second one. Most preventive actions are taken at the third level and comprise testing procedures, cleansing and disinfection and the issuing of health certificates to guarantee freedom of disease. Presence of virus can, however, never be ruled out for certain by these types of preventive actions, due to human errors, sampling procedures, sensitivity and specificity of tests, etc. Preventive measures can also be taken at the fourth level, e.g. by a ban on swill-feeding or by assuring adequate heat-treatment of swill. However, preventing all possible contacts of pathways with susceptible domestic animals is difficult, especially when considering people and air currents. This is particularly true for pigs kept in extensive production systems with outdoor facilities. If all domestic pigs were immune to CSF and thus no susceptible animals were present, contacts with infected pathway-units would have no consequences. A policy of mass vaccination aims at reducing the population of susceptible animals to a minimum, but cannot completely prevent the presence of susceptible animals, especially young piglets, and therefore leads to the risk of undetected infections.

Eliminating the presence of pathways, i.e. intervening at the first level of the pathway diagram is the most effective way of preventing CSFV introduction under the current non-vaccination policy of the EU. This is usually done when pathways originate from areas where the disease is known to be prevalent. This, however, does not reduce the LVI_CSF to zero, since often the virus is present in a region for several weeks or even more than a month before the first outbreak is detected (Terpstra, 1996; Horst et al., 1998; Elbers et al., 1999; Sharpe et al., 2001). Furthermore, although some pathways may be eliminated or their numbers reduced by taking preventive actions, other pathways simply cannot be excluded (MacDiarmid, 1997). Air currents will always exist, tourism is impossible to forbid, laboratories are required for virological and serological tests and production of vaccines, and illegal activities cannot be excluded. Moreover, implementation of a zero-risk policy for imports of live animals and animal products would impede international trade to a large extent and is no longer attainable under the current agreements of the World Trade Organization (WTO) (Kellar, 1993; Pritchard et al., 1995; Zepeda et al., 2001). In addition, a zero-risk policy is often not recommendable when considering economic aspects. There is usually a trade-off between the risk of virus introduction, the costs of preventive actions and the benefits from, for example, importing live animals and genetic material.

2.5. APPLICATION OF THE PATHWAY DIAGRAM

Application of the pathway diagram will be illustrated in this section with two realistic but very different examples, as follows:

- estimation of the LVI_CSF for certain regions in the EU and
- evaluation of the direction and magnitude of change in the LVI_CSF for a region following structural changes of the pig production sector.

2.5.1. Qualitative assessment of the likelihood of classical swine fever virus introduction

The pathway diagram of Fig. 2.3 was used to qualitatively assess the LVI_CSF for five DPLAs and five sparsely populated livestock areas (SPLAs) in the EU. Information about the presence of pathways (level 1 of the pathway diagram) and the possibility that they could transmit virus to susceptible domestic pigs (level 4) was used to classify the regions according their LVI_CSF.

Table 2.2a presents basic information available for each region. This information was used to calculate pig and farm densities and to derive an estimate of the number of pigs exported or imported by the region (Table 2.2b). Net piglet imports or exports were estimated on the basis of the fattening pig/sow ratio of the region, assuming that with a ratio of about

Table 2.2a

Basic information[a] on five densely and five sparsely populated livestock areas in the EU used for the qualitative assessment of the likelihood of CSFV introduction

Variables	The Netherlands		Germany		Italy		Belgium		France	
	South	South-West	Süd-oldenburg	Hannover	Mantova	Rovigo	West-Flanders	Namur	Côtes d'Armor	Orne
	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA
Surface area (km^2)	7 050	4 544	2 230	2 290	2 339	1 922	3 293	4 418	6 878	6 103
Number of sows (*10^3)	777	26	85	12	47	5	349	3	189	8
Number of fattening pigs (*10^3)	4 095	198	1 395	67	625	41	2 747	27	1 168	53
Total number of pigs (*10^3)	8 754	336	1 636	105	797	55	4 413	43	2 200	90
Total number of pig farms	7 688	957	3 400	695	1 101	1 364	5 376	261	7 381	1 170
Annual number of pigs slaughtered (*10^3)	7 225	600	4 676	178	1 352	208	4 639	5	2 598	21
Number of airports with regular flights	2	1	0	1	0	0	2	0	4	1
Number of laboratories working with classical swine fever virus	0	0	0	3	0	0	0	0	2	0
Estimated number of wild boar	136	0	120	>1 170[b]	0	0	0	1 250	700	5 500
Estimated number of infected wild boar	0	0	0	0	0	0	0	0	0	0
Swill-feeding allowed?	No	No	Yes	Yes	No	No	No	No	No	No

DPLA: densely populated livestock area

SPLA: sparsely populated livestock area

[a] Information was derived from the database described by Michel and De Vos (2000) and from research groups participating in the EU Research Project FAIR5-PL97-3566 (Anonymous, 2000).

[b] No estimate of the wild boar population was available. In the period between 1 April 1999 and 31 March 2000, 1 170 wild boar were killed.

Table 2.2b

Calculated and estimated data for five densely and five sparsely populated livestock areas in the EU used for the qualitative assessment of the likelihood of CSFV introduction

	The Netherlands		Germany		Italy		Belgium		France	
Variables	South	South-West	Süd-oldenburg	Hannover	Mantova	Rovigo	West-Flanders	Namur	Côtes d'Armor	Orne
	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA
Pig density (pigs/km^2)	1 242	74	733	46	341	29	1 340	10	320	15
Pig farm density (farms/km^2)	1.09	0.21	1.52	0.30	0.47	0.78	1.63	0.06	1.07	0.19
Fattening pig/sow ratio	5.27	7.69	16.39	5.55	13.38	8.58	7.88	8.00	6.19	6.51
Net number of imported piglets per year[a] (*10^3)	–1 622	9	769	–22	281	6	182	2	–220	–7
Net number of imported fattening pigs per year[a] (*10^3)	–4 272	45	758	–11	–402	94	–3 075	-71	–681	–129

DPLA: densely populated livestock area

SPLA: sparsely populated livestock area

[a] A negative net number of imported animals signifies a net number of exported animals.

7.4, theoretically no net imports or exports of piglets are required[4]. Slaughter capacity in the region was used to estimate the net imports or exports of live fattening pigs. The estimates derived are the minimum numbers of pigs imported or exported. In most cases, these are an underestimate of the gross imports and exports.

Information on the number of pathway-units present was only available for net imports and exports of live animals, the latter indicating the number of returning livestock trucks into a region, and the endogenous pathways. Furthermore, information was available on pig and farm densities and swill-feeding, which are indicators of the probability that CSFV will affect susceptible domestic pigs once the virus has been introduced.

Table 2.2b indicates that regions with high pig densities have larger net imports or exports of pigs than regions with low pig densities. Südoldenburg (Germany), Mantova (Italy) and West-Flanders (Belgium) are major net importers of piglets, whereas South (the Netherlands) and the Côtes d'Armor (France) are major net exporters. Südoldenburg has a net import of fattening pigs, whereas South, Mantova, West-Flanders and the Côtes d'Armor show net exports of fattening pigs due to a shortage of slaughter capacity. Regions with high pig densities also have high pig farm densities, except for Mantova, with pigs concentrated on large intensive farms. The number of airports with regular flights is highest for the Côtes d'Armor which has four. The number of laboratories working with CSFV is highest for Hannover (Germany) which has three, including the EU Reference Laboratory for CSF. The number of wild boar is highest for the Orne (France), with an estimated population of 5 500 animals. No CSF infections in wild boar have, however, been detected in recent years in the regions listed in Table 2.2a (Laddomada, 2000). Swill-feeding is forbidden in all but the German regions. In Germany, the practice is still permitted, but only after adequate heat-treatment. Therefore, if all regulations were observed, none of the regions of Table 2.2a would suffer from primary CSF outbreaks caused by swill-feeding.

Eight criteria listed in the left column of Table 2.3 were used to classify the regions as having a low, moderate or high LVI_CSF. If a region meets none or only one of these criteria, it is considered as having a low LVI_CSF. If a region meets two or three of these criteria, the LVI_CSF is considered moderate, and if a region meets four or more criteria, the LVI_CSF is considered as high. On the basis of these criteria, the LVI_CSF for the regions South,

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[4] Figures used: weaned piglets per sow per year: 22; replacement rate: 0.4; percentage mortality from weaning to slaughter: 4%; fattening period (20 kg to slaughter weight): 130 days.

Table 2.3

Classification of five densely and five sparsely populated livestock areas for their likelihood of CSFV introduction, using eight criteria (left column)

	The Netherlands		Germany		Italy		Belgium		France	
Classification criteria	South	South-West	Süd-oldenburg	Hannover	Mantova	Rovigo	West-Flanders	Namur	Côtes d'Armor	Orne
	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA	DPLA	SPLA
Net number of piglets imported > $1*10^5$ per year	–	–	+	–	+	–	+	–	–	–
Net number of pigs exported > $5*10^5$ per year	+	–	–	–	–	–	+	–	+	–
Airports with regular flights present	+	+	–	+	–	–	+	–	+	+
Laboratories working with classical swine fever virus present	–	–	–	+	–	–	–	–	+	–
Wild boar present	+	–	+	+	–	–	–	+	+	+
Pig density > 50 pigs/km^2	+	+	+	–	+	–	+	–	+	–
Pig farm density > 1 farm/km^2	+	–	+	–	–	–	+	–	+	–
Swill-feeding allowed	–	–	+	+	–	–	–	–	–	–
Expected likelihood of classical swine fever virus introduction	high	moderate	high	high	moderate	low	high	low	high	moderate

DPLA: densely populated livestock area
SPLA: sparsely populated livestock area
– : no
+ : yes

Südoldenburg, Hannover, West-Flanders, and Côtes d'Armor was classified as high. The LVI_CSF for South-West (the Netherlands), Mantova and the Orne was considered as moderate, whereas the LVI_CSF for the remaining regions – the SPLAs of Italy and Belgium – was considered as low (Table 2.3).

2.5.2. Impact of structural changes in the pig production sector on the likelihood of classical swine fever virus introduction

Parts of Dutch legislation to restructure pig production (Anonymous, 1998b; Anonymous, 2002) and ideas of explorative studies on prospects for future pig production in the Netherlands (Anonymous, 1998c) were used to elaborate three scenarios for structural changes in the pig production sector at regional level. These scenarios, their main aims and expected consequences are described in Table 2.4. The pathway diagram was used to qualitatively evaluate the effects of the scenarios on the LVI_CSF, assuming that current risk management at farm level will not be changed by the different scenarios.

The scenarios in Table 2.4 do not directly affect the pathways of illegal imports, imports of wild animals, imports of animal products for human consumption, tourists, laboratories, harbours and airports and wildlife. For the other pathways, the direction and magnitude of expected change in the LVI_CSF compared to the current situation are given in Table 2.5.

In scenario 1, the pig population is reduced and hence the number of pig transports. Moreover, the LVI_CSF by pathways that disseminate virus over short distances might be somewhat decreased because of reduced pig farm density. In scenario 2, the LVI_CSF over short distances is reduced due to pig-free corridors. Furthermore, farmers will try to minimise the number of contact pig farms because of the differentiated levies for the stamping-out fund. This will result in a reduced number of pig transports. Movement of pigs over long distances is, however, not reduced by this scenario. In scenario 3, the transport of pigs and genetic material is no longer necessary. Between-chain contacts with professional people can be largely avoided since the extensive industrial pig farms contain all the stages of the livestock production chain and thus have most expertise at their disposal. Virus transmission over short distances will also be decreased since these industrial farms are located at a minimum distance of 3 000 m from one another (Anonymous, 1998c).

All the scenarios are expected to reduce the LVI_CSF. Although reducing the LVI_CSF was not the primary aim of scenario 1, this scenario seems comparable with scenario 2 in terms of reducing the LVI_CSF. The latter scenario would reach this goal more effectively if discounts on the levy for the stamping-out fund were only granted if contact pig farms were located in the same cluster. This would eventually lead to more closed clusters and therefore higher reductions in the LVI_CSF by pig transports. Scenario 3 reduces the LVI_CSF most, but is difficult to implement. Changing pig production from family-based farming to an industrial activity implies high costs and requires significant turnover in the general perception of pig farming, as well as high adaptability of the primary and secondary industries involved.

Table 2.4

Three scenarios for structural changes in the pig production sector at regional level in the Netherlands

	Scenario 1	Scenario 2	Scenario 3
Name	Reduced pig population	Clustered areas with pig-free corridors	Integrated chains of industrialised pig farming
Description	Pig population of each farmer reduced by 20%. Pig production rights for remaining 80%. Extending a farm only possible after buying production rights from other farmers	Clustered areas of pig production separated by pig-free corridors of at least 1 000 m in width. Differentiated levies for stamping-out fund used to finance control of epidemic disease outbreaks: the fewer farms with which pigs are exchanged, the lower the levy a farmer has to pay	Pig production in large industrialised farms located in 'industrial parks', together with supplying and processing industries, thus providing a well-closed production system
Main aim	Reduce environmental problems of intensive pig farming industry	Reduce risk of contagious animal diseases in densely populated livestock areas	Reduce risk of contagious animal diseases
Expected consequences (in comparison to current situation)	Reduced pig numbers and thus less manure production. Reduced pig farm density because small pig farmers and farmers for whom pig production is of secondary importance will discontinue production	Equal pig density. Reduced pig farm density because small pig farmers in corridors who are forced to move will discontinue production. Fewer pig farm contacts	Well-closed pig production systems that are concentrated in small areas with extremely high pig densities
References	Anonymous, 1998b	Anonymous, 1998b; Anonymous, 2002	Anonymous, 1998c

Structural changes in the pig production sector will not only affect the LVI_CSF, but also the possible spread of virus once introduced and hence, the economic consequences of virus introduction (Fig. 2.2). The latter aspects should also be taken into account when evaluating the three scenarios for their impact on the risk of CSFV introduction. Although scenario 3 reduces the LVI_CSF most, it might result in major economic losses once the virus has been introduced. Only a comprehensive quantitative risk analysis will provide insight into which set of structural changes most reduces the risk of CSFV introduction.

Table 2.5

Expected impact[a] of three scenarios[b] for structural changes in the pig production sector on the likelihood of CSFV introduction

Pathway	Scenario 1	Scenario 2	Scenario 3
Imports of genetic material	0/+	0	++
Returning livestock trucks	++	+	+
Imports of batches of domestic animals	++	+	+++
Professional staff	0	0	++
Imports of manure	0	0	0
Birds, pets, arthropods and rodents	+	+++	+++
Air currents	+	+++	+++

0 : no change
+ : slight reduction
++ : considerable reduction
+++ : major reduction, almost reducing the likelihood to zero

[a] Changes in the likelihood of CSFV introduction in comparison to the current situation.

[b] Scenarios:
1 : reduced pig population
2 : clustered areas with pig-free corridors
3 : integrated chains of industrialised pig farming

2.6. DISCUSSION AND CONCLUSIONS

2.6.1. Regional approach

The establishment of the free internal market in 1993 led to the abolishing of veterinary border checks between member states. Controls on animal movements now mainly occur at the place of dispatch, but can also be carried out at the place of destination if deemed necessary. The conceptual framework described in this paper therefore aimed at exploring the risk of regional CSFV introduction in the EU.

The regions used for controlling CSF epidemics are usually based on the installed control and surveillance zones around infected premises. Using such regions is, however, impossible for the prevention of CSFV introduction. The authors therefore decided to employ the administrative regions used by the EU systems to prevent disease introduction and spread, such as the ADNS. A major advantage of these regions is that they are under control of local veterinary authorities. A disadvantage is that styles of pig production are not definitely homogenous when referring to administratively defined regions. However, the smaller the regions considered, the more homogenous pig production will be.

The regional approach for disease prevention seems to function relatively well as long as no threats of nearby epidemic diseases exist. However, as soon as, for example, CSF or foot-and-mouth disease (FMD) outbreaks occur in the EU, member states take preventive measures at national level and revert to national border controls. Nevertheless, exploring the risk of CSFV introduction at regional level is a valuable exercise as this approach provides more insight into which regions are most at risk. Up until the present, the most densely populated regions such as the south-eastern part of the Netherlands, Flanders in Belgium, Lower-Saxony in Germany and Brittany in France have been considered to be ‘problem areas’ (Dijkhuizen and Davies, 1995), not in the least because some of the most recent CSF epidemics occurred in these regions. However, pig density is not the only determinant for the risk of CSFV introduction. This risk is also assumed to be markedly higher in areas where CSFV circulates in the wild boar population. As an example, the majority (80%) of all primary outbreaks in the period between 1993 and 1997 in Germany were in areas at risk from wild boar fever (Fritzemeier et al., 1998).

2.6.2. Conceptual framework

Insight into all the factors contributing to the risk of CSFV introduction is required to decide which preventive actions are cost-effective, i.e. achieve considerable risk reduction at reasonable costs. Preventive actions should therefore not only be evaluated for their potential to reduce the LVI_CSF, but also for their impact on spread and economic losses once the virus has been introduced. The pathway diagram presented in Fig. 2.3 was found to be helpful in qualitatively assessing the LVI_CSF for regions in the EU. Additional tools, such as simulation models as described by Saatkamp et al. (1996) and Jalvingh et al. (1999) and the economic model described by Meuwissen et al. (1999), are required to evaluate subsequent spread and economic consequences.

Elaboration of a pathway diagram provides further insight into all possible pathways and events contributing to the occurrence of an adverse event. This process should therefore be recommended as part of hazard identification, which is the first step in risk analysis (Wooldridge et al., 1996). The more pathways involved, the more complex the diagram becomes. For this reason, only the main events leading to the occurrence of a primary CSF outbreak were involved in the pathway diagram shown in Fig. 2.3. Scenario trees can be used to describe each pathway in more detail (Miller et al., 1993; Corso, 1997; Rugbjerg et al., 1998; Stärk and Rasmussen, 1999).

The pathway diagram in Fig. 2.3 was especially designed for CSFV introduction into regions of the EU under a non-vaccination policy. The diagram might also be applicable to other highly contagious viral pig diseases such as FMD, African swine fever (ASF) and swine vesicular disease (SVD). If used for other parts of the world or other diseases, the diagram should be carefully examined for redundant or missing pathways or events.

2.6.3. Application of the pathway diagram

The pathway diagram was used to qualitatively assess the LVI_CSF for DPLAs and SPLAs in the EU. This qualitative assessment showed that DPLAs generally had a higher LVI_CSF than SPLAs, although this could not be attributed to pig density only. The results should be interpreted with care as for some of the pathways in the diagram, no information was available. Furthermore, the contribution of pathways to the overall LVI_CSF will differ, but to which extent is unknown. Some pathways play a more important role in introducing CSFV to a region than others (Table 2.1). The criteria of Table 2.3 were, however, given equal weight in the qualitative assessment. The relative contribution of the pathways also differs per region as a function of the number of pathway-units present, the region of origin of the pathway-units and their use. Horst et al. (1998) obtained expert estimates of the relative importance of pathways for CSFV introduction. These were, however, specifically for CSFV introduction into the Netherlands and could therefore not be used for different European regions. Quantitative information on the presence of pathways and their main events is therefore required for a more adequate estimation of the LVI_CSF for regions in the EU.

The pathway diagram was also used to explore the impact of preventive actions on the LVI_CSF. Three scenarios of structural changes in the pig production sector were evaluated. These scenarios mainly reduced the number of pig transports and dissemination of virus over short distances. The scenario of integrated chains of industrialised pig farming reduced the

LVI_CSF most effectively. However, more information is required to decide on preventive actions. The reductions in the LVI_CSF achieved by the scenarios should be quantitatively assessed and the impact of the scenarios on virus spread and economic losses once the virus has been introduced should also be taken into account. Furthermore, the financial and social costs of implementing the scenarios need to be determined, as well as the possible impact of the scenarios on the risk attitude of farmers, i.e. risk management at farm level.

The scenarios for structural changes in the pig production sector were derived from legislation in the Netherlands and explorative studies on prospects for intensive pig production in the Netherlands by the end of 1999. Scenarios considering more extensive pig production as a starting point were not taken into account in this qualitative assessment. Recent crises in the livestock production sector of the EU, caused by, among others, FMD and bovine spongiform encephalopathy (BSE), have strengthened the call for more organic farming. Although this will result in lower pig and pig farm densities and less long-distance pig transports, organic farming also implies new risks of contracting contagious diseases due to, for example, outdoor pig keeping.

2.6.4. Quantitative estimates of the likelihood of classical swine fever virus introduction

Quantitative assessment of the LVI_CSF requires obtaining information for all the events distinguished in the pathway diagram, as the overall LVI is the sum of all the probabilities for the individual pathways. Databases can be used to obtain exact figures or estimates for the number of pathway-units entering a region. The number of animals imported or exported can, for example, be derived from national identification and recording systems (I&R) and the European animal movement system (ANIMO). For most pathways, however, information at regional level is not readily available and will have to be derived from national statistics or expert opinion. Obtaining estimates for the probabilities expressed at levels 2, 3 and 4 of the pathway diagram is difficult, all the more so since they might differ per region. Some probabilities might be derived from past outbreaks, experiments or scientific literature. This information is, however, scarce and might already be outdated due to rapid changes in, for example, trade patterns and control strategies. Expert opinion is therefore an important source of information for most probabilities. Sensitivity analysis should indicate the possible impact of missing and uncertain data and therefore help to set priorities for further (empirical) research (Dijkhuizen et al., 1997).

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Chapter 3

Scenario tree modelling to analyse the probability of classical swine fever virus introduction into member states of the European Union

Paper by De Vos, C.J., Saatkamp, H.W., Nielen, M., Huirne, R.B.M., 2004. Risk Analysis 24, 237-253. Reproduced with permission of the Society for Risk Analysis.

Abstract

The introduction of classical swine fever virus (CSFV) into a country free of disease without vaccination may have huge consequences in terms of both disease spread and economic losses. More quantitative insight into the main factors determining the probability of CSFV introduction (P_{CSFV}) is needed to optimally use resources for the prevention of CSFV introduction. For this purpose a spreadsheet model was constructed that calculates the annual P_{CSFV} into member states of the European Union (EU). The scenario pathway approach was used as most probabilities in the model are very small. Probability distributions were used to take into account inherent variability of input parameters. The model contained pathways of CSFV introduction including the import of pigs and pork products, returning livestock trucks and contacts with wild boar. All EU member states were included as possible sources of CSFV. Default results for the Netherlands showed a mean overall annual P_{CSFV} of approximately 0.06, indicating that the Netherlands can expect CSFV introduction on average once every 18 years from the pathways and countries included in the model. Almost 65% of this probability could be attributed to the pathway returning livestock trucks. The most likely sources of CSFV introduction were Germany, Belgium and the United Kingdom. Although the calculated probabilities were rather low when compared with expert estimates and recent history, the most likely causes of CSFV introduction indicated by the model were considered to be realistic. It was therefore concluded that the model is a useful tool to structure and analyse information for decision-making concerning the prevention of CSFV introduction.

Key words: Classical swine fever; European Union; Probability analysis; Scenario pathway approach; Virus introduction

3.1. INTRODUCTION

Classical swine fever (CSF) is a highly contagious viral disease that affects both domestic pigs and wild boar. Transmission of the virus from infected to susceptible pigs is possible by many routes, including both direct and indirect contacts. Examples of transmission routes are animal movements, transport vehicles, human contacts, swill feeding, genetic material, manure and air currents (Elbers et al., 1999; De Vos et al., 2003a). The incubation period of the disease is 7 – 10 days (Moennig, 2000). The diagnosis of CSF based on clinical signs is often difficult as symptoms may vary considerably, depending on age and/or breed of the affected animals and on the viral strain (Dahle and Liess, 1992; Terpstra, 1997). Young animals are usually affected more severely than older animals. Mortality rates may reach 90% in young pigs. Several countries, including Australia, New Zealand, Canada, United States of America (USA), and some member states of the European Union (EU), have succeeded in eradicating the virus. In most other parts of the world with significant pig production, the CSF virus (CSFV) is still present, causing substantial economic damage (Edwards et al., 2000).

In the EU a non-vaccination policy has been applied since the early 1990s, consisting of eradication of the disease based on screening and tracing, movement standstills and stamping out infected and contact herds. Although this policy has proven to be quite successful, the introduction of CSF remains a continuing threat to the pig production sector of the EU. Sporadic outbreaks in the domestic pig population still occur, some resulting in large epidemics incurring high economic losses. The most striking example is a series of epidemics that started at the end of 1996 in Germany due to illegal swill feeding. The virus was subsequently spread to several regional pig farms and presumably from Germany to the Netherlands and then subsequently to Spain, Italy and Belgium (Elbers et al., 1999). More than 550 confirmed outbreaks could be attributed to these epidemics (Moennig, 2000; Edwards et al., 2000). The costs of these epidemics (i.e. direct costs and consequential losses to farms and related industries) were estimated at US$ 2.3 billion for the Netherlands only (Meuwissen et al., 1999). More recently, epidemics occurred in the United Kingdom, Luxembourg and Spain, among others (Sharpe et al., 2001; OIE, 2002). In addition, CSF occurs in an endemic form in wild boar populations in some areas of Germany, France, and Italy, representing a permanent CSFV reservoir (Laddomada, 2000). In recent years infected wild boar were also found in Austria and Luxembourg (OIE, 2002).

In general it takes from a few weeks up to several months before the introduction of CSFV into a region free of CSF is detected (Terpstra, 1996; Horst et al., 1998; Elbers et al., 1999; Sharpe et al., 2001). In the period between first infection and first detection, the so-called high-risk period (HRP), the virus can spread freely to other farms as at this stage no control measures have yet been taken to reduce virus spread and eradicate the disease. A country in the HRP of a CSF epidemic therefore constitutes a considerable risk for its trade partners and neighbouring countries. As soon as the CSFV has been detected, control measures are put in place in the affected region and other countries take additional measures to prevent the introduction of CSFV into their territory. A schematic representation of the course of an epidemic over time is given in Fig. 3.1.

Many factors contribute to the probability of CSFV introduction (P_{CSFV}) and their relative importance will differ for each country. The major causes of CSFV introduction for a country have to be known in order to optimally use resources available for prevention. Partial knowledge on this matter is available from both historical outbreaks (see e.g. Elbers et al., 1999; De Vos et al., 2000) and risk analyses performed (see e.g. Corso, 1997; Rugbjerg et al., 1998; Horst et al., 1999). A pathway diagram presenting all factors that possibly contribute to the P_{CSFV} and their interactions is given by De Vos et al. (2003a). Based on this diagram, a spreadsheet model was constructed in order to calculate the P_{CSFV} for a country. The main aim of this model is to analyse which pathways (i.e. carriers and mechanisms that can transmit the virus from an infected to a susceptible animal) contribute to the P_{CSFV} for a particular country and from where these pathways originate. The model can be used to support decision-makers in setting priorities for the prevention of CSFV introduction.

The objective of this paper is to describe the modelling approach used to calculate the P_{CSFV}, with the Netherlands as an example, and to discuss its strengths and weaknesses.

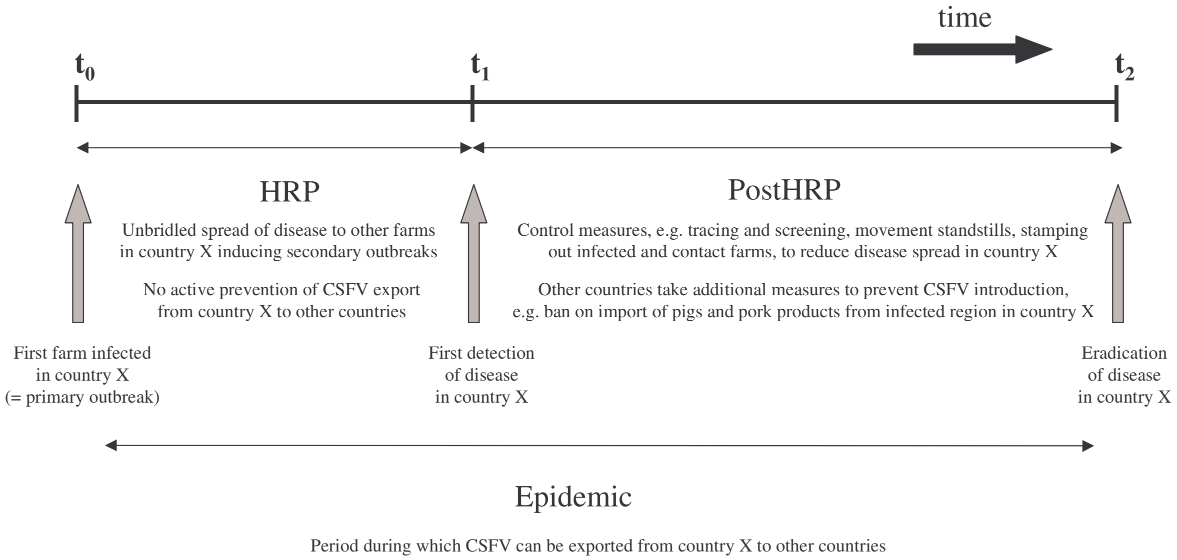

Fig. 3.1. Schematic representation of the course of a CSF epidemic over time.

3.2. DESCRIPTION OF THE MODEL USED TO ANALYSE THE PROBABILITY OF CSFV INTRODUCTION

3.2.1. Modelling approach

The model calculates the P_{CSFV} into the domestic pig population of a country by different pathways[5]. Pathways can either be exogenous or endogenous. Exogenous pathways are linked with virus sources outside the country where they might cause a primary outbreak, whereas endogenous pathways reside within the country affected. Examples of exogenous pathways include legal and illegal imports of pigs, genetic material, and pork products, returning livestock trucks, tourists, and air currents. Examples of endogenous pathways are laboratories working with CSFV and infected wild boar populations (De Vos et al., 2003a). The countries where exogenous pathways may come from are called countries of origin, whereas the country affected is called the target country. The probability of virus introduction by endogenous pathways depends only on the situation in the target country, whereas the probability of virus introduction by exogenous pathways depends on conditions in the country of origin as well as in the target country. Exogenous pathways only constitute a risk when CSFV is present in the country of origin, i.e. during a CSF epidemic.

Most probabilities calculated in the model are very low, as they are calculated per epidemic[6] for each country of origin and separately for each exogenous pathway. Therefore, the scenario pathway approach was used as a modelling technique, and not simulation, because the scenario pathway approach requires relatively little computing time and can easily calculate extremely low probabilities (Vose, 1997). In the scenario pathway approach, the probability of each possible scenario leading to CSFV introduction is explicitly calculated,

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[5] The focus in this article is on CSFV introduction into the domestic pig population of a country. Virus introduction into the wild boar population has not been considered, because prevention and control strategies (CEC, 2001) and economic consequences of such an introduction are different.

[6] An epidemic is defined as one primary outbreak and all secondary outbreaks linked with this primary outbreak. The definition of a primary outbreak was derived from EU Council Directive 82/894/EEC: 'an outbreak not epizootiologically linked with a previous outbreak in the same region of a member state, or the first outbreak in a different region of the same member state' (CEC, 1982).

whereas in simulation the possible outcomes, i.e., is CSFV introduced by a certain pathway-unit[7] or not, are generated as a natural consequence of the random simulation.

In the scenario pathway approach, the sequence of events that would ultimately lead to CSFV introduction into the domestic pig population of the target country is determined, starting with the event of a pathway-unit being infected or contaminated with the virus and ending with the event of an infective viral dose being transmitted to a susceptible pig in the target country. These events are ordered in a scenario tree (Miller et al., 1993; Sutmoller et al., 2000). Only those events that are decisive in terms of whether or not a pathway-unit will transmit virus to susceptible animals are included in the scenario tree (Vose, 1997). Each event in the scenario tree is assigned a probability that it will occur. These are all conditional probabilities, i.e. the probability of occurrence given that all previous events have occurred.

For each pathway in the model, a scenario tree was constructed. To calculate the P_{CSFV} for a certain pathway, all probabilities along its scenario tree were multiplied. The scenario trees for the exogenous pathways were calculated separately for each country of origin. Combining the outcome of all scenario tree calculations gave insight into the relative contribution of countries of origin and pathways to the P_{CSFV} for the target country.

The annual P_{CSFV} into the target country is not a single or constant value, because it depends on the occurrence of CSF in the countries of origin, the contacts (e.g. trade) between these countries and the target country and the presence of infected wild boar populations in the target country, all of which are not constant over time. To take into account the variability of some of these input parameters, probability distributions were used and model calculations were iterated using Latin Hypercube sampling (Vose, 2000), resulting in a range of possible output values for the P_{CSFV} into the target country.

The model was constructed in Microsoft Excel 97 with the add-in programme @Risk 4.5.2. (Palisade Corporation, 2002).

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[7] Unit in which a pathway is measured, e.g., a batch of animals, a metric ton of animal products or a returning livestock truck.

3.2.2. Model contents

3.2.2.1. Countries of origin

All 15 EU member states were included in the model as possible countries of origin. No third countries were included for two reasons: (i) import of live pigs and pork products from third countries was marginal compared to trade within the EU (less than 5% of total imports) and (ii) information available on the occurrence of CSF in third countries was not sufficiently detailed.

3.2.2.2. Target countries

The model is constructed such that calculations can be performed for all EU member states if sufficient information is available (see Section 3.2.3.1). In the current model, the Netherlands was included as a target country because we had the most extensive data for this EU member state.

3.2.2.3. Pathways

A selection was made of all pathways that possibly contribute to the P_{CSFV} for inclusion in the model (De Vos et al., 2003b). Two selection criteria were used: (i) expected importance for CSFV introduction on the basis of historical data and scientific literature and (ii) availability of knowledge and data to quantify the underlying probabilities. The model structure is, however, such that additional pathways can easily be incorporated.

The major routes for CSFV introduction within the EU - since the cessation of preventive mass vaccination - were the feeding of improperly heated swill, direct or indirect contact with wild boar and animal movements (De Vos et al., 2000; Fritzemeier et al., 2000). Therefore, the exogenous pathway import of domestic pigs and the endogenous pathways direct and indirect contact with wild boar were included in the model. Furthermore, the exogenous pathway import of pork products was included, as it is one of the routes that might contribute to CSFV introduction due to (illegal) swill feeding. The exogenous pathway returning livestock trucks was included in the model because data could be derived from the total number of animals exported and experts considered it to be an important risk factor for CSFV introduction into the Netherlands (Horst et al., 1998).

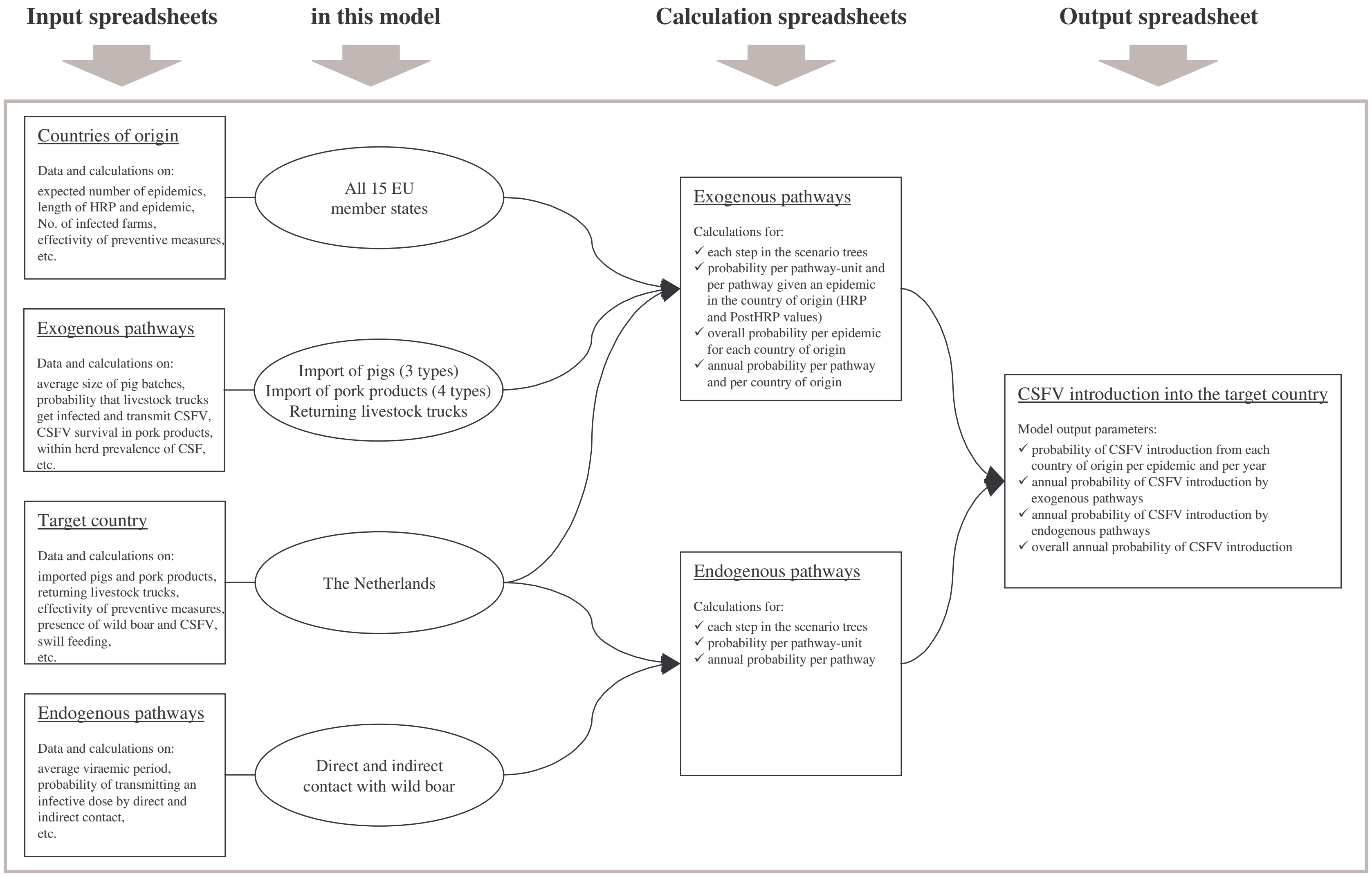

Fig. 3.2. General structure of the spreadsheet model for CSFV introduction.

The pathways were divided into subgroups according to pig or product type in order to perform the model calculations. The imports and exports of pigs were subdivided into three categories, i.e., piglets, breeding pigs and fattening pigs, as it was assumed that the risks of CSFV introduction might differ between these categories. Fattening pigs are transported to slaughterhouses, whereas piglets and breeding pigs become part of the pig population in the target country. Furthermore, it was assumed that more preventive measures would be applied for the import of breeding pigs than for piglets. Additionally, the number of animals per transport is different for each category. The import of pork products was subdivided into four categories, i.e., fresh or chilled, frozen, non-heat-treated, and heat-treated pork products, since the probability that CSFV will survive maturing and processing differs between these categories (Terpstra, 1986; Tersptra, 1991; Farez and Morley, 1997; Edwards, 2000).

3.2.3. Model structure and calculations

In Fig. 3.2 the general structure of the spreadsheet model is given. The model consists of four input spreadsheets, two calculation spreadsheets and one output spreadsheet.

3.2.3.1. Input

The four input spreadsheets contain all data, probability distributions and basic calculations that are required in order to determine the probabilities of the events in the scenario trees. The spreadsheet ‘countries of origin’ contains data and calculations on parameters that have different values for each country of origin. The spreadsheet ‘target country’ contains data and calculations on parameters that are specific for the target country for which the model calculations are performed. The spreadsheet ‘exogenous pathways’ contains data and calculations on parameters that apply to all countries of origin and target countries and are needed for the model calculations concerning exogenous pathways. The spreadsheet ‘endogenous pathways’ contains data and calculations on parameters that apply to all target countries and are needed for the model calculations concerning endogenous pathways. To give an example of these input spreadsheets, the input parameters, probability distributions, and calculations in the spreadsheet 'countries of origin' are presented in the Appendix[8].

3.2.3.2. *Calculations*

In the two calculation spreadsheets the probabilities of the events in the scenario trees are computed, after which the P_{CSFV} by each pathway and from each country of origin can be calculated for the target country (see Fig. 3.2).

3.2.3.2.1. *Exogenous pathways*

The P_{CSFV} by exogenous pathways is calculated in four steps. In the first step (step 1), the probability that a single pathway-unit will cause CSFV introduction into the target country is calculated, given a CSF epidemic in the country of origin. The scenario trees described in Section 3.2.1 are used in this step. The starting point in the scenario trees is that CSFV is present in the country of origin. The three main events that can be distinguished in all scenario trees are:

- is the pathway-unit infected or contaminated with CSFV?
- if so, is the infection or contamination detected or eliminated by preventive measures?
- if not, does the infected or contaminated pathway-unit come into contact with susceptible pigs in the target country and transmit an infective viral dose?

As an example, the scenario tree for the pathway import of piglets is given in Fig. 3.3. The first event in this scenario tree is whether or not the batch of piglets transported from the country of origin to the target country contains any infected piglets. This probability was set as being equal to the cumulative incidence (CI) of the disease at herd level in the country of origin during the epidemic. The second event is whether or not the infected piglets will be detected by preventive measures taken in the country of origin, such as the clinical inspection of pigs before issuing a health certificate. This probability was set as being equal to the sensitivity of overall detection (SE_{co}). The third event is whether or not the infected animals will be detected by preventive measures taken in the target country. This probability was also

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[8] The descriptions of the other input sheets and the calculation sheets are available on request.

set as being equal to the sensitivity of overall detection (SE_{tc}), which was assumed to be zero during the HRP of epidemics in the countries of origin. This is because for intra-EU trade no veterinary controls are carried out at the borders following the establishment of the free internal market in 1993 (Anonymous, 1993). The sensitivities of overall detection depend on the kind of preventive measures taken and the quality of veterinary services. Their values can be changed in order to calculate the effect of more or different preventive measures aimed at the detection of CSFV. In this scenario tree, no event was included for contact with susceptible pigs in the target country and transmission of an infective viral dose. This is because it was assumed that the import of an infected piglet would always lead to a primary outbreak if the infection is not detected on time and the piglet is brought onto a farm in the target country. The probability that a batch of piglets causes CSFV introduction if it comes from a country where CSFV is present is hence calculated by:

$$P_{\{batch\_piglets\}} = CI \times (1 - SE_{co}) \times (1 - SE_{tc}) \tag{1}$$

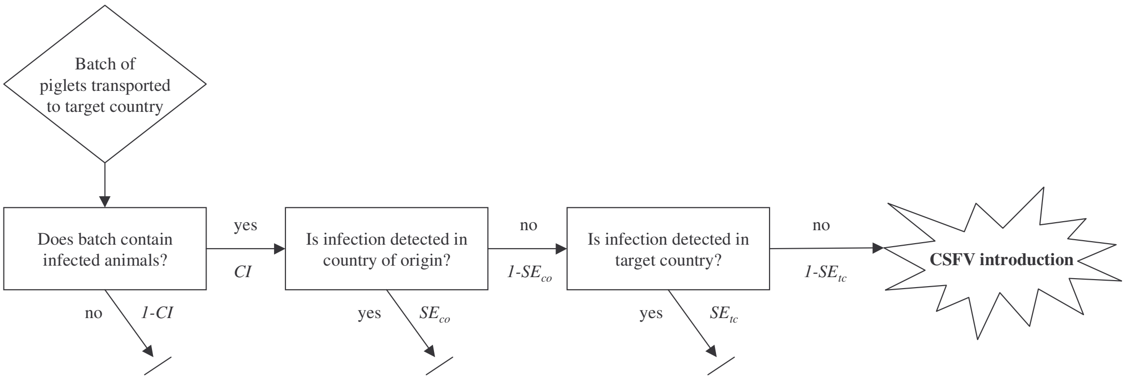

Fig. 3.3. Scenario tree for the exogenous pathway import of piglets.

The probabilities used in the scenario tree are different for the HRP and the remainder of the epidemic (PostHRP) as control measures will be put in place in the country of origin as soon as CSFV infected pigs are detected. The target country will then also take additional measures in order to prevent CSFV introduction from this country of origin (see Fig. 3.1). Therefore $P_{\{batch\_piglets\}}$ has different values for the HRP and PostHRP.

In the second step (step 2), the probability that CSFV is introduced by a particular pathway is calculated using a binomial distribution (Vose, 2000):

$$P_{\{pathway\}} = 1 - \left(1 - P_{\{pathway-unit\}}\right)^{n} \tag{2}$$

with $P_{\{pathway\text{-}unit\}}$ is the P_{CSFV} per pathway-unit and n = number of pathway-units going from the country of origin to the target country during the period that CSFV is present. This number will also differ for the HRP and PostHRP. Therefore calculation (2) is performed separately for the HRP and PostHRP. At the end of step 2 the probabilities for the HRP and PostHRP are added as shown:

$$P_{\{pathway\_epidemic\}} = 1 - \left(1 - P_{\{pathway\_HRP\}}\right) \times \left(1 - P_{\{pathway\_PostHRP\}}\right) \tag{3}$$

Steps 1 and 2 are performed for all exogenous pathways in the model. Then, in the third step (step 3), the probability of CSFV being introduced into the target country during an epidemic in the country of origin is calculated by adding together the probabilities of all n exogenous pathways:

$$P_{\{epidemic\}} = 1 - \prod_{i=1}^{n} \left(1 - P_{\{pathway\_epidemic\}i}\right) \tag{4}$$

In the fourth step (step 4), the probability obtained in step 3 is used in a binomial distribution (Vose, 2000) to calculate the annual P_{CSFV} into the target country from a particular country of origin:

$$P_{\{year\}} = 1 - \left(1 - P_{\{epidemic\}}\right)^{N} \tag{5}$$

with N = simulated number of CSF epidemics for one year in this country of origin.

This whole procedure is repeated for all countries of origin (i.e. all EU member states except the target country) in the model. Hence, in total 224 scenario tree calculations are performed for the exogenous pathways (8 pathways * 2 epidemic phases * 14 countries of origin) and combined.

3.2.3.2.2. Endogenous pathways

For the two endogenous pathways, i.e. direct and indirect contact with wild boar, the P_{CSFV} is calculated in two steps. In the first step, the probability that an individual wild boar will cause CSFV introduction into the domestic pig population of the target country is calculated using a scenario tree. The three main events in this scenario tree are:

- is an individual wild boar infected with CSFV?
- if so, does this wild boar come into contact with susceptible domestic pigs?
- if so, is an infective viral dose transmitted to those pigs?

As an example, the scenario tree for the pathway direct contact with wild boar is given in Fig. 3.4. The probability of infection (*INF*) was estimated using results from serological surveys (see e.g. Elbers and Dekkers, 2000). The probability of direct contact with susceptible pigs (CSA_{direct}) was estimated using information on the geographical distribution of wild boar and domestic pig production, whether wild boar are restricted in their movements by, for example, fences, and the proportion of pig farms with outdoor facilities. The probability of transmitting an infective dose if direct contact occurs (ID_{direct}) was assumed to be rather high and therefore set at 0.9. The annual P_{CSFV} by direct contact with a single wild boar is hence calculated as shown:

$$P_{\{boar\}} = INF \times CSA_{direct} \times ID_{direct} \tag{6}$$

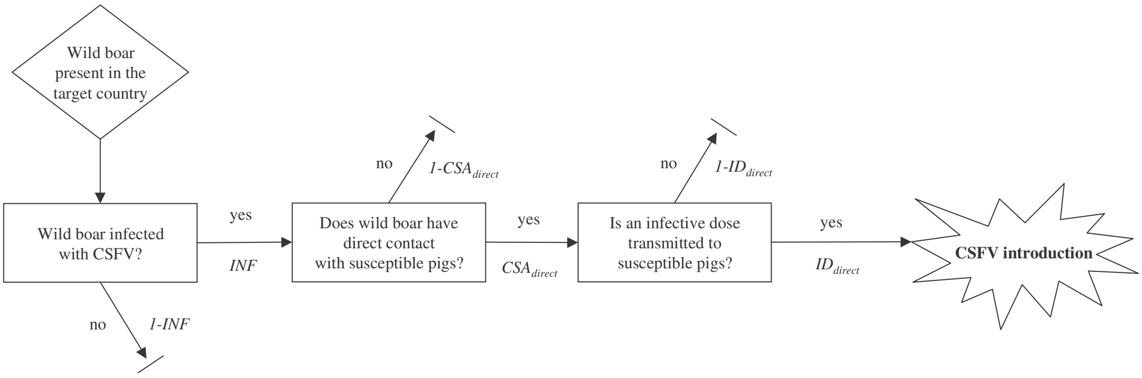

Fig. 3.4. Scenario tree for the endogenous pathway direct contact with wild boar.

In the second step, the annual probability of CSFV being introduced for each of the endogenous pathways is calculated using a binomial distribution (Vose, 2000):

$$P_{\{pathway\}} = 1 - \left(1 - P_{\{boar\}}\right)^{n} \tag{7}$$

with $P_{\{boar\}}$ is the P_{CSFV} by either direct or indirect contact per individual wild boar per year and n = total number of wild boar in the target country.

3.2.3.3. Output

In the output spreadsheet, figures and graphical representations are given of:

1. the P_{CSFV} into the target country from each country of origin per epidemic and per year, and the relative contribution of exogenous pathways, the HRP, and PostHRP to these probabilities;
2. the annual P_{CSFV} into the target country by exogenous pathways and the relative contribution of exogenous pathways and countries of origin to this probability;
3. the annual P_{CSFV} into the target country by endogenous pathways and the relative contribution of endogenous pathways to this probability;
4. the overall annual P_{CSFV} into the target country.

The latter is obtained by adding the annual P_{CSFV} by exogenous pathways to the annual P_{CSFV} by endogenous pathways:

$$P_{\{year\_overall\}} = 1 - \left(1 - P_{\{year\_exogenous\_pathways\}}\right) \times \left(1 - P_{\{year\_endogenous\_pathways\}}\right) \tag{8}$$

3.2.4. What-if analysis

To explore the impact of changes in the target country, in the countries of origin, or in the contacts between the countries of origin and the target country on model output, the values of input parameters can be changed. Theoretically, thousands of what-if scenarios can be constructed, as input parameters in the model can be changed for each pathway and each country of origin separately. This what-if analysis was used as a tool to verify the model by checking whether the direction and magnitude of change in model outcome was reasonable (Law and Kelton, 1991).

3.3. MODEL RESULTS

The model was run with The Netherlands as the target country. Trade statistics from 1999 were used. The number of iterations required was determined by the auto-stop simulation convergence option in @Risk (Palisade Corporation, 2002). The simulation was terminated when the distribution statistics (i.e. mean, standard deviation and percentiles [in 5% increments]) of all output variables changed by less than 1%. A total of 6 900 iterations were needed in order to stabilise all output distributions. The output variables selected were (i) the P_{CSFV} from each country of origin per epidemic (both HRP and PostHRP) and per year, (ii) the annual P_{CSFV} by exogenous pathways and the relative contribution of each exogenous pathway to this probability, (iii) the annual P_{CSFV} by endogenous pathways, and (iv) the overall annual P_{CSFV}.

3.3.1. Default output for the Netherlands

3.3.1.1. Overall annual probability of CSFV introduction

In Fig. 3.5 the cumulative distribution function (cdf) for the overall annual P_{CSFV} into the Netherlands by the pathways included in the model is shown. This cdf represents uncertainty about the overall annual P_{CSFV} into the Netherlands due to yearly changes in the occurrence and course of CSF epidemics in the countries of origin. In years with few and small CSF epidemics in the countries of origin, the probability is at its minimum level and in years with many and large CSF epidemics in the countries of origin, the probability is at its maximum level. The median value for the overall annual P_{CSFV} is 0.0376, indicating that for 50% of the years the overall annual P_{CSFV} will be lower than this value. The 0.95 percentile is 0.174, indicating that – if the current situation remained the same – then the overall annual P_{CSFV} would only exceed 17.4% for five years in every century. The mean value for the overall annual P_{CSFV} is 0.0560, indicating that the Netherlands can expect CSFV introduction on average once every 18 years from the pathways and countries of origin included in the model.

The mean, median, 0.05 and 0.95 percentile values of the overall annual P_{CSFV} were used as the expected value (i.e. λ) in a Poisson distribution. The probabilities of 0, 1, 2, and 3 or more CSFV introductions per year for each output value are given in Table 3.1. Using the mean value, CSFV will not be introduced into the Netherlands in 94.56% of the years concerned. CSFV will, however, be introduced once in 5.29% of the years in question and twice in 0.15% of the years involved.

In the default model calculations, the overall annual P_{CSFV} is equal to the annual P_{CSFV} by exogenous pathways. The annual P_{CSFV} by the endogenous pathways direct and indirect contact with wild boar is zero, as no CSF infections have occurred in Dutch wild boar populations in recent years (Elbers and Dekkers, 2000).

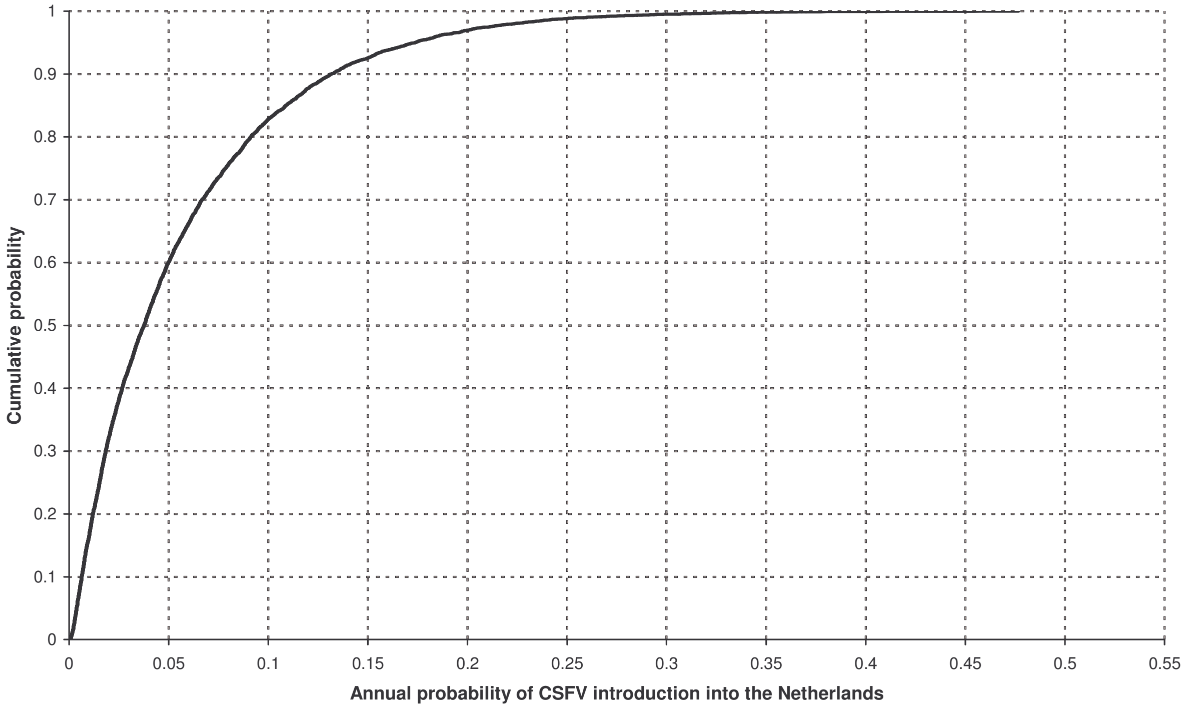

Fig. 3.5. Cumulative probability distribution for the annual probability of CSFV introduction into the Netherlands by 10 studied pathways.

Table 3.1

Probability of 0, 1, 2, and 3 or more CSFV introductions into the Netherlands per year when using different model outputs for the overall annual probability of CSFV introduction

	Output used			
CSFV introductions per year	Mean (%)	0.05 percentile	Median (%)	0.95 percentile
0	94.56	99.63	96.31	84.05
1	5.29	0.37	3.62	14.60
2	0.15	0.00	0.07	1.27
3 or more	0.00	0.00	0.00	0.08

3.3.1.2. More detailed results for exogenous pathways

The countries of origin and the exogenous pathways included in the model determine the annual P_{CSFV} by exogenous pathways. Fig. 3.6 gives insight into the main countries of origin contributing to this probability for the Netherlands. Both the average probability per epidemic and the average probability per year are shown. For some countries of origin, i.e. Greece, Portugal, Austria, Finland, and Sweden, the probability that they cause CSFV introduction into the Netherlands is very small (probability per epidemic $< 1.4*10^{-5}$) and could not therefore be displayed in the figure. Germany, Belgium, and the United Kingdom are the countries of origin that contribute most to the annual P_{CSFV} into the Netherlands. The P_{CSFV} into the Netherlands during a single epidemic in Germany is much lower than the annual probability, which is explained by the high number of expected epidemics per year in Germany (see the Appendix). The annual P_{CSFV} from Belgium and the United Kingdom is smaller than that from Germany. During an epidemic in these countries, however, the probability is three to four times the annual level. This means that although the annual P_{CSFV} from Germany is higher, the Netherlands should pay more attention to the prevention of CSFV introduction from Belgium and the United Kingdom as soon as CSFV is present in one of these countries of origin. For Germany, preventive measures should be in place continuously in order to prevent CSFV introduction from this country of origin.

Fig. 3.7 presents an overview of the relative contribution of exogenous pathways to the annual P_{CSFV} into the Netherlands. On average, returning livestock trucks contribute most to the P_{CSFV} with 64.8%. Import of breeding pigs contributes next with 17.6%. The high contribution of returning livestock trucks to the annual P_{CSFV} is mainly due to the large number of pathway-units present: the Netherlands is a major exporter of pigs ($5.14*10^6$ pigs exported versus $5.40*10^5$ pigs imported in 1999). The majority of imported pigs consist of fattening pigs (89% in 1999). Nevertheless, they contribute less to the annual P_{CSFV} than breeding pigs. This is explained by (i) the P_{CSFV} per pathway-unit, in general being highest for pigs imported for life (piglets and breeding pigs) and (ii) batch size, in general being quite small for imported breeding pigs (on average 28 pigs/batch in 1999). Hence, although the number of breeding pigs imported is only 5% of total pig imports, they account for 23% of the total number of batches imported. Import of pork products only contributes marginally to the P_{CSFV} into the Netherlands and this can for 95% be attributed to fresh/chilled and frozen pork products. 73% of the total amount of pork products imported by the Netherlands in 1999 consisted of fresh/chilled and frozen pork products. Furthermore, the probability of CSFV survival is much higher for these product types (Farez and Morley, 1997; Edwards, 2000).

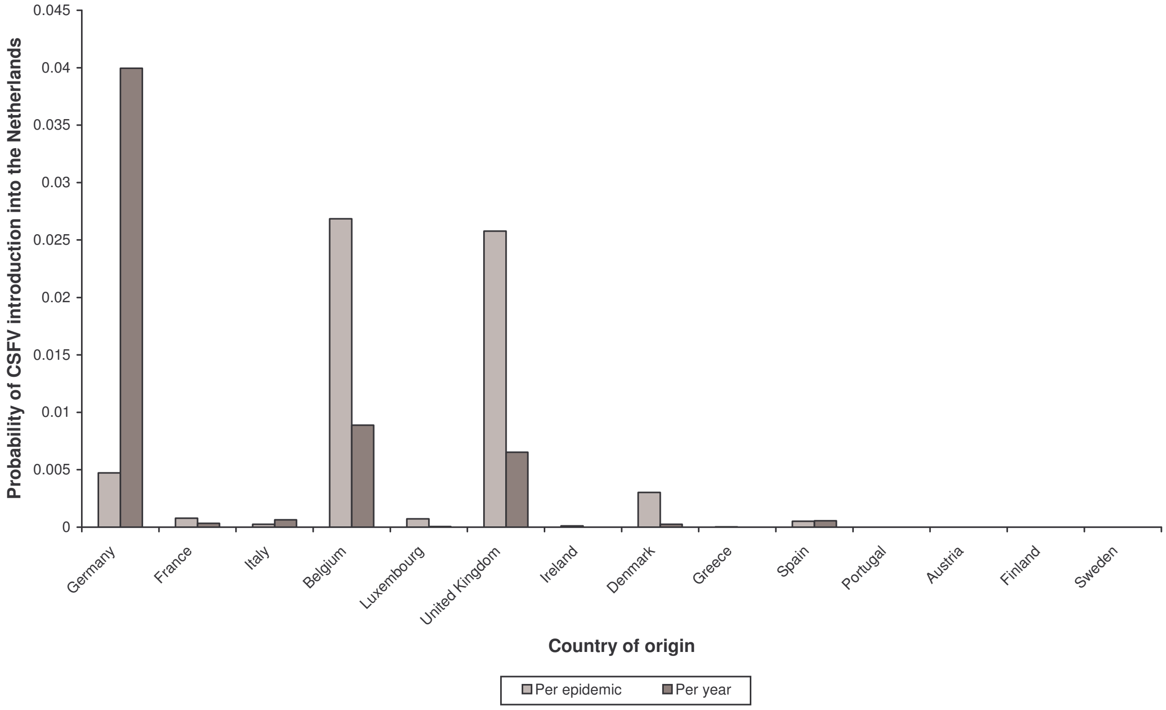

Fig. 3.6. Probability of CSFV introduction into the Netherlands per epidemic and per year from each country of origin in the model (all EU member states) by 8 studied exogenous pathways.

3.3.2. Results of the what-if analysis

What-if analysis was performed to verify the model calculations on CSFV introduction. The outcome of some what-if scenarios is presented in a tornado chart (Fig. 3.8), showing the relative change of the mean overall annual P_{CSFV} into the Netherlands compared to the default output value. A seroprevalence higher than zero for CSFV in wild boar in the Netherlands and a longer HRP in all countries of origin led to an increase of the annual probability, whereas this probability was decreased by the other scenarios explored. A 10% seroprevalence for CSFV in the Dutch wild boar population and a shorter or longer HRP length in the countries of origin changed the annual P_{CSFV} into the Netherlands by more than 40%. The impact of the hypothetical scenario that no swill is fed at all – not illegally either[9] - was only marginal. Reducing the import of pigs by 50% decreased the annual P_{CSFV} by less than 10%, whereas

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[9] Feeding swill to pigs is prohibited in the EU (CEC, 2001).

reducing the export of pigs by 50%, i.e. 50% less returning livestock trucks, decreased the annual P_{CSFV} by more than 30%.

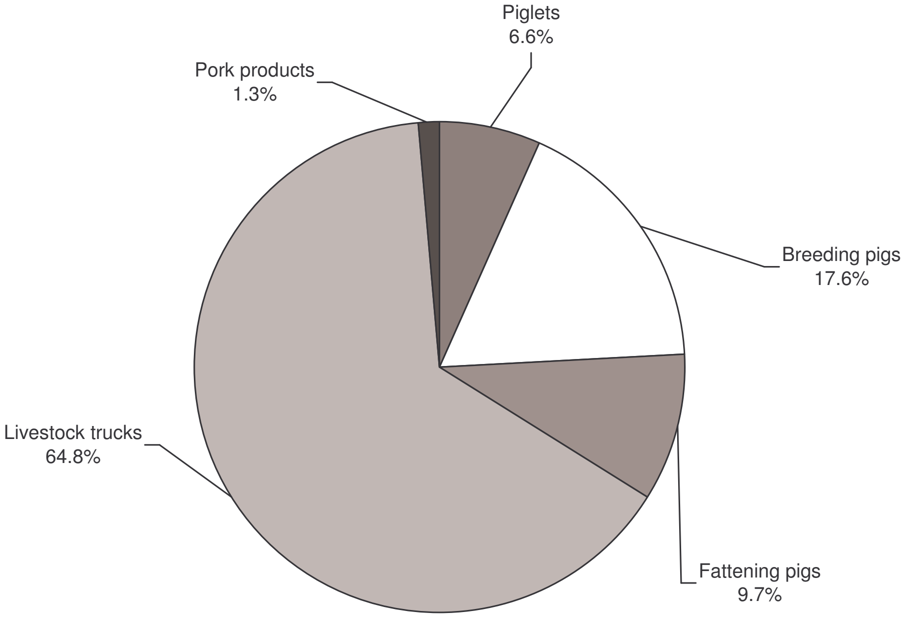

Fig. 3.7. Relative contribution of the exogenous pathways in the model to the overall annual probability of CSFV introduction into the Netherlands.

3.4. DISCUSSION

The spreadsheet model described in this paper was developed in order to obtain more quantitative insight into the main factors determining the P_{CSFV} into a country. As such, it shows which countries of origin and which pathways contribute most to the overall annual P_{CSFV}. This information can help policy makers in setting priorities for strategic preventive measures. Furthermore, the probability of CSFV being introduced into the target country during a single epidemic in each country of origin has been calculated, indicating in which circumstances additional tactical preventive measures are required. The model can estimate the impact of both strategic and tactical preventive measures as well by changing relevant input parameters. The target country selected for the current model calculations was the Netherlands. Calculations can, however, easily be performed for other member states of the EU. Only the values of the input parameters in the input spreadsheet 'target country' should be changed for this purpose.

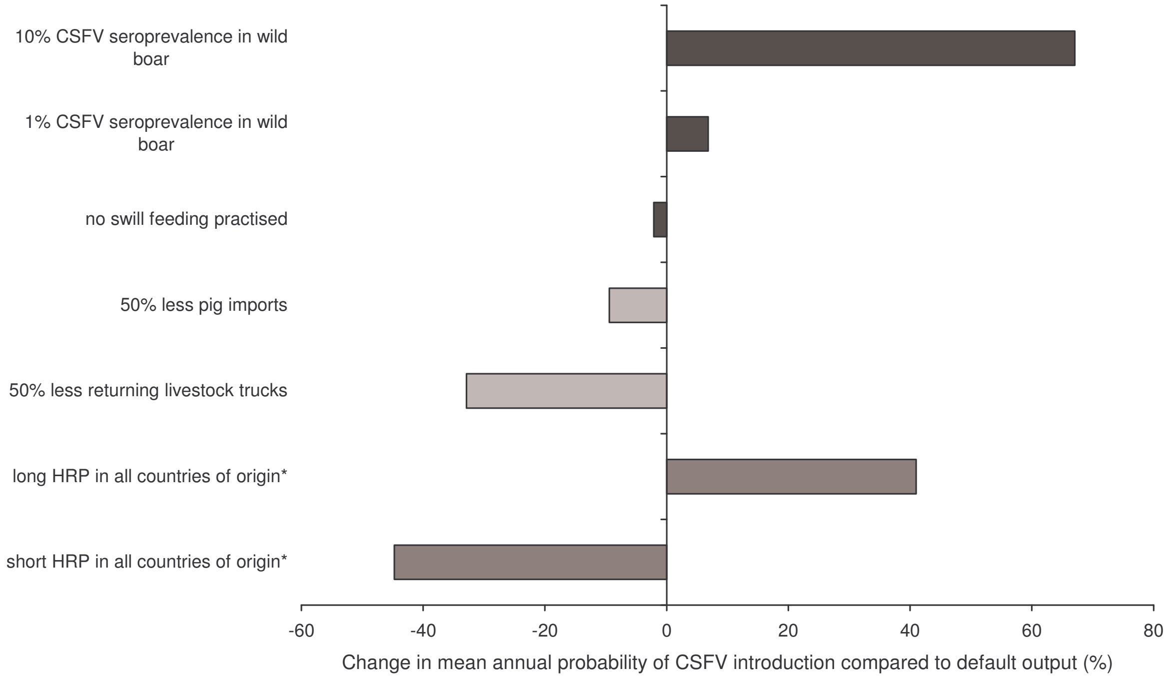

Fig. 3.8. The relative change (in percentages) of the mean overall annual probability of CSFV introduction into the Netherlands compared to the default output value for different what-if scenarios.

■ changes in target country
□ changes in contacts between target country and countries of origin
▨ changes in countries of origin
* Default HRP length is defined by a RiskPert(19, 40, 70) (see the Appendix); the short HRP length is defined by a RiskPert(9, 19, 30); the long HRP length is defined by a RiskPert(40, 63, 92)

3.4.1. Modelling approach

The scenario pathway approach was used to calculate the annual P_{CSFV}. It was assumed that, as long as this probability is small (say $p \leq 0.2$), it could be used as the expected value (i.e. λ) in a Poisson distribution in order to estimate the expected number of CSFV introductions per year (see Table 3.1). A simulation model would have led directly to this result. Simulation, however, would have required many iterations to get only a few ‘hits’, i.e. virus introductions, because the probabilities calculated by the model are very small. The scenario pathway approach, on the other hand, made it possible to perform model calculations rather quickly (Vose, 1997) (6 900 iterations in less than five minutes).

A general property of the scenario pathway approach is that the more events in a scenario tree, the smaller the calculated probability of occurrence of the adverse event, since the probabilities assigned to the events in the tree are all ≤ 1. Therefore only those events that are decisive in whether a pathway-unit will transmit CSFV to susceptible pigs in the target country were included in the scenario trees. The number of events in the scenario trees for the exogenous pathways differed. It was least for the import of piglets and breeding pigs and most for returning livestock trucks. This resembles reality: CSFV introduction by pigs imported for life only requires a few steps (see Fig. 3.3), whereas CSFV introduction by returning livestock trucks is a more indirect transmission route, requiring that the livestock truck visited an infected farm in the country of origin and got contaminated, that the virus was not removed by cleansing and disinfecting either in the country of origin, or in the target country, that the virus survived the journey from the country of origin to the target country, that the livestock truck came into contact with susceptible pigs in the target country and that an infective viral dose was then transmitted. Despite this, the pathway returning livestock trucks contributed most to the annual P_{CSFV} into the Netherlands due to the high number of pathway-units present.

Using the scenario pathway approach implied that the complex reality of CSFV introduction was reduced to a set of scenario tree calculations. Model limitations should be kept in mind when interpreting its output. Each iteration of the model resembles one year. In every iteration one value is sampled for the length of the HRP, the length of the epidemic, and the number of infected farms in each country of origin. Hence, when the simulated number of epidemics for a country of origin exceeds one, all epidemics are described by the same characteristics. For most countries of origin in the model, i.e. for most EU member states, the expected number of CSF epidemics per year is less than one (see the Appendix). For Germany, Italy and Spain, however, the average number of epidemics per year over the last twelve years exceeds one. This might lead to an overestimation of the annual probability if the total epidemic period (which also depends on the length of the epidemics) exceeds one year. The contribution of Italy and Spain to the annual P_{CSFV} into the Netherlands was rather small, but the German contribution was quite large, mainly due to the high average number of epidemics per year (see Fig. 3.5). Another limitation is that the model treats each country of origin as a homogenous entity, without taking spatial variability into account. Hence, the calculations assume that CSF epidemics are evenly distributed over a country of origin and that exogenous pathways originate from all over the country. In reality, however, it might be that epidemics occur mainly in those parts of a country of origin where most pathway-units are exported from to the target country. The model then underestimates the annual probability that CSFV is exported from this country of origin to the target country. The annual probability will, however, be overestimated when epidemics occur mainly in areas different to those from where most exogenous pathways are exported.

Only limited data was available in order to quantify all input parameters. Furthermore, data obtained from CSF epidemics in the past, experiments or simulations might already be outdated due to rapid changes in, for example, trade patterns, preventive measures, and control strategies applied. Hence, the model contains many uncertain input parameters. Other parameters, such as length of HRP and epidemic, and number of infected farms, are variable. The latter were represented by probability distributions. For uncertain input parameters, however, point estimates were used to avoid mixing uncertainty and variability. Such mixing would make it impossible to see how much of the total uncertainty about output parameters comes from variability and how much comes from uncertainty. This separation is useful because uncertainty represents lack of knowledge of parameter values that may be reduced by further measurement or study, whereas variability is the effect of chance and a function of the system, which can only be reduced by changing the physical system (Ferson and Ginzburg, 1996; Anderson and Hattis, 1999; Nauta, 2000; Vose, 2000). Consequently, the cdf in Fig. 3.5 represents uncertainty due to variability only. It was not feasible to use the method of second order risk modelling as described by Vose (2000), among others, due to the large number of uncertain input parameters. Furthermore, each uncertain parameter should then have been replaced by a probability distribution whose (uncertain!) form and parameters also had to be specified (Ferson and Ginzburg, 1996). The next step will be to perform an extensive sensitivity analysis to investigate the impact of uncertain input parameters on model output (see e.g. Kleijnen, 1999). Such an analysis will also indicate priorities for further empirical research in the epidemiological field of CSF.

3.4.2. Results

The ultimate aim of the model was not to give exact estimates of the P_{CSFV}, but to gain more insight into which pathways and countries of origin contribute most to this probability. Model results as presented in Fig. 3.6 and 3.7 gave clear insight into this matter for the Netherlands. If necessary, model results can be analysed in even more detail to reveal the major causing pathways from a specific country of origin.

The annual P_{CSFV} into the Netherlands calculated by the model is quite low when compared with expert estimates (Horst et al., 1998; Meuwissen et al., 2000) and recent history (see the Appendix: the Netherlands experienced one or more primary CSF outbreaks in 1990, 1992 and 1997 [Elbers et al., 1999; De Vos et al., 2000]). The model most probably underestimates the overall annual P_{CSFV} as not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries (see Section 3.2.2). Absolute values of model outcome should therefore not be considered as true values for the P_{CSFV}.

Only exogenous pathways contributed to the annual P_{CSFV}, as no CSF infections have occurred in Dutch wild boar populations in the recent past (Elbers and Dekkers, 2000). This is, however, not a guarantee that Dutch wild boar populations will remain free of CSFV in future. Contacts between Dutch and German wild boar populations cannot be excluded in the southern part of the Netherlands, while CSFV is endemic in parts of the German wild boar population (Laddomada, 2000; Elbers and Dekkers, 2000). The huge increase in the annual P_{CSFV} when assuming a 10% seroprevalence for CSFV in the Dutch wild boar population (see Fig. 3.8) indicates that it is worth the effort to ensure that the wild boar population remains free of CSFV.

In general, the P_{CSFV} into the Netherlands was highest during the HRP of epidemics in the countries of origin. To give some examples, the mean P_{CSFV} into the Netherlands during an epidemic in Germany can for 88% be attributed to the HRP. For Belgium this is 93% and for the United Kingdom as high as 97%. It is, however, impossible for the target country to take additional preventive measures during the HRP of epidemics in the countries of origin because the presence of CSFV has not yet been detected in this phase of an epidemic, i.e., nobody knows it is there (see Fig. 3.1). Reducing the length of the HRP in the countries of origin is thus an important tool in terms of diminishing the P_{CSFV}. The what-if analysis showed that a short HRP in the countries of origin indeed led to a considerable reduction of the P_{CSFV} into the Netherlands (see Fig. 3.8). Early detection of CSF infections is thus important, even more so as a short HRP will in most cases go with a shorter total length of the epidemic and fewer infected farms, hence decreasing the total economic losses for the country experiencing the epidemic.

Model behaviour was verified by the what-if analysis. Outcome of the different scenarios resulted in a reasonable change of the mean annual P_{CSFV} with the beforehand expected sign. Therefore model structure and calculations were considered adequate. A comparison between model output and data from the real system in order to validate the model was impossible. Only few CSFV introductions occurred in recent years in the Netherlands and since such introductions are largely determined by chance (Poisson process), the number of observations is far too few to determine the annual P_{CSFV} or to draw conclusions on the main causing factors (pathways and countries of origin). Face validation of model output was considered impossible either, because of the small probabilities calculated. The annual P_{CSFV} into the Netherlands calculated by the model varied between $2.5*10^{-4}$ and $4.8*10^{-1}$. Changes in such small numbers are difficult to interpret, especially for people not familiar with quantitative risk analysis. It was thus concluded that the model performed as intended, but that one should not concentrate too much on the absolute probabilities obtained.

3.5. CONCLUSIONS

The scenario pathway approach proved to be a useful tool to structure and analyse information and data in relation to CSFV introduction. Furthermore, calculations could be performed quickly. In addition, although the calculated probabilities were rather low when compared with expert estimates and recent history, the most likely causes of CSFV introduction indicated by the model were considered to be realistic. The model can thus be used as a tool for decision-makers when setting priorities for the prevention of CSFV introduction.

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APPENDIX

Input spreadsheet: countries of origin

Country-of-origin-specific input parameters

Country of origin	Expected No. of epidemics per year[a]	Total No. of pig holdings[b] (*1000)	Surface area of country of origin[c] (*1000 km^2)
	C_01[d]	C_02[d]	C_03[d]
Germany	8.83	205	357
France	0.42	78	544
Italy	2.67	250	301
The Netherlands	0.5	21	41
Belgium	0.33	12	31
Luxembourg	0.08	1	3
United Kingdom	0.25	14	242
Ireland	0.08	2	69
Denmark	0.08	19	43
Greece	0.08	21	132
Spain	1.08	285	505
Portugal	0.08	130	92
Austria	0.17	100	84
Finland	0.08	6	338
Sweden	0.08	8	411

[a] Source: Animal Disease Notification System (ADNS) of the European Union.

[b] Source: EU (2002).

[c] Source: Eurostat (2000).

[d] Code used in calculations.

General input parameters[a] with different values for the HRP[b] and PostHRP[b] of an epidemic

Code	Parameter	HRP value	PostHRP value
C_04	Piglets: sensitivity of overall detection in the country of origin	0.7	0.8
C_05	Breeding pigs: sensitivity of overall detection in the country of origin	0.7	0.8
C_06	Fattening pigs: sensitivity of overall detection in the country of origin	0.5	0.7
C_07	Effectiveness of cleansing and disinfecting returning livestock trucks before leaving the country of origin[c]	0.25	0.6

[a] These input parameters could be made country-of-origin-specific if sufficient data is available.

[b] HRP: high-risk period, i.e., the period from first infection with virus until first detection of disease; PostHRP: period from first detection of disease until eradication of disease.

[c] Values based on Nijskens (1995).

General probability distributions[a] for input parameters[b]

Code	Parameter	Formula[f]
C_08	Length of HRP (days)[c]	RiskPert(19, 40, 70)
C_09	Length of epidemic (days)[d]	RiskPert(24, 88, 365)
C_10	No. of infected farms at end of HRP [d]	RiskPert(1, 7, 55)
C_11	No. of farms infected during epidemic [d]	RiskPert(1, 9, 218)
C_12	Percentage of farms infected outside installed control zones	RiskPert(0, 0.05, 0.5)
C_13	Radius of installed control zones (km)[e]	RiskDiscrete({RiskBetaSubj(10, 20, 25, C_16), C_16}, {0.95, 0.05})
C_14	No. of epidemics in one year	RiskPoisson(C_01)

[a] Probability distributions used to model variability (i.e. inherent randomness of the system) (Vose, 2000).

[b] These input parameters could be made country-of-origin-specific if sufficient data is available.

[c] Values based on among others Tambeur (1993) and Elbers et al. (1999).

[d] Values based on InterCSF simulations performed by Mangen et al. (2002).

[e] The minimum radius of installed control zones was set at 10 km, as this is the minimum radius of protection and surveillance zones according to EU legislation (CEC, 2001).

[f] A brief description of the @Risk distribution functions used is given in the table below. For further details see Vose (2000) and Palisade Corporation (2002).

Distribution function in @Risk	Returns
RiskPert(*minimum, most likely, maximum*)	Pert distribution (as special form of the beta distribution) with a minimum, most likely and maximum value as specified
RiskDiscrete(*{X1,X2,…,Xn}, {p1,p2,…,pn}*)	Discrete distribution with *n* possible outcomes with the value *X* and probability weight *p* for each outcome
RiskBetaSubj(*minimum, most likely, mean, maximum*)	Beta distribution with a minimum and maximum value as specified; the shape parameters are calculated from the defined most likely value and mean
RiskPoisson(*lambda*)	Poisson distribution with the specified lambda value

Parameters calculated for each country of origin

Code	Parameter	Formula
C_15	No. of farms infected outside installed control zones	(C_11 – C_10) * C_12
C_16	Maximum radius of installed control zones (km)	SQRT(C_03 / π)
C_17	Surface area of installed control zones	$C\_13^2 * \pi$
C_18	Herd density (pig herds/km^2)	C_02 / C_03
C_19	No. of farms in installed control zones	C_17 * C_18
C_20	Cumulative incidence of disease during HRP	C_10 / C_02
C_21	Cumulative incidence of disease during PostHRP outside installed control zones	IF(C_02 – C_19) > 0, C_15 / (C_02 – C_19), 0)
C_22	Proportion of pigs slaughtered during HRP	C_08 / 365
C_23	Proportion of pigs slaughtered during PostHRP	(C_09 – C_08) / 365

Correlation

The RiskCorrmat function (Palisade Corporation, 2002) was used to correlate the Length of HRP, Length of epidemic, No. of infected farms at end of HRP, and No. of infected farms during epidemic for each country of origin. The correlation matrix used is presented in the table below. Furthermore, a check was included to make sure that Length of epidemic ≥ Length of HRP and No. of infected farms during epidemic ≥ No. of infected farms at end of HRP for each country of origin.

A negative correlation of –1 was incorporated for the parameters Radius of installed control zones and Percentage of farms infected outside installed control zones using the RiskIndepC and RiskDepC functions (Palisade Corporation, 2002).

Correlation matrix[a]

	Length of HRP	Length of epidemic	No. of infected farms at end of HRP	No. of infected farms during epidemic
Length of HRP	1			
Length of epidemic	0.3	1		
No. of infected farms at end of HRP	0.2	0.7	1	
No. of infected farms during epidemic	0.1	0.8	0.9	1

[a] Values based on InterCSF simulations of Dutch CSF epidemics performed by Mangen et al. (2002).

NB: The Round function was used to obtain whole numbers when required, e.g. for the length of HRP and epidemic, the No. of infected farms, etc.

Chapter 4

Sensitivity analysis to evaluate the impact of uncertain factors in a scenario tree model for classical swine fever introduction

Paper by De Vos, C.J., Saatkamp, H.W., Nielen, M., Huirne, R.B.M. Submitted to European Journal of Operational Research.

Abstract

Introduction of classical swine fever virus (CSFV) is a continuing threat to the pig production sector in the European Union. A scenario tree model was developed to obtain more insight into the main risk factors determining the probability of CSFV introduction (P_{CSFV}). As this model contains many uncertain input parameters, sensitivity analysis was used to indicate which of these parameters influence model results most. Group screening combined with the statistical techniques of Design of Experiments and metamodelling was applied to detect the most important uncertain input parameters among a total of 257. The response variable chosen was the annual P_{CSFV} into the Netherlands. Only 128 scenario calculations were needed to specify the final metamodel. A consecutive one-at-a-time sensitivity analysis was performed with the main effects of this metamodel to explore their impact on the ranking of risk factors contributing most to the annual P_{CSFV} . The results indicated that model outcome is most sensitive to the uncertain input parameters concerning the expected number of classical swine fever epidemics in Germany, Belgium, and the United Kingdom and the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km.

Keywords: Classical swine fever; Probability analysis; Robustness and sensitivity analysis; Scenario tree model; Uncertainty modelling

4.1. INTRODUCTION

Classical swine fever (CSF) is a highly contagious viral disease that affects both domestic pigs and wild boar (Moennig, 2000). CSF epidemics can be very costly, both for the agricultural and the public sector (see e.g. Meuwissen et al., 1999). Total losses depend on the length and size of the epidemic, the control strategy applied, and trade restrictions with regard to the export of pigs and pork products (see e.g. Nielen et al., 1999; Mangen et al., 2001; Mangen et al., 2002). Since the early 1990s, CSF control in the European Union (EU) is based on a strategy of non-vaccination and eradication of infected herds (CEC, 2001). As a consequence of this policy, the whole EU domestic pig population has become fully susceptible to CSF virus (CSFV). This, combined with the existence of areas with dense pig populations, has occasionally led to large epidemics incurring high economic losses (Vanthemsche, 1996; Elbers et al., 1999; Moennig, 2000; Edwards et al., 2000). Introduction of CSFV remains a continuing threat to the EU member states, as sporadic outbreaks in the domestic pig population still occur. In addition, CSF occurs in an endemic form in wild boar populations in some areas of Germany, France, and Italy (Laddomada, 2000) representing a permanent CSFV reservoir. In recent years infected wild boar were also found in Austria, Belgium, and Luxembourg (OIE, 2003).

Many factors contribute to the probability of CSFV introduction (P_{CSFV}) and their relative importance differs for each country. In order to optimally use resources for prevention of CSFV introduction, more quantitative insight into the main factors determining the P_{CSFV} is needed. Therefore, a scenario tree model was constructed that calculates the annual P_{CSFV} into member states of the EU (De Vos et al., 2004). The main aim of this model is to provide a better understanding of the importance of the different introduction routes of CSFV. The model can be used to support decision-makers in setting priorities for the prevention of CSFV introduction and to enable ‘experimenting’ with various preventive strategies, which is impossible in real-life.

Only limited data was available to quantify all input parameters required for this scenario tree model. Furthermore, data obtained from experiments or historic CSF epidemics are limited in their use, due to, for example, low frequency of epidemics, differences in virus strains, and changes in preventive measures and control strategies used. Hence, the model contains many uncertain input parameters. In the default calculations, point estimates were used for these input parameters. Using different point estimates for these uncertain input parameters may, however, have large impact on model results and, consequently, the conclusions drawn. The model outcome of most interest for decision support is the ranking of those risk factors contributing most to the annual P_{CSFV} into a certain country. If using other values for uncertain input parameters results in a different ranking, model outcome is not robust and might result in different decisions when prioritising preventive measures.

The main goal of the current study was to investigate which of the uncertain input parameters influence model results most and thus require further (empirical) research. For this purpose an extensive sensitivity analysis was performed based on the techniques of group screening (Watson, 1961; Law and Kelton, 2000) and Design of Experiments (DOE) and metamodelling (Kleijnen, 1998; Kleijnen, 1999). The approach of DOE and metamodelling has been described for and applied to simulation models in different research areas including the fields of animal health economics (Vonk Noordegraaf et al., 2003) and food-safety risks for humans (Van der Gaag et al., 2004). In this study, DOE and metamodelling is, however, used for a scenario tree model, which differs from simulation models in that it calculates probabilities directly (Vose, 1997). The scenario tree model for CSFV introduction exhibits, nevertheless, many similarities with a simulation model. The scenario tree model was also built to gain more insight into and analyse a so-called problem entity of the real world (Kleijnen and Sargent, 2000). For this purpose many input parameters were required and a multitude of calculations was performed to obtain the model's input-output transformation. Like a simulation model, the scenario tree model can be treated as a black box and used as decision support tool, once validated. Traditionally, in DOE ordinary least squares (OLS) regression is used when fitting a metamodel to the results of a modelling experiment. Since the output parameters of the scenario tree model are probabilities, a logit transformation of these parameters was required before performing OLS (Oude Voshaar, 1994; Rothman and Greenland, 1998).

In this paper the approach used to perform the sensitivity analysis is described and its main results are presented.

4.2. BRIEF INTRODUCTION TO THE SCENARIO TREE MODEL FOR CSFV INTRODUCTION

The principles of the scenario pathway approach were used to construct the scenario tree model for CSFV introduction (Vose, 1997). The model calculates the P_{CSFV} into member states of the EU in order to get more quantitative insight into the main risk factors for CSFV introduction. These were subdivided in two categories: pathways and countries of origin. Pathways are defined as carriers and mechanisms that can transmit virus from an infected to a susceptible animal. Pathways included in the model are import of pigs and pork products, returning livestock trucks and contacts with wild boar. The countries of origin are the possible sources of CSFV introduction. All 15 EU member states were included as such. The country for which calculations are performed is called the target country. Model calculations result in the annual P_{CSFV}, but the user can select more detailed results per country of origin or per pathway to analyse the risk factors for CSFV introduction.

The scenario tree model is a stochastic model taking into account the inherent variability of CSF epidemics in the countries of origin. Probability distributions were used for the input parameters describing these epidemics. Model calculations were iterated using Latin Hypercube Sampling (LHS) (Vose, 2000), resulting in a probability distribution for each output parameter. More details on the model can be found in De Vos et al. (2004).

Default calculations were performed with the Netherlands as target country, 1999 trade figures, and data on CSF prevalence in wild boar from the 1999/2000 hunting season. The annual P_{CSFV} into the Netherlands calculated was on average 0.06, but varied between $2.5*10^{-4}$ and $4.8*10^{-1}$. This variation was due to yearly changes in the occurrence and course of CSF epidemics in the countries of origin. The pathway returning livestock trucks contributed most to the annual P_{CSFV} with almost 65%. The most likely sources of CSFV introduction into the Netherlands were Germany, Belgium, and the United Kingdom.

True validation of the model by comparing model results and data from the real system was impossible due to lack of (recent) real-life data. Only few CSFV introductions occurred in recent years and since such introductions are largely determined by chance, the number of observations is far too few to determine the annual P_{CSFV} or to draw conclusions on the main causing risk factors. In such a case, sensitivity analysis is considered an important step in the model validation process and will identify those uncertain input parameters that influence model results most (Vonk Noordegraaf et al., 2003).

4.3. MATERIAL AND METHODS

To investigate the impact of all uncertain input parameters in the model on the ranking of risk factors a ‘simple’ one-at-a-time (OAT) sensitivity analysis was considered most appropriate, requiring two scenarios for each uncertain input parameter. The scenario tree model contained 49 uncertain input parameters, 16 of which were country-of-origin-specific. This means that these parameters should be checked for their impact on model outcome for each country of origin separately, resulting in a total of 257 (33 + 16 × 14) uncertain input parameters to include in the sensitivity analysis. An OAT design including all uncertain input parameters would thus require 514 scenario calculations of which the results should be compared with the default. Therefore, the techniques of group screening and DOE and metamodelling were used to reduce the number of uncertain input parameters in the final OAT sensitivity analysis (Watson, 1961; Kleijnen and Van Groenendaal, 1992; Law and Kelton, 2000).

In DOE terminology, model input parameters are called factors (X) and output measures are called response variables (Y) (Law and Kelton, 2000). A metamodel approximates the model's input-output behaviour by statistical analysis (e.g. least squares regression) of a modelling experiment (Kleijnen, 1995; Kleijnen and Sargent, 2000). In such an experiment of which the design should be guided by the statistical theory of DOE, values of one or more factors change and each set of factor combinations is a scenario in the experiment. For more details on DOE and metamodelling we refer to Kleijnen (1998). Using group screening, individual factors are aggregated into groups and these groups are experimented with as if they were individual factors (Law and Kelton, 2000).

All 257 uncertain input parameters were selected as factors for the modelling experiment. Factors were grouped taking into account (i) their natural coherence in the scenario tree model and (ii) their expected impact on model outcome. Based on the results of the default calculations (see De Vos et al., 2004), factors were put together in small groups if they were expected to significantly influence model outcome, whereas a priori expected insignificant factors were clustered into larger groups (see Watson, 1961). In this way we hoped to maximally reduce the total number of factors left for the next modelling experiment(s). Only one response variable could be selected for the group screening procedure. We decided to use the annual P_{CSFV} as this output parameter summarises model results. Model calculations do not return one single value for the annual P_{CSFV} but a probability distribution (see Section 4.2). As this distribution appeared to be rather skewed (long right tail), the median value of the annual P_{CSFV} was used in the analysis.

Each factor was assigned a low and a high value for the experiment[10]. Since this study was specifically aimed at investigating the impact of uncertainty about input parameter values on model results, we chose the minimum value considered to be possible for a factor as the low value and the maximum value considered to be possible as the high value. It was expected that, with approximately 95% confidence, the true value would be in the range covered by these values. The point estimates used in the default calculations were either equal to the low or the high value, or any value in between. To enable comparison of factor effects by relative importance, factor values were standardised at -1 (low value) and 1 (high value) in the experimental design and metamodel (Kleijnen and Van Groenendaal, 1992).

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[10] A complete overview of the factors in the experimental design and their default, low, and high values is available on request.

Group screening assumes that the direction of the influence that a factor has on the model outcome is known (Bettonvil and Kleijnen, 1996). Using this knowledge, a group was assigned the value 1 if all its component factors were at their individual value that was expected to result in an annual P_{CSFV} higher than or equal to the default calculations. This could either be the low or the high value of an individual factor. The individual factors within one group thus were not all set at their high value when the group was set at 1 in order to avoid that individual factors within a group would cancel out each other (Watson, 1961). Analogously, a group was set at –1 if all its component factors contributed to a lower or equal annual P_{CSFV}.

To start with, the 257 factors were aggregated into 14 groups, each group either containing all factors linked to one or several countries of origin or all factors linked to a certain pathway (either target-country-specific or general). These groups were very different in size (varying from 2 to 90 parameters per group). An R-4 design was constructed to obtain unbiased estimates of the main effects of these 14 groups not confounded with two-way interactions (Van Groenendaal and Kleijnen, 1997; Kleijnen, 1998). This design contained 32 ($2^{(14-9)} = 2^5$) scenarios (Kleijnen, 1987). All 32 scenarios were calculated in one run with the model, performing 1000 iterations for each scenario to estimate the median of the annual P_{CSFV}, using the RiskSimtable function in @Risk (Palisade Corporation, 2002).

Results of the modelling experiment were used to specify a regression metamodel with the groups as independent variables and the median of the annual P_{CSFV} as dependent variable. The metamodel was specified as the following simple first-order polynomial with *k* groups:

$$\underline{y_i} = \beta_0 + \sum_{h=1}^{k} \beta_h x_{i,h} + \underline{e_i} \tag{1}$$

where $\underline{y_i}$ denotes the value of the response variable in scenario *i*, β_0 the intercept, β_h the main effect of group *h*, $x_{i,h}$ the standardised value of group *h* in scenario *i*, and $\underline{e_i}$ the approximation error plus intrinsic noise in scenario *i*. To fit this first-order polynomial to data from the modelling experiment a logit transformation[11] was applied to the response variable,

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[11] The logit transformation is given by: $y_i' = \ln\left(\frac{y_i}{1-y_i}\right)$.

i.e. the median annual P_{CSFV}, to project the interval (0,1) at the interval $(-\infty,\infty)$ and enable linear regression (Oude Voshaar, 1994; Rothman and Greenland, 1998). Quadratic effects were not considered, as this would have required more than two levels for each factor (for example a Central Composite design). OLS regression was used, performing a stepwise selection procedure with $p \leq 0.20$ (SPSS, 1999). Non-significant groups were thereby excluded from the model. The fit of the metamodel was evaluated by the R^2_{adj}. Residual plots were produced to visually check for model inadequacies, such as heteroskedasticity (Montgomery et al., 2001).

Next, the groups with significant main effects in this metamodel were subdivided into smaller groups. A second R-4 design was constructed to obtain unbiased estimates of the main effects of these groups and again a metamodel was specified using OLS ($p \leq 0.20$). These steps were repeated until the number of factors in the groups with significant main effects was sufficiently small to construct an R-4 design with individual factors. This design was then used to specify the final metamodel. Due to the multi-stage nature of this group screening procedure, the total number of experiments, and thus scenario calculations, could not be specified in advance.

The final metamodel, containing individual factors, was validated by ‘leave-one-out’ cross-validation (Kleijnen and Sargent, 2000) using the DfFit diagnostic (SPSS, 1999). Applying cross-validation, scenarios are eliminated one by one, after which the regression model is re-estimated. The resulting model is then used to predict the model’s realisation of the eliminated scenario (Van Groenendaal and Kleijnen, 1997). This approach had the advantage that no new scenario calculations were required to test the validity of the final metamodel. To indicate the quality of the predictions obtained through cross-validation, a scatter plot of metamodel predictions and model realisations for each scenario was made. If the metamodel were perfect, the scatter plot would be a straight line. The performance was quantified by the Pearson linear correlation coefficient.

The factors with significant main effects in the final metamodel were ultimately included in the OAT sensitivity analysis to investigate their impact on the ranking of risk factors contributing most to the annual P_{CSFV}. The OAT design contained two scenarios for each factor. Each factor was assigned its low value in one scenario, its high value in a second scenario, and its default value in all other scenarios. The ranking of risk factors in the scenarios of this OAT experiment was compared with the ranking obtained in the original default calculations (De Vos et al., 2004).

4.4. RESULTS

4.4.1. Group screening, DOE and metamodelling

Three modelling experiments were needed to obtain the final metamodel containing only 6 out of the 257 uncertain input parameters (Fig. 4.1). In the first experiment five out of the 14 groups had significant main effects in the regression metamodel at $p \leq 0.20$. The R^2_{adj} of this model was 0.637. Plots of the residuals $\underline{e_i}$ versus the corresponding fitted values $\hat{y}_i$ did not reveal violations of model assumptions, such as homoskedasticity.

The groups with significant main effects contained input parameters concerning the countries of origin Germany (G1), Belgium (G2), and the United Kingdom (G3), and the pathway returning livestock trucks, both target-country-specific (G8) and general (G12)[12]. In the default calculations, these countries of origin and pathway contributed most to the annual P_{CSFV}. Therefore, the first experiment in the group screening procedure did not give unexpected results.

The five groups with significant main effects in the metamodel of experiment 1 together contained 70 individual factors, still too many for an R-4 design. Therefore these five groups were subdivided into 30 subgroups, that were composed such that each group contained factors that were closely related and could be attributed to only one country of origin or pathway. The subgroups varied in size from 1 to 11 parameters. The R-4 design constructed for this second experiment consisted of 64 scenarios. Based on the results of this R-4 design a second regression metamodel was specified with significant main effects for seven out of the 30 subgroups at $p \leq 0.20$. The R^2_{adj} of this model was 0.625. Plots of the residuals $\underline{e_i}$ versus the corresponding fitted values $\hat{y}_i$ did not reveal violations of model assumptions, such as homoskedasticity.

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[12] The allocation of factors to groups and subgroups is available on request.

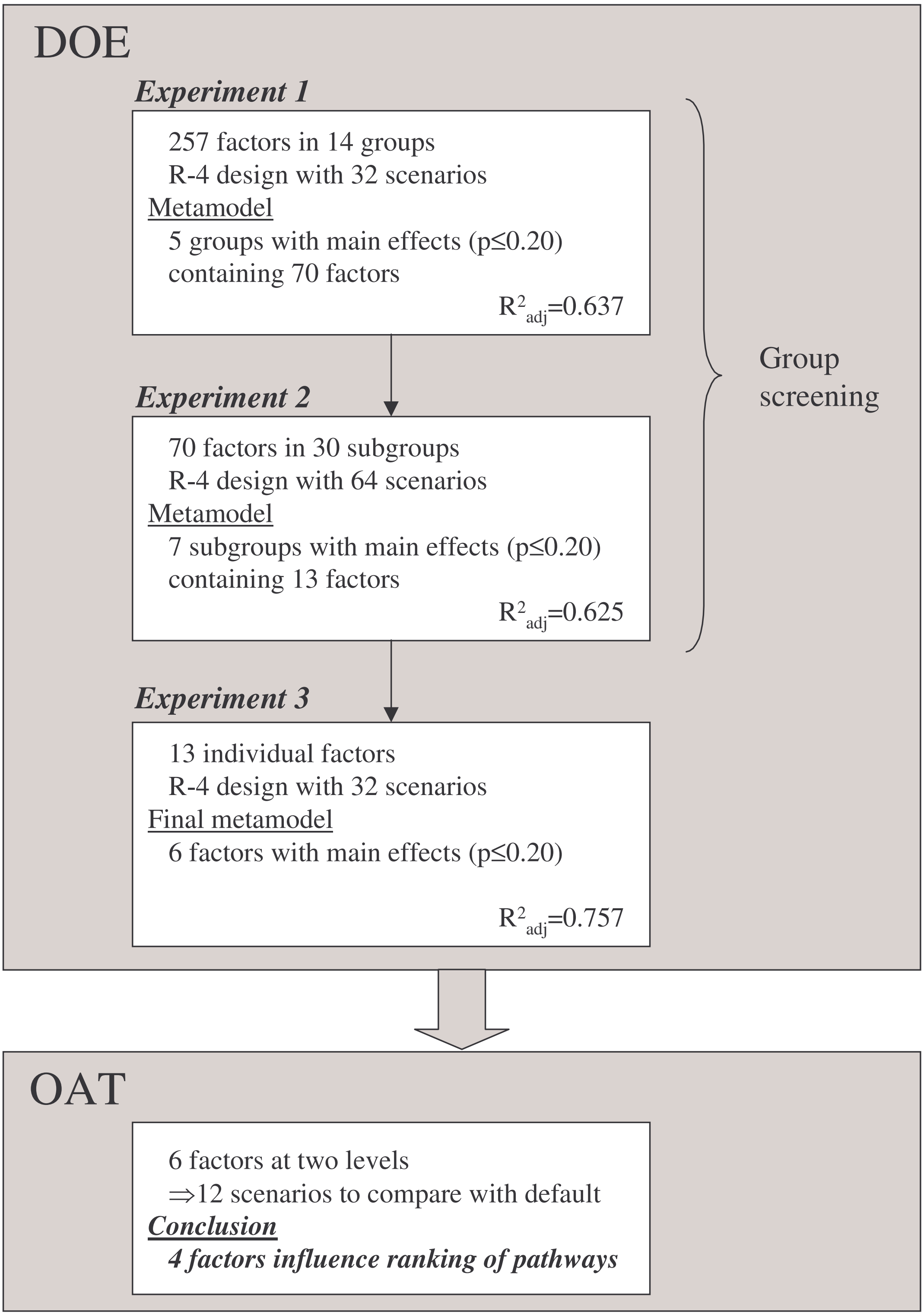

Fig. 4.1. Overview of the different steps in the sensitivity analysis and their results.

The seven subgroups with significant main effects in the metamodel of experiment 2 contained a total of 13 individual factors only. Therefore, the third experiment was based on individual factors. The R-4 design constructed for this experiment consisted of 32 scenarios. OLS regression on the results of this third experiment resulted in six individual factors with significant main effects at $p \leq 0.20$ (Table 4.1). The R^2_{adj} of this regression metamodel was 0.757. Plots of the residuals $\underline{e_i}$ versus the corresponding fitted values $\hat{y}_i$ did not reveal violations of model assumptions, such as homoskedasticity. Factor estimates (ß) in Table 4.1 reflect the expected effect on the logit of the median annual P_{CSFV} when changing a factor from its low to its high value. Cross-validation of this final metamodel resulted in a Pearson linear correlation coefficient of 0.949. Fig. 4.2 shows the scatter plot based on this cross-validation with, for all 32 scenarios, the metamodel predictions on the X-axis and the logit of the median annual P_{CSFV} obtained in the modelling experiment on the Y-axis.

Table 4.1

Significant factor effects ($p \leq 0.20$) in the final metamodel; dependent variable is the logit of the median annual P_{CSFV}

Factor	Description	ß	S.E.	p-value
X_0	Intercept	-3.332	0.137	0.000
X_1	Expected number of CSF epidemics per year in Germany	0.700	0.137	0.000
X_{16}	Expected number of CSF epidemics per year in Belgium	0.426	0.137	0.005
X_{31}	Expected number of CSF epidemics per year in the United Kingdom	0.986	0.137	0.000
X_{245}	Probability of an infective dose of CSFV being transmitted from a contaminated livestock truck to a susceptible pig	0.252	0.137	0.078
X_{246}	Probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km	0.387	0.137	0.009
X_{247}	Probability that CSFV survives in an empty livestock truck travelling over a distance of 901-1800 km	0.269	0.137	0.061

4.4.2. OAT design for ranking of risk factors

The OAT sensitivity analysis was performed with the six factors that had significant main effects in the final metamodel and hence consisted of 12 scenarios that were compared with the default. A description of the scenarios and their median annual P_{CSFV} is given in Table 4.2. The median annual P_{CSFV} into the Netherlands was highest for scenario 6 (almost 0.10) and lowest for scenario 9 (almost 0.01). For scenarios 10, 11, and 12 the annual P_{CSFV} was almost equal to the value obtained in the default calculations.

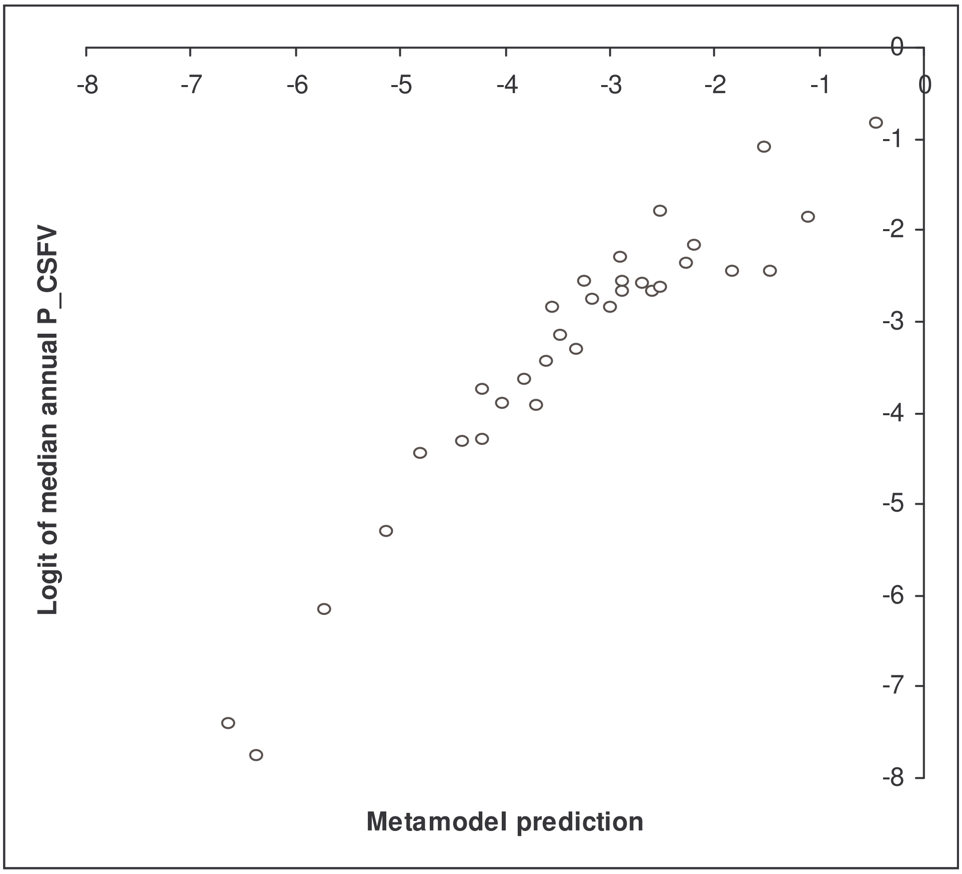

Fig. 4.2. Scatter plot of metamodel predictions and the scenario tree model's outcome in experiment 3, based on cross-validation of 32 scenarios.

Table 4.2

Description of the scenarios used in the OAT experiment and the median annual P_{CSFV} obtained (see Table 4.1 for a description of the factors)

Scenario	Description	Median annual P_{CSFV}
	Default	0.038
1	X_1 low	0.012
2	X_1 high	0.083
3	X_{16} low	0.030
4	X_{16} high	0.050
5	X_{31} low	0.031
6	X_{31} high	0.097
7	X_{245} low	0.015
8	X_{245} high	0.054
9	X_{246} low	0.009
10	X_{246} high	0.037
11	X_{247} low	0.036
12	X_{247} high	0.037

In Fig. 4.3, for each scenario the relative contribution of pathways to the annual P_{CSFV} into the Netherlands is shown. It is evident that returning livestock trucks contributed most to the annual P_{CSFV} in all scenarios except for scenarios 6 and 9. In these scenarios import of breeding pigs ranked highest. In all other scenarios import of breeding pigs ranked second except for scenarios 4 and 5, in which import of fattening pigs ranked second. In all other scenarios import of fattening pigs ranked third except for scenarios 2 and 3, in which import of piglets ranked third. All scenarios not mentioned equalled the default scenario with regard to the ranking of pathways. Import of pork products always ranked lowest. The pathways concerning contact with wild boar did not contribute to the annual P_{CSFV} in the scenarios calculated as the seroprevalence for CSFV in the wild boar populations of the Netherlands was zero in all scenarios.

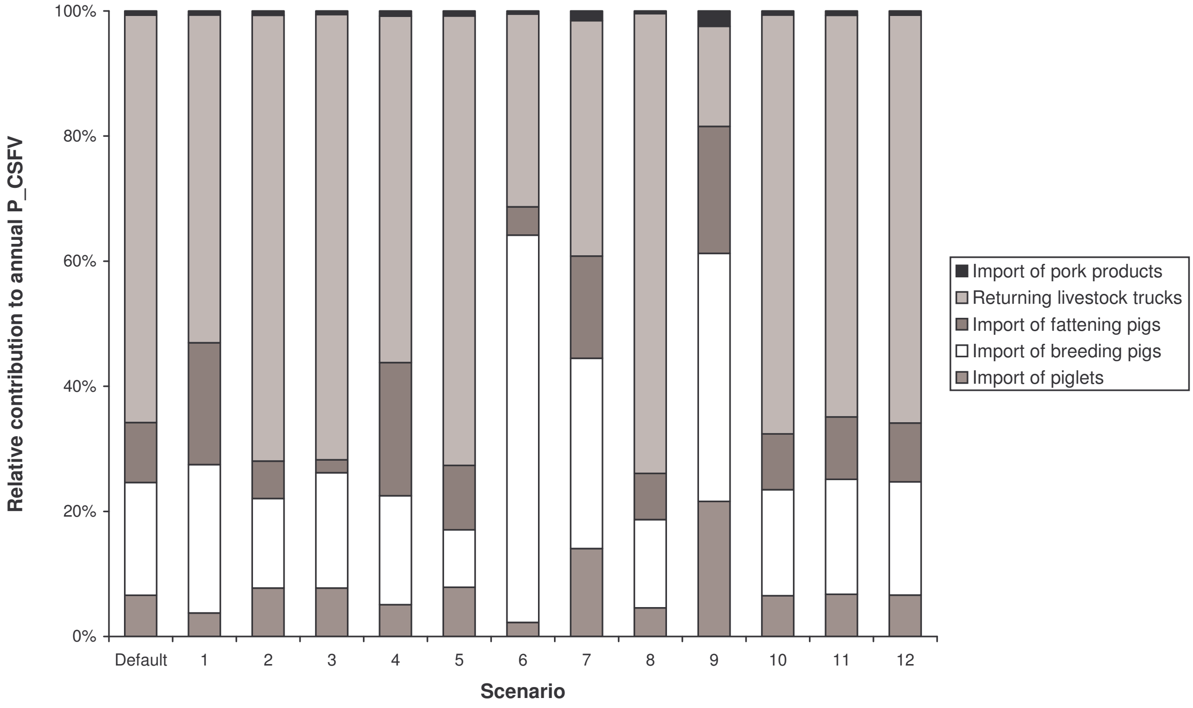

Fig. 4.3. Relative contribution of pathways to the annual P_{CSFV} in the default calculations and the scenarios of the OAT design.

Based on these results it can be concluded that especially a high expected number of CSF epidemics per year in the United Kingdom (scenario 6) and a low probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km (scenario 9) changed the ranking of pathways. The input parameters concerning the expected number of CSF epidemics per year in Germany and Belgium also influenced the ranking of pathways, but to a lesser extent (scenarios 2-4).

4.5. DISCUSSION

4.5.1. Approach

To investigate the impact of uncertain input parameters in the scenario tree model for CSFV introduction we chose to perform an extensive sensitivity analysis instead of incorporating the uncertainty in the scenario tree model. In order to include uncertainty in the model we had to use probability distributions for uncertain input parameters next to those used to represent inherent variability of the system. This would have made it impossible to see how much of the total uncertainty about output parameters is due to inherent variability and how much due to uncertainty[13] (Vose, 2000). Furthermore, it would have required that for each uncertain input parameter a probability distribution was specified, including its (uncertain!) form and parameters (Ferson and Ginzburg, 1996). For a sensitivity analysis, on the contrary, only the minimum and maximum value considered possible for the uncertain input parameters had to be determined. Another strong argument in favour of using sensitivity analysis was that sensitivity analysis explicitly indicates which factors are important (Van Groenendaal and Kleijnen, 1997). Exactly this information is essential in determining which uncertain input parameters influence model results most, which was the ultimate goal of this study.

To use the scenario tree model as a decision support tool for prevention of CSFV introduction, the ranking of risk factors given by the model should be robust despite uncertainty about the exact values of input parameters. As it was impossible to evaluate the effects of all 257 uncertain input parameters on this ranking, we started with a screening procedure based on the techniques of group screening and DOE and metamodelling. Only one response variable could be selected for this procedure. The annual P_{CSFV} was chosen, because the output parameters on which the ranking of risk factors is based, are all used to calculate this output parameter. A logit transformation was applied to this response variable to enable OLS regression for estimating the metamodels. Due to this transformation, the interpretation of the estimates of the main effects in the metamodel (β in Table 4.1) is not straightforward, which was considered a drawback of the approach used. The goal of the metamodels was,

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[13] Variability is a function of the system, whereas uncertainty is due to imperfect knowledge about the parameters that charasterise the system being modelled.

however, understanding, more specifically screening, and not prediction (see Kleijnen and Sargent, 2000). For this purpose, the constructed metamodels sufficed, as they indicated which factors, and thus which uncertain input parameters, influenced the response variable most.

No interaction terms were included in the metamodels. Since the ultimate goal of the sensitivity analysis was screening, i.e., to obtain adequate information about the sensitivity of the model to its uncertain input parameters, while keeping the computational cost low (Campolongo et al., 2000), an R-4 design was used, giving at least unbiased estimators of all main effects. This, however, involved a small risk of missing factors that do significantly influence model outcome, although not individually. To estimate unbiased effects of all two-factor interactions, an R-5 design would have been needed (Law and Kelton, 2000), implying many more factor combinations and thus model calculations. When performing DOE, based on an R-4 design, it is a common procedure to include only two-factor interactions between factors with significant main effects (see e.g. Van Groenendaal and Kleijnen, 1997; Vonk Noordegraaf et al., 2003; Van der Gaag et al., 2004). Although including these interactions improved the fit of the metamodel, they did not change the relative importance of significant main effects. Therefore, we decided not to include these interactions given the goal of the metamodels (i.e. screening). Furthermore, the meaning of interactions was questionable due to the logit transformation of the response variable. Interaction terms would, at least, have been very difficult to interpret in this case.

Groups and factors were included in the metamodels if they had a significant main effect at $p \leq 0.20$. This p-value was chosen as the threshold, because the metamodels were aimed at screening. The fit of the metamodels was evaluated by the R^2_{adj} and considered sufficiently accurate if the R^2_{adj} was equal to or greater than 0.6. We decided no longer to aggregate factors into groups but use individual factors in the experimental design if the total number of factors left would be equal to or smaller than 31. This is the maximum number that can be included in an R-4 design with 64 (2^6) scenarios. Including more factors would at least double the computational cost ($2^7 = 128$). Based on these criteria, we only needed a total of three experiments – two with groups and one with individual factors – to estimate the final metamodel (see Fig. 4.1).

Screening methods aim to provide adequate information about the sensitivity of a model to its inputs, while keeping the computational cost, i.e. the number of model calculations required in the whole experiment low (Campolongo et al., 2000). In total, 128 scenarios were calculated with the model to identify the six most important factors among a total of 257. The design used was thus a supersaturated one requiring fewer scenario calculations than factors (Campolongo et al., 2000). It was therefore concluded that the screening procedure applied was very efficient.

The most important uncertain input parameters indicated by the screening procedure were subsequently evaluated for their impact on the ranking of risk factors contributing most to the annual P_{CSFV}. For this purpose a simple OAT design was used. It appeared that the factors changing the ranking of risk factors were those that had the most significant main effects in the final metamodel, i.e., the values of their betas were highest (see Table 4.1). The scenario tree model was thus sensitive to the same uncertain input parameters for both types of model outcome selected in the sensitivity analysis. It can thus be concluded that the screening procedure with the annual P_{CSFV} as response variable was an effective tool to detect important uncertain input parameters. Nevertheless, it cannot be excluded that uncertain input parameters not indicated by the screening procedure also influence the ranking of risk factors.

4.5.2. Results

The OLS regression estimates in the final metamodel gave a reasonable fit to the model's input-output data ($R^2_{adj} = 0.757$). Furthermore, cross-validation showed that this metamodel predicted the scenario tree model's outcome in experiment 3 quite well (ρ=0.949). All factor estimates in the final metamodel were positive. This was according to prior expectation as for all factors in the metamodel an increase of their value, i.e. a change from low to high, was expected to contribute to a higher annual P_{CSFV}. As such, the sensitivity analysis supported internal validation of the model (Kleijnen, 1999).

The consecutive OAT design indicated that model conclusions depended mainly on four uncertain input parameters, viz. the expected number of CSF epidemics per year for Germany (X_1), for Belgium (X_{16}), and for the United Kingdom (X_{31}) and the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km (X_{246}). Especially for these parameters information should thus be as accurate as possible to improve the model's use as a decision support tool on prevention of CSFV introduction. For the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km a wide range between the low and high value was used in the modelling experiments as no hard data were available for this parameter. This wide range, in combination with the large number of livestock trucks returning to the Netherlands, most probably explains the importance of this uncertain input parameter. Experiments can and should be conducted to estimate this parameter more precisely. For the parameters concerning the expected number of CSF epidemics per year, a more precise estimate can only be obtained by 'waiting' to see what the future holds with respect to the occurrence of CSF epidemics. The default value used in the model calculations was the average number of CSF epidemics per year observed in the period 1990-2001, but since this is a rather short time-span, there is uncertainty involved in this estimate. Countries might have been lucky in not experiencing any CSF epidemic during this period, for example. If a longer time period is observed, the average value will generally become more stable. Observing longer time periods is, however, only possible if the situation regarding, for example, the pig production sector, trade contact patterns, and CSF prevention and control does not change essentially, i.e., it should be comparable to the current situation. Therefore, only data from 1990 onwards were used, as by then all EU member states had ceased preventive mass-vaccination.

Only results for the ranking of pathways were given in Section 4.4.2. Countries of origin are, however, also indicated as risk factors in the scenario tree model. Examining the results of the OAT sensitivity analysis for the ranking of those countries of origin contributing most to the annual P_{CSFV} into the Netherlands, it was seen that this ranking changed most in scenarios 6 and 9 and to a lesser extent in scenarios 1, 3, 4, and 5 (results not shown). It can thus be concluded that the ranking of both types of risk factors is changed by the same uncertain input parameters, i.e., X_1, X_{16}, X_{31}, and X_{246}. This is partly explained by the fact that the importance of pathways and countries of origin is correlated: breeding pigs are mainly imported from the United Kingdom, whereas about 60% of the returning livestock trucks comes from Germany. Hence, when import of breeding pigs ranks first, the United Kingdom will in most cases rank first, whereas a first rank for returning livestock trucks will in most cases result in a first rank for Germany.

The basic model used for the sensitivity analysis contained the Netherlands as target country, 1999 trade figures, and data on CSF prevalence in wild boar from the 1999/2000 hunting season. Conclusions drawn are thus only valid under these conditions. Other uncertain input parameters might be more important in determining the ranking of pathways and countries of origin if, for example, more recent trade figures would be used. Based on trade figures from the years 1993-1999 it is, however, expected that, although absolute numbers of pigs imported and exported (and thus returning livestock trucks) might fluctuate considerably, tendencies will be rather stable. Given this and the kind of uncertain input parameters that appeared to be most important, the results of this sensitivity analysis will probably also apply when trade figures of other years are used. Occurrence of CSF infections in the Dutch wild boar population or selection of another target country, on the other hand, can easily lead to different results of the sensitivity analysis and hence the conclusions drawn.

Sometimes the regression metamodel obtained in sensitivity analysis can help to determine the directions in which inputs that are under the decision-makers' control (i.e. manageable input parameters) should be steered (Kleijnen, 1995). The uncertain input parameters with most impact on the annual P_{CSFV} were, however, not under the decision-makers' control. The sensitivity analysis did thus not help to unravel which manageable input parameters should be targeted to reduce the annual P_{CSFV} into the Netherlands. If that had been the primary objective of the sensitivity analysis, we should have chosen another subset of factors for the experiments, not including all uncertain input parameters but all manageable input parameters. Further research will be dedicated to these manageable input parameters in order to determine which measures to prevent CSFV introduction are most effective in reducing the annual P_{CSFV} into the Netherlands.

4.6. CONCLUSIONS

This study showed that group screening combined with the statistical techniques of DOE and metamodelling proved to be an effective and efficient screening method to identify those uncertain input parameters in the scenario tree model for CSFV introduction that influenced model results most. It was concluded that four uncertain input parameters change the ranking of risk factors contributing most to the annual P_{CSFV} and thus require a more accurate estimate of their values to make model outcome robust. For one of them, i.e. the probability of CSFV survival in an empty livestock truck travelling over a distance of 0-900 km, experiments can be conducted to estimate its value more precisely. For the others, i.e. the expected number of CSF epidemics per year in Germany, Belgium, and the United Kingdom, a more precise estimate can only be obtained by observing a longer time period.

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Chapter 5

Cost-effectiveness of measures to prevent classical swine fever introduction into the Netherlands

Paper by De Vos, C.J., Saatkamp, H.W., Huirne, R.B.M. Submitted to Preventive Veterinary Medicine.

Abstract

Recent history has demonstrated that classical swine fever (CSF) epidemics can incur high economic losses, especially for exporting countries that have densely populated pig areas and apply a strategy of non-vaccination, such as the Netherlands. Introduction of CSF virus (CSFV) remains a continuing threat to the pig production sector in the Netherlands. Reducing the annual probability of CSFV introduction (P_{CSFV}) by preventive measures is therefore of utmost importance. The choice of preventive measures depends not only on the achieved reduction of the annual P_{CSFV}, but also on the expenditures required for implementing these measures. The objective of this study was to explore the cost-effectiveness of tactical measures aimed at the prevention of CSFV introduction into the Netherlands. For this purpose for each measure (i) model calculations were performed with a scenario tree model for CSFV introduction and (ii) its annual cost was estimated. The cost-effectiveness was then determined as the reduction of the annual P_{CSFV} achieved by each preventive measure (ΔP) divided by the annual cost of implementing that measure (ΔC). The measures analysed reduce the P_{CSFV} caused by import or export of pigs. Results showed that separation of national and international transport of pigs is the most cost-effective measure, especially when risk aversion is assumed. Although testing piglets and breeding pigs by a quick and reliable PCR also had a high cost-effectiveness ratio, this measure is not attractive due to the high cost per pig imported. Besides, implementing such a measure is not allowed under current EU law, as it is trade restrictive.

Keywords: Classical swine fever; Cost-effectiveness; Prevention; Risk assessment; Virus introduction

5.1. INTRODUCTION

Since the early 1990s, classical swine fever (CSF) control in the European Union (EU) has been based on a strategy of non-vaccination and the stamping-out of infected herds (CEC, 2001). As a consequence of this policy, the whole EU domestic pig population has become fully susceptible to CSF virus (CSFV). This, combined with the existence of areas with dense pig populations, has occasionally led to large epidemics incurring high economic losses (Vanthemsche, 1996; Elbers et al., 1999; Moennig, 2000; Edwards et al., 2000). The most striking example is a series of epidemics that started at the end of 1996 in Germany due to illegal swill feeding. The virus subsequently spread to several regional pig farms and presumably from Germany to the Netherlands and then to Spain, Italy and Belgium (Elbers et al., 1999). More than 550 confirmed outbreaks could be attributed to these epidemics (Moennig, 2000; Edwards et al., 2000). The costs of these epidemics (i.e. direct costs and consequential losses to farms and related industries) were estimated at 2.3 billion USD for the Netherlands only (Meuwissen et al., 1999). More recently, sporadic outbreaks of CSF occurred in the domestic pig populations of Germany, Italy, France, Luxembourg, and Spain (OIE, 2004), showing that the introduction of CSF remains a continuing threat to the pig production sector in the EU. In addition, CSF is endemic in wild boar populations in some areas of Germany, France, and Italy (Laddomada, 2000), representing a permanent CSFV reservoir. In recent years infected wild boar were also found in Austria, Belgium, and Luxembourg (Artois et al., 2002; OIE, 2004).

In reaction to the CSF epidemic of 1997/98, in the Netherlands much research has been dedicated to analysing the spread of the disease and determining the optimum control strategy (see e.g. Jalvingh et al., 1999; Nielen et al., 1999; Stegeman et al., 1999; Mangen et al., 2001; Mangen et al., 2002; Klinkenberg et al., 2003). Furthermore, existing regulations have been amended to reduce the risk of introduction onto and spread from primary farms (LNV, 2004). The emphasis has thus been on control of the disease and not on preventing its (re-)introduction into the country. A similar tendency was observed after the foot-and-mouth disease (FMD) epidemic in 2001 (Greutink et al., 2002).

Reducing the annual probability of contagious animal disease introduction by preventive actions is, however, another way to reduce losses incurred by epidemics over the long term. In order to use resources optimally for prevention of CSFV introduction, more quantitative insight is needed into the factors which contribute most to the annual probability of CSFV introduction (P_{CSFV}) into the Netherlands. It is, however, impossible to acquire this information by analysing data from recent CSFV introductions. The Netherlands ‘only’ experienced primary CSF outbreaks in 1990, 1992, and 1997 under the non-vaccination strategy (Elbers et al., 1999; De Vos et al., 2000). The number of observations is thus far too low to determine the annual P_{CSFV} or draw conclusions about the main causing risk factors. Therefore, a scenario tree model was constructed that calculates the annual P_{CSFV} into the domestic pig population of the Netherlands and provides information on the relative contribution of risk factors to the annual P_{CSFV} (De Vos et al., 2004a). Furthermore it enables 'experimenting' with preventive strategies, which is impossible in real life.

In the present study this model was used to estimate the effectiveness of tactical measures for preventing the introduction of CSFV into the Netherlands. For decision-makers, however, the cost of implementing these measures is equally important. Therefore, for each of the measures its cost-effectiveness was determined as the ratio between the achieved reduction of the annual P_{CSFV} (ΔP) and the annual cost of achieving this reduction (ΔC) (Belli et al., 2001).

The objective of this paper was to describe the cost-effectiveness analysis of tactical measures aimed at the prevention of CSFV introduction into the Netherlands and to present its main results.

5.2. MATERIALS AND METHODS

5.2.1. Scenario tree model for CSFV introduction

5.2.1.1. Brief introduction to the model

A computer model for CSFV introduction was developed to obtain more quantitative insight into the main risk factors for CSFV introduction into member states of the EU. The risk factors were subdivided into two categories: pathways and countries of origin. Pathways are defined as carriers and mechanisms that can transmit the virus from an infected to a susceptible animal. Pathways included in the model are import of pigs (subdivided into three subgroups: piglets, breeding pigs, and fattening pigs), import of pork products (subdivided into four subgroups: fresh/chilled, frozen, non-heat-treated, and heat-treated), returning livestock trucks, and contacts with wild boar (subdivided into direct and indirect contacts). The countries of origin are the possible sources of CSFV introduction. All 15 EU member states were included as such[14]. The model is constructed such that calculations can be performed for all EU member states if sufficient information is available. In this study model calculations were performed for the Netherlands only. Model calculations result in the annual P_{CSFV}, but the user can select more detailed results by country of origin or by pathway to

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[14] The research described was carried out before the enlargement of the EU by 10 new member states on May 1, 2004.

analyse the risk factors for CSFV introduction. In Fig. 5.1 a schematic representation of the model design is given. More details on the model can be found in De Vos et al. (2004a).

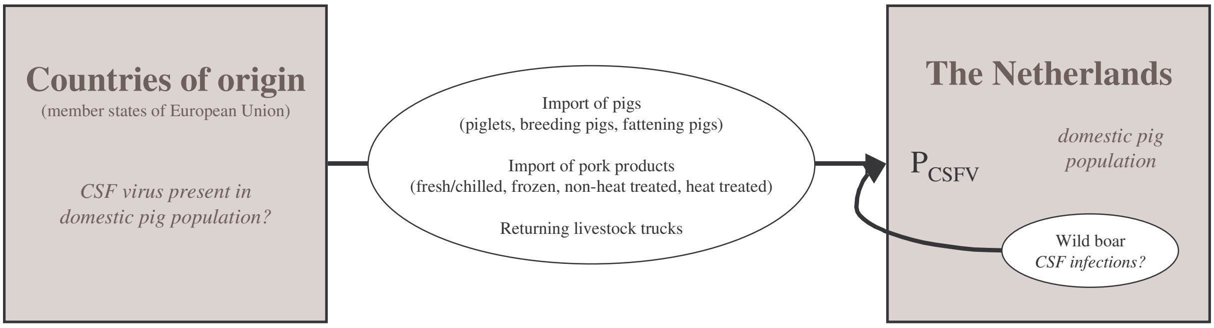

Fig. 5.1. Schematic representation of the structure of the scenario tree model for CSFV introduction.

The principles of the scenario pathway approach (Vose, 1997) were used to construct the model for CSFV introduction. Using this approach, the sequence of events that would ultimately lead to CSFV introduction into the domestic pig population of the Netherlands was determined, starting with the event of a pathway-unit (i.e. unit in which a pathway is measured, e.g., a batch of animals, a metric ton of animal products or a returning livestock truck) being infected or contaminated with the virus and ending with the event of an infective viral dose being transmitted to a susceptible pig in the Netherlands. For each pathway in the model these events were ordered in a scenario tree (Miller et al., 1993; Sutmoller et al., 2000). Each event in the scenario trees was assigned a probability of occurrence. To calculate the P_{CSFV} for a certain pathway, all probabilities along its scenario tree were multiplied. Combining the outcome of all scenario tree calculations gave insight into the relative contribution of countries of origin and pathways to the P_{CSFV} into the Netherlands.

The scenario tree model is a stochastic model taking into account the inherent variability of CSF epidemics in the countries of origin. Probability distributions were used for the input parameters describing these epidemics. Model calculations were iterated using Latin Hypercube Sampling (LHS) (Vose, 2000), resulting in a probability distribution for each output parameter. The model was constructed in Microsoft Excel 97 with the add-in programme @Risk 4.5.2 (Palisade Corporation, 2002).

Table 5.1

The expected number of CSF epidemics per year, total number of pig holdings, export of pigs and pork products to the Netherlands per year, and livestock trucks returning to the Netherlands per year for each country of origin in the scenario tree model for CSFV introduction

	Expected number of CSF epidemics per year[a]	Total number of pig holdings[b]	Batches of piglets exported to the Netherlands per year[c]	Batches of breeding pigs exported to the Netherlands per year[c]	Batches of fattening pigs exported to the Netherlands per year[c]	Metric tons of pork products exported to the Netherlands per year[d]	Livestock trucks returning to the Netherlands per year[c]
Germany	7.86	116 000	30	65	587	138 769	18 890
France	0.43	55 000	16	46	11	20 048	199
Italy	2.36	230 000	0	0	0	7 164	4 003
Belgium	0.29	10 000	14	24	953	100 827	6 702
Luxembourg	0.14	500	0	0	0	332	1
United Kingdom	0.21	11 000	0	32	0	3 673	0
Ireland	0.07	1 000	9	0	41	876	0
Denmark	0.07	13 000	13	3	78	12 050	0
Greece	0.07	23 000	0	0	0	0	24
Spain	1.00	69 000	0	1	3	10 290	3 170
Portugal	0.07	121 000	0	0	0	11	0
Austria	0.14	76 000	0	0	0	424	14
Finland	0.07	4 000	0	0	0	120	0
Sweden	0.07	4 000	0	0	0	32	0

[a] Based on period 1990-2003. Sources: Animal Disease Notification System (ADNS) of the European Union; OIE (2004).

[b] Data from 2001. Source: EU (2004).

[c] Data from 2003. Source: Animal Movement system (ANIMO), National Inspection Service for Livestock and Meat (RVV), Voorburg.

[d] Data from 2003. Source: Statistics Netherlands (CBS), Voorburg.

5.2.1.2. Model adaptations for the present study

The model used in the present study slightly differs from the previous model version as described by De Vos et al. (2004a). Firstly, model input was updated to represent better the current situation in the pig production sector of the Netherlands and the EU. A summary hereof is given in Table 5.1. Secondly, some changes were made that resulted from an extensive sensitivity analysis. This analysis indicated that four out of the 257 uncertain input parameters in the scenario tree model had significant impact on the ranking of risk factors (De Vos et al., 2004b). To obtain a more precise estimate for the expected number of CSF epidemics in Germany, Belgium, and the United Kingdom the observed period was extended from 1990-2001 to 1990-2003 (Table 5.1). For the uncertain input parameter of the probability of CSFV survival in an empty livestock truck travelling a distance of 0-900 km experts were consulted who recommended setting its probability value at 0.9 for all distance classes. They also recommended increasing the values for the effectiveness of cleansing and disinfection of returning livestock trucks and decreasing the values for the sensitivity of overall detection of CSFV infection in imported pigs. Values were changed accordingly. Besides, the calculations for separate supply and delivery routes at the primary farm were improved.

5.2.2. Selection of preventive measures

In principal, the annual P_{CSFV} is determined by the number of pathway-units present and the probability of CSFV introduction per pathway-unit. The latter depends on (i) either the CSF situation in the countries of origin or in the Dutch wild boar population and (ii) preventive actions taken to detect or inactivate the virus. In this study the cost-effectiveness of implementing additional preventive actions was explored. The results of the default calculations were used to make a first selection of preventive measures. Then experts in the field of CSF and/or the Dutch pig production sector were asked for their opinion on how realistic and effective the selected measures would be. This ultimately resulted in six preventive measures for which the cost-effectiveness analysis was performed. Most of the selected measures were directed at mitigating the risk of returning livestock trucks, as this pathway contributes most to the annual P_{CSFV} into the Netherlands. A short description of the measures is given in Table 5.2.

Table 5.2

Overview of tactical preventive measures

Abbreviation	Preventive measure	Brief description
LT_C&D	Cleansing and disinfection of all returning livestock trucks	– all livestock trucks are cleaned and disinfected at a listed washing point when returning to the Netherlands – disinfection by certified washing point personnel
LT_N&I	Separation of national and international transport of pigs	– livestock trucks are used for either national or international transports only – as a consequence, all batches of pigs for export are transferred to an international livestock truck at assembly points for export
LT_CONT	Livestock trucks with detachable containers	– livestock truck brings empty container to primary farm – farmer loads container with pigs – livestock truck returns to pick up full container
PF_S&D	Separate supply and delivery routes on primary farms	– physical barrier between ‘clean’ part of enterprise and transport routes – paved transport routes – only admittance to ‘clean’ part of enterprise by hygiene channel – no admittance of vehicles at ‘clean’ part of enterprise
SL_LOG	Logistic supply of fattening pigs at slaughterhouses	– first supply of Dutch fattening pigs, then supply of imported fattening pigs – no physical contacts between Dutch and imported pigs, also not in the lairage – additional cleaning and disinfection of slaughter line and lairage after supply of imported pigs
IMP_TEST	Testing piglets and breeding pigs by a quick and reliable PCR	– all pigs in a batch tested – test results known within 24 hours

5.2.3. Cost-effectiveness of preventive measures

5.2.3.1. Calculation of effectiveness

The scenario trees of the pathways at which the preventive measures are directed are given in Fig. 5.2. The events at which the preventive measures intervene are indicated. The values of these input parameters of the scenario tree model were adjusted to mimic the effect of the preventive measures. Experts were consulted to determine the new values for these parameters. If no substantiated new value could be determined, values were either doubled or halved. In Table 5.3 an overview of default and new values is given.

The scenario tree model was run for the default scenario and for each preventive measure. The output variables selected were (i) the overall annual P_{CSFV} into the Netherlands, (ii) the relative contribution of pathways to the annual P_{CSFV}, and (iii) the P_{CSFV} from each country of origin per epidemic and per year. Model calculations were iterated 2500 times and hence did not return a single value for the annual P_{CSFV} but rather a probability distribution (see also Section 5.2.1.1). Comparing the cumulative distribution function (cdf) for the overall annual P_{CSFV} of the default scenario and the scenarios with preventive measures gives clear insight into the effectiveness of the measures. To determine the cost-effectiveness of the preventive measures, however, the effectiveness of the measures had to be expressed by a single value. As the uncertainty distribution of the annual P_{CSFV} appeared to be rather skewed (long right tail), the median and 0.95 percentile values of the annual P_{CSFV} were used to calculate the achieved reduction of the annual P_{CSFV} ($\Delta P_{0.50}$ and $\Delta P_{0.95}$).

5.2.3.2. Calculation of annual costs

Implementing the selected preventive measures results in extra costs due to investments and labour. For each preventive measure an estimate was made of the extra annual cost in comparison with the current situation. The annual investment cost was calculated using the annuity method (Van den Tempel and Giessen, 1992). For all investments the depreciation rate was set at 6.7%, maintenance costs at 1%, and interest rate at 6%. Furthermore, variable costs for extra livestock trucks (insurance, fuel, etc.) were set at 4% of the initial cost. An overview of the annual cost of each preventive measure is given in Table 5.4. This table also displays the main assumptions and data sources used for the calculations. As there is wide diversity among pig farms, pig transporters, and slaughterhouses with regard to, for example,

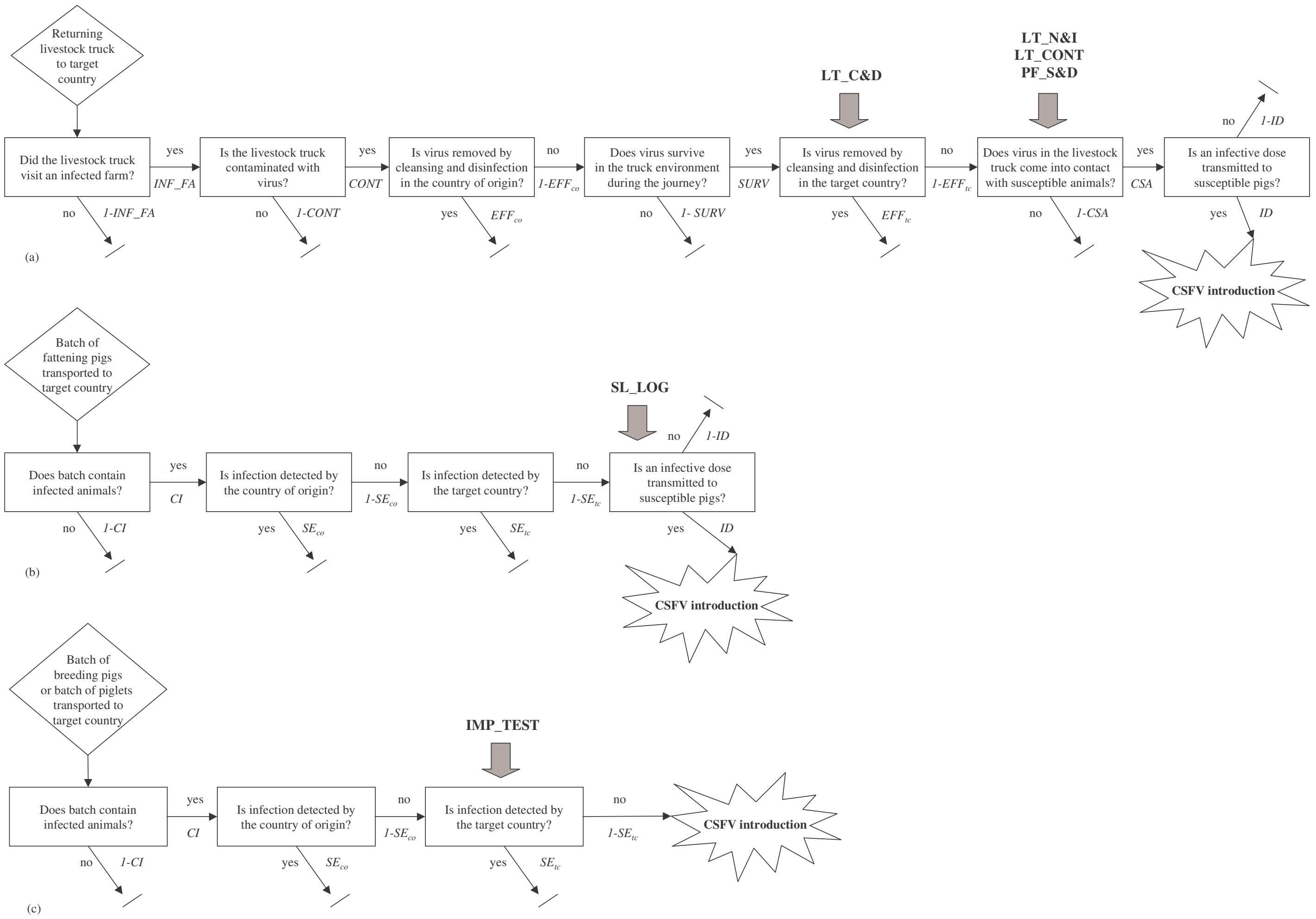

Fig. 5.2. Scenario trees for the pathways returning livestock trucks (a), import of batch of fattening pigs (b), and import of batch of breeding pigs or batch of piglets (c).

Table 5.3

Values of model input parameters for calculating effectiveness of preventive measures

Preventive measure	Pathway	Parameter[a]	Default value[c]	New value[c]
LT_C&D	Returning livestock trucks	EFF_{tc}	HRP: 0.25 PostHRP: 0.9	HRP: 0.9 PostHRP: 0.99
LT_N&I	Returning livestock trucks	CSA[b]	0.5 * RiskDiscrete(0.05, 0.75; 0.39, (1 – 0.39))	0.01 * RiskDiscrete(0.05, 0.75; 0.39, (1 – 0.39))
LT_CONT	Returning livestock trucks	CSA[b]	0.5 * RiskDiscrete(0.05, 0.75; 0.39, (1 – 0.39))	0.5 * RiskDiscrete(0.025, 0.75; 0.9, (1 – 0.9))
PF_S&D	Returning livestock trucks	CSA[b]	0.5 * RiskDiscrete(0.05, 0.75; 0.39, (1 – 0.39))	0.5 * RiskDiscrete(0.05, 0.75; 0.78, (1 – 0.78))
SL_LOG	Import of fattening pigs	ID	HRP: 0.1 PostHRP: 0.05	HRP: 0.05 PostHRP: 0.025
IMP_TEST	Import of piglets	SE_{tc}	HRP: 0 PostHRP: 0.5	HRP: 0.9 PostHRP: 0.99
IMP_TEST	Import of breeding pigs	SE_{tc}	HRP: 0 PostHRP: 0.8	HRP: 0.9 PostHRP: 0.99

[a] See scenario trees of Fig. 5.2 for an explanation of parameter meaning.

[b] The parameter CSA is calculated by multiplying the proportion of returning livestock trucks coming into contact with primary farms by a RiskDiscrete distribution that calculates the probability that a contaminated livestock truck comes into contact with susceptible animals at the primary farm. This RiskDiscrete distribution is defined as RiskDiscrete (probability that contaminated livestock truck comes into contact with susceptible animals if separate supply and delivery routes, probability that contaminated livestock truck comes into contact with susceptible animals if no separate supply and delivery routes; proportion of farms with separate supply and delivery routes, (1 – proportion of farms with separate supply and delivery routes)).

[c] HRP: high-risk period, i.e., the period from first infection with virus until first detection of disease; PostHRP: period from first detection of disease until eradication of disease.

Table 5.4

Overview of annual costs of preventive measures, main assumptions and sources of information used[a]

Preventive measure	Annual cost (million Euro)	Assumptions	Sources
LT_C&D	8.34	– 144 listed washing places need 1 additional employee at 43 900 Euro/year – 20 542 returning livestock trucks to be cleaned and disinfected when returning to the Netherlands at 25 Euro/livestock truck – 17 extra livestock trucks are needed to export the same number of pigs at 32 887 Euro/year for investment and 55 200 Euro/year for wages of driver	National Inspection Service for Livestock and Meat (RVV), Voorburg; Animal Movement system (ANIMO); Scenario tree model calculations; Dijkstra, 1995; Lambooij, 2002; KWIN, 2003
LT_N&I	4.61	– 46 extra livestock trucks are needed to export the same number of pigs at 32 887 Euro/year for investment and 55 200 Euro/year for wages of driver – 22 112 livestock trucks need extra cleaning and disinfection at 25 Euro/livestock truck	Animal Movement system (ANIMO); Dijkstra, 1995; Lambooij, 2002; Meuwissen et al., 2002
LT_CONT	21.66	– 1 400 livestock trucks are replaced by a more expensive livestock truck with detachable container at 6 883 Euro/year for extra investment – 127 extra livestock trucks are needed to export the same number of pigs at 39 770 Euro/year for investment and 55 200 Euro/year for wages of driver	Dijkstra, 1995; Lambooij, 2002; Ipema et al., 2002
PF_S&D	9.47	– 80% of pig farms already have separate supply and delivery routes – 20% of 1 275 multiplier farms have to build two hygiene channels and to pave an area of 700 m^2 at 5 219 Euro/year for investment – 20% of 3 798 farrow-to-finish farms have to build two hygiene channels and to pave an area of 700 m^2 at 4 383 Euro/year for investment – 20% of 6 778 finishing farms have to build two hygiene channels and to pave an area of 700 m^2 at 3 547 Euro/year for investment	KWIN, 2003; PVE, 2003

Table 5.4 (continued)

Preventive measure	Annual cost (million Euro)	Assumptions	Sources
SL_LOG	5.70	– 14 616 000 pigs slaughtered at 0 Euro/pig for logistic supply[b] – 14 616 000 pigs slaughtered at 0.39 Euro/pig for additional cleaning at the end of the day	PVE, 2003; Van der Gaag, 2004; Van der Gaag et al., 2004
IMP_TEST	0.82	– blood samples collected for 254 batches of pigs at 85 Euro/batch (fixed costs) and 5.67 Euro/pig (variable costs) – 17 640 pigs tested at 27 Euro/test – 2.5 extra livestock trucks are needed to import the same number of pigs at 32 887 Euro/year for investment and 55 200 Euro/year for wages of driver	CIDC-Lelystad; Animal movement system (ANIMO); Dijkstra, 1995; Lambooij, 2002

[a] More detailed information on the calculation of costs is available on request.

[b] Cost of logistic supply was not calculated due to lack of information on input variables.

size, investments already made, working methods, etc., the annual costs calculated for the preventive measures are only a rough estimate. Because of the uncertainties involved in the cost calculations, a sensitivity analysis was performed to test the robustness of the conclusions. In this sensitivity analysis the annual cost of each preventive measure was increased and decreased by 25%.

5.2.3.3. *Calculation of cost-effectiveness*

To calculate the cost-effectiveness of the preventive measures the reduction of the annual P_{CSFV} achieved by each preventive measure (ΔP) was divided by the annual cost required to implement that measure (ΔC). The cost-effectiveness ratios were calculated for both the median and 0.95 percentile values of the annual P_{CSFV}. In formulas:

$$CE_{0.50} = {}^{\Delta P_{0.50}}\!\big/_{\Delta C} \tag{1}$$

$$CE_{0.95} = {}^{\Delta P_{0.95}}\!\big/_{\Delta C} \tag{2}$$

5.3. RESULTS

5.3.1. Probability of CSFV introduction into the Netherlands

5.3.1.1. *Default scenario*

Default calculations with the scenario tree model for CSFV introduction show that the overall annual P_{CSFV} into the Netherlands varies between $6.2*10^{-4}$ (minimum) and $3.5*10^{-1}$ (maximum). These differences are due to yearly changes in the occurrence and course of CSF epidemics in the countries of origin. In years with few and small CSF epidemics in the countries of origin, the probability is at its minimum level and in years with many and large CSF epidemics in the countries of origin, the probability is at its maximum level. The median value for the overall annual P_{CSFV} into the Netherlands is 0.0246, indicating that for 50% of the years the overall annual P_{CSFV} will be lower than this value. The 0.95 percentile is 0.1279, indicating that – if the current situation remained the same – then the overall annual P_{CSFV}

would only exceeded 12.8% for five years in every century. The mean value for the overall annual P_{CSFV} is 0.0398, indicating that the Netherlands can expect CSFV introduction on average once every 25 years from the pathways and countries of origin included in the model.

Fig. 5.3 gives insight into the main countries of origin contributing to the overall annual P_{CSFV} into the Netherlands. Both the average probability per epidemic and the average probability per year are shown. For some countries of origin, i.e., Portugal, Austria, Finland, and Sweden, the probability that they cause CSFV introduction into the Netherlands is very small (probability per epidemic $< 5.0*10^{-6}$) and could not therefore be displayed in the figure. Germany, Belgium, and Spain are the countries of origin that contribute most to the annual P_{CSFV} into the Netherlands. The P_{CSFV} into the Netherlands during a single epidemic in Germany is much lower than the annual probability, which is explained by the high number of expected epidemics per year in Germany (see Table 5.1). For Spain the expected number of epidemics is exactly 1 per year, which results in a probability per epidemic equal to the probability per year. For most other countries of origin the expected number of epidemics per year is less than 1, which explains that the probability per year is smaller than the probability per epidemic for those countries. The probability per epidemic is highest for Belgium, indicating that the Netherlands is most at risk for CSFV introduction if CSFV is present in this country of origin. During an epidemic in Ireland the P_{CSFV} into the Netherlands is also quite high. This is explained by the small number of pig farms in Ireland (see Table 5.1), resulting in a relatively high probability that batches of pigs imported into the Netherlands originate from an infected farm.

Fig. 5.4 presents an overview of the relative contribution of pathways to the overall annual P_{CSFV} into the Netherlands. On average, returning livestock trucks contribute most to P_{CSFV} with 50.1%. This is mainly due to the large number of pathway-units present: the Netherlands is a major exporter of pigs ($9.31*10^6$ pigs exported versus $3.11*10^5$ pigs imported in 2003). Import of fattening pigs contributes next with 22.2%. Although the majority of imported pigs consists of fattening pigs (94% in 2003), these contribute only slightly more than pigs imported for life (breeding pigs 13.8% and piglets 7.2%). This is explained by the P_{CSFV} per pathway-unit, which is highest for pigs imported for life. Import of pork products contributes only 6.6%, and this can be attributed to 96% to the import of fresh/chilled and frozen pork products. Direct and indirect contact with wild boar did not contribute to the annual P_{CSFV} into the Netherlands, as no CSF infections have occurred in Dutch wild boar populations in recent years (Elbers and Dekkers, 2000; A.R.W. Elbers, personal communication).

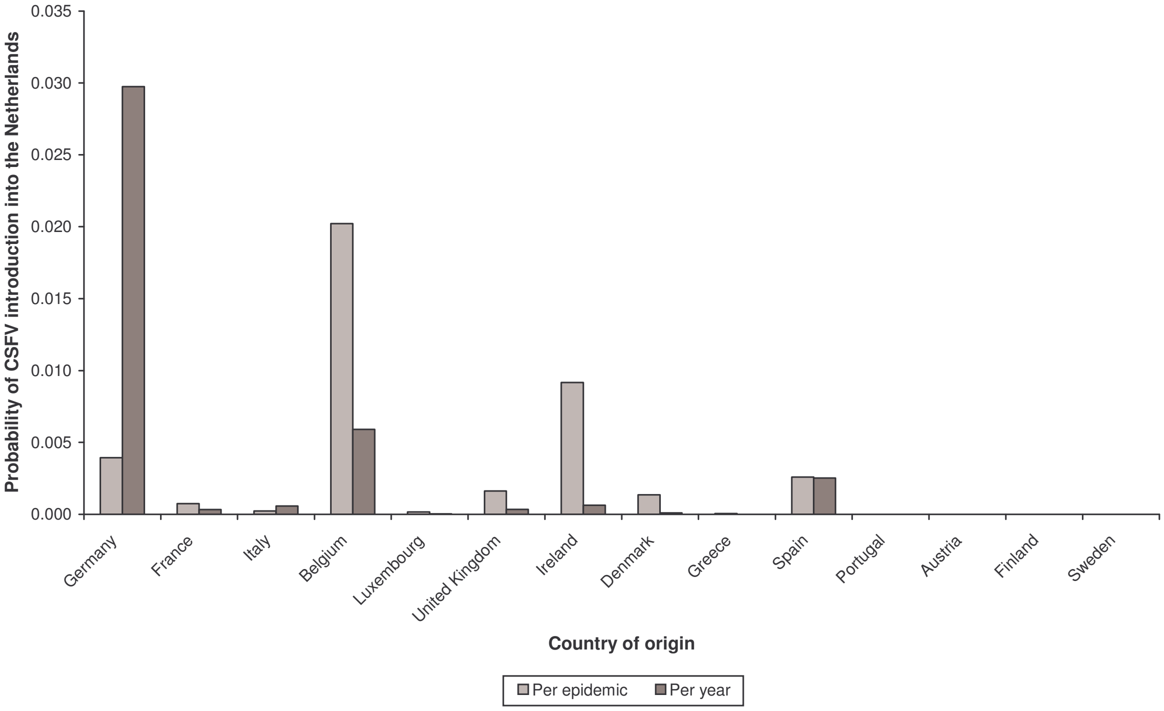

Fig. 5.3. Probability of CSFV introduction into the Netherlands from each country of origin in the model (all EU member states), both per epidemic in the country of origin and per year.

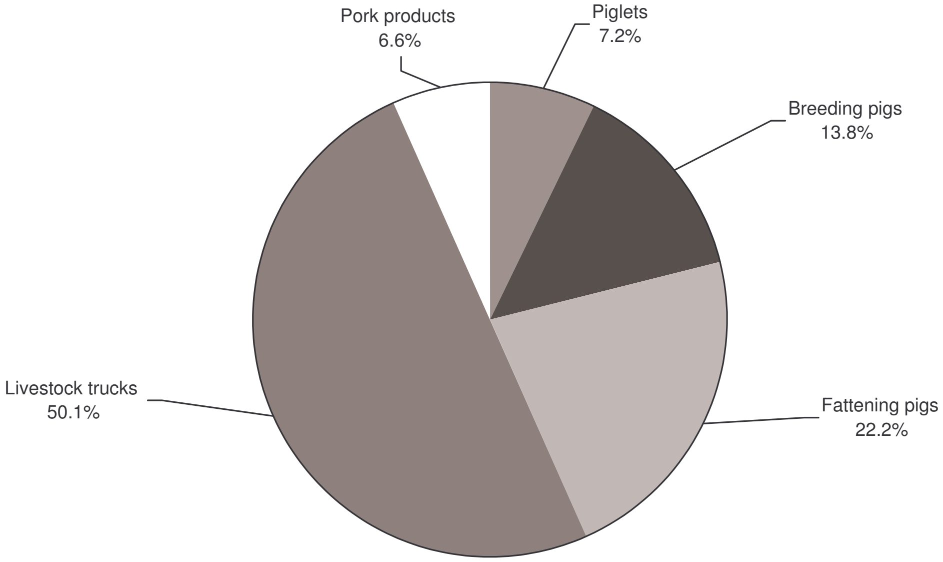

Fig. 5.4. Relative contribution of pathways in the model to the overall annual probability of CSFV introduction into the Netherlands.

5.3.1.2. *Effect of preventive measures*

Table 5.5 shows the mean, median, 0.95 percentile, and maximum values of the annual P_{CSFV} into the Netherlands for all scenarios. In Fig. 5.5 the cdf for the overall annual P_{CSFV} into the Netherlands is shown for the default scenario and when each of the preventive measures is applied. It is evident that the P_{CSFV} is highest for the default scenario, i.e. when no additional preventive measures are applied. Separation of national and international transport of pigs (LT_N&I) appears to be most effective in reducing the annual P_{CSFV}. Cleansing and disinfection of all returning livestock trucks (LT_C&D) and livestock trucks with detachable containers (LT_CONT) are equally effective up till about the 0.85 percentile, but differ in their effectivity with regard to worst-case situations. Applying LT_CONT, the maximum P_{CSFV} is 0.2476, whereas applying LT_C&D the maximum P_{CSFV} is only 0.1394. Comparing these values to the maximum P_{CSFV} in the default scenario, which is 0.3533, it can be concluded that LT_C&D is more effective than LT_CONT. A logistic supply of fattening pigs at slaughterhouses (SL_LOG) and testing piglets and breeding pigs by a quick and reliable PCR (polymerase chain reaction) (IMP_TEST) are equally effective and attain only a small reduction in P_{CSFV} compared with the default scenario.

Table 5.5

Mean, median, 0.95 percentile, and maximum values of the annual probability of CSFV introduction into the Netherlands for the default scenario and when applying six different measures aimed at preventing the introduction of CSFV into the country

Preventive measure	Mean	Median	0.95 Percentile	Maximum
Default	0.0398	0.0246	0.1279	0.3533
LT_C&D	0.0174	0.0125	0.0502	0.1394
LT_N&I	0.0144	0.0102	0.0412	0.1082
LT_CONT	0.0191	0.0120	0.0566	0.2476
PF_S&D	0.0250	0.0150	0.0826	0.2476
SL_LOG	0.0366	0.0216	0.1224	0.3363
IMP_TEST	0.0353	0.0200	0.1204	0.3353

Fig. 5.6 shows the annual P_{CSFV} into the Netherlands from the countries of origin contributing most to the overall annual P_{CSFV}, i.e., Germany, Belgium, and Spain. LT_N&I is the most effective measure for these countries of origin. For Belgium, the difference in effectiveness of the measures is, however, not as big as for the overall annual P_{CSFV} into the Netherlands, whereas for Spain the differences are even more emphasised. This is because the pathway returning livestock trucks is the main contributor to the annual probability of CSFV

introduction from Spain (98%), whereas for Belgium the import of fattening pigs has a relatively large share in the annual P_{CSFV} (52%). The absolute reduction of the annual P_{CSFV} by applying preventive measures is highest for Germany. Directing preventive measures at this country of origin alone results in a reduction in the overall annual P_{CSFV} into the Netherlands of about 55% (SL_LOG) up to about 80% (LT_C&D, LT_N&I, LT_CONT, and separate supply and delivery routes on primary farms (PF_S&D)) of the reduction achieved when directing preventive measures at all countries of origin.

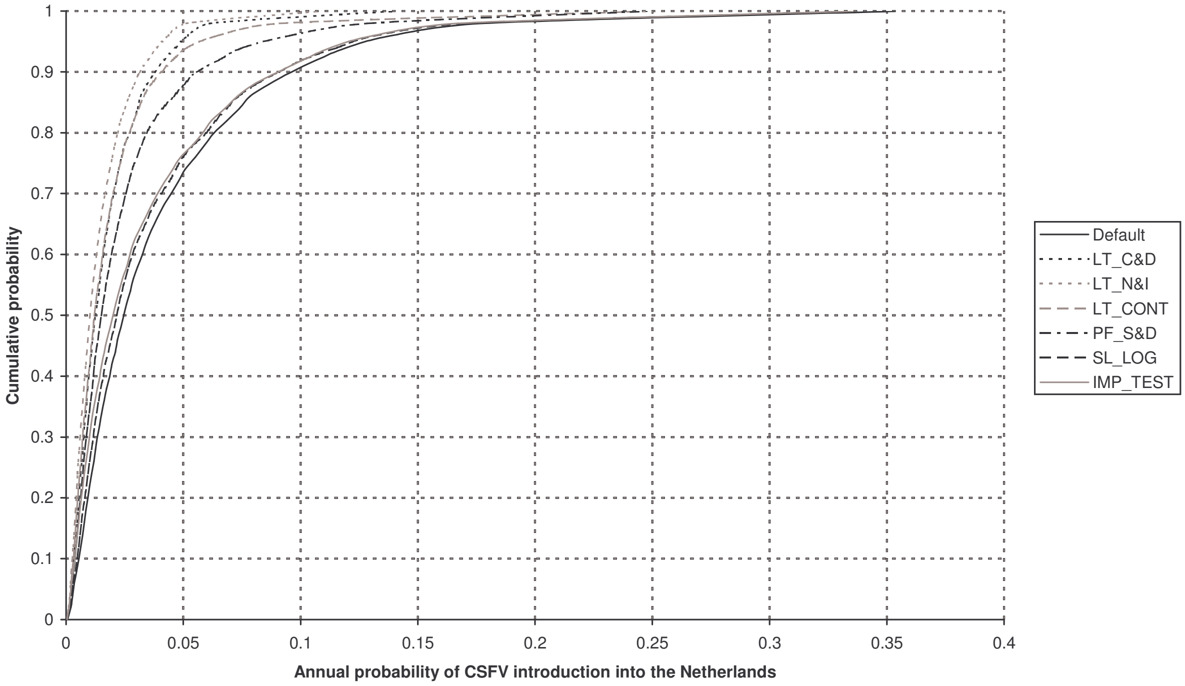

Fig. 5.5. Cumulative distribution function of the annual probability of CSFV introduction into the Netherlands for the default scenario and when applying six different measures aimed at preventing the introduction of CSFV into the country.

Fig. 5.7 shows the relative contribution of pathways to the annual P_{CSFV} into the Netherlands for the default scenario and when each of the preventive measures is applied. The shifts in relative importance are as expected: applying LT_C&D, LT_N&I, LT_CONT, and PF_S&D reduces the relative importance of returning livestock trucks, applying SL_LOG reduces the relative importance of import of fattening pigs, whereas applying IMP_TEST reduces the relative importance of import of breeding pigs and piglets. Again it is clearly shown that LT_N&I is most effective: the relative importance of returning livestock trucks is reduced from 50% in the default scenario to only 5% when applying this measure. Although applying IMP_TEST results in only a slight reduction of the overall annual P_{CSFV}, it almost

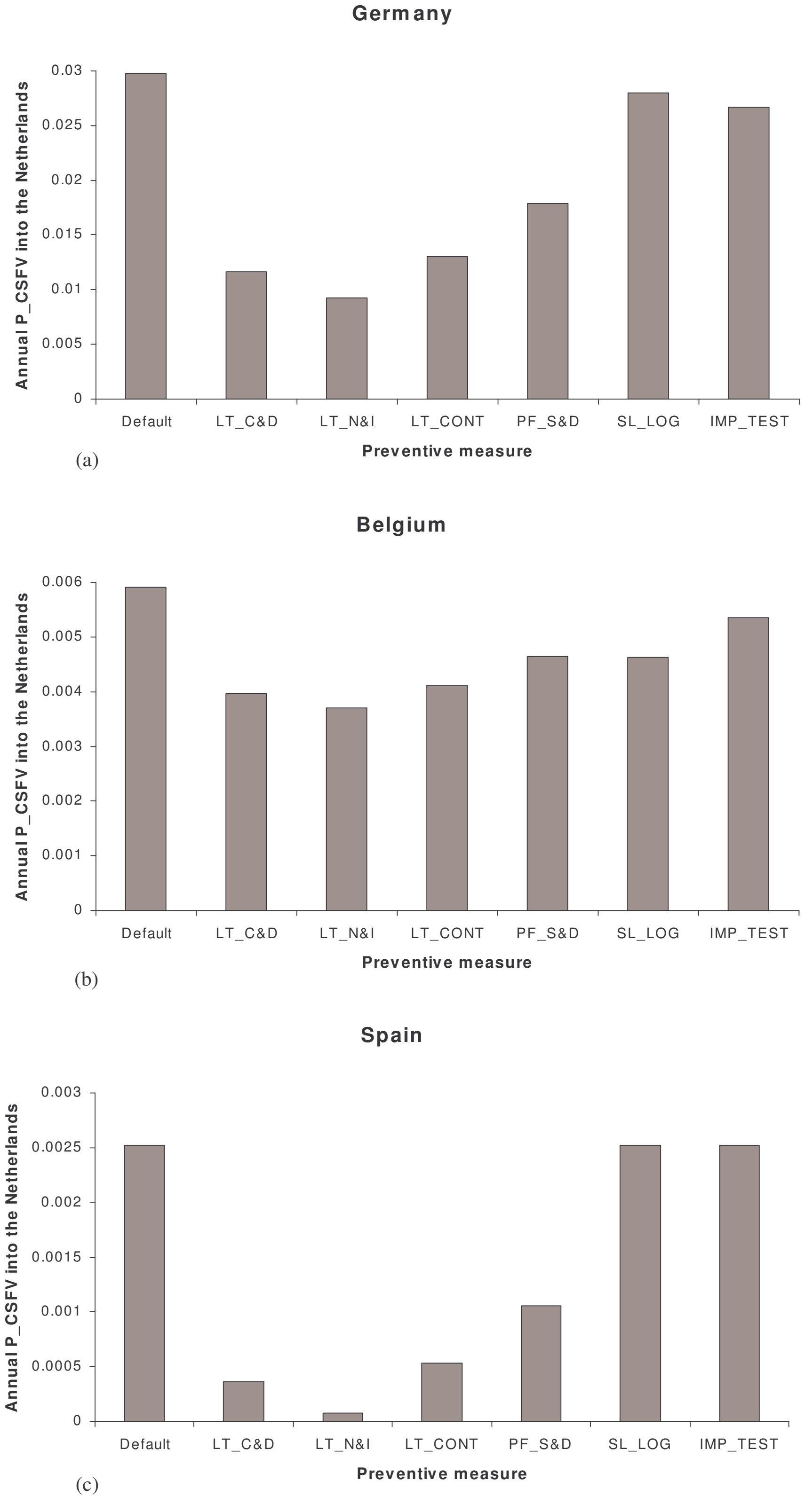

Fig. 5.6. Annual probability of CSFV introduction into the Netherlands from (a) Germany, (b) Belgium, and (c) Spain for the default scenario and when applying six different measures aimed at preventing the introduction of CSFV.

eliminates the risk constituted by the import of breeding pigs and piglets. Therefore, it can be concluded that IMP_TEST is a very effective measure in itself, but contributes only slightly to the reduction of the overall annual P_{CSFV} into the Netherlands, as imports of breeding pigs and piglets are small (see Table 5.1).

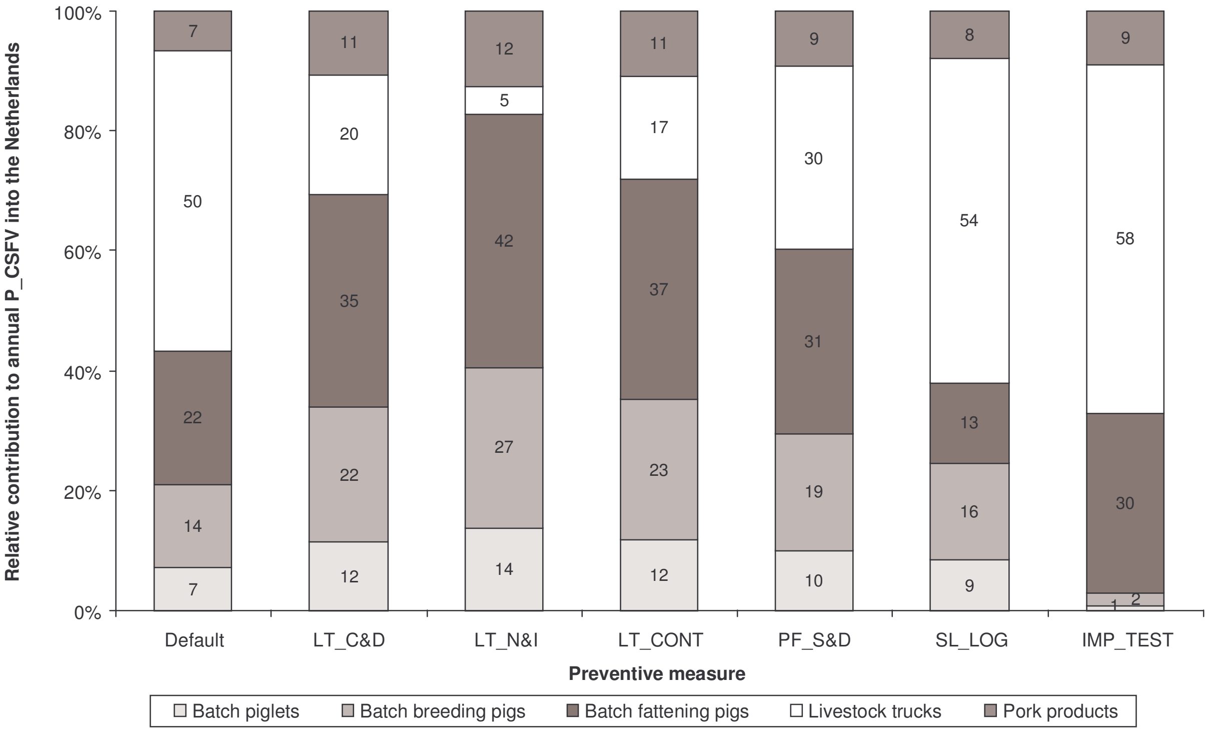

Fig. 5.7. Relative contribution of pathways in the model to the overall annual probability of CSFV introduction into the Netherlands for the default scenario and when applying six different measures aimed at preventing the introduction of CSFV into the country.

5.3.2. Cost-effectiveness of preventive measures

Fig. 5.8 shows a scatter plot with for each preventive measure, its annual cost (ΔC) at the x-axis, and the achieved reduction of the median annual P_{CSFV} ($\Delta P_{0.50}$) at the y-axis. From this graph it is evident that only LT_N&I and IMP_TEST are cost-efficient, i.e., implementing the other preventive measures brings higher annual cost whereas the achieved reduction of the annual P_{CSFV} is equal or less. In Table 5.6 the cost-effectiveness ratios of the preventive measures are given. These values indicate that IMP_TEST is most cost-effective in reducing the annual P_{CSFV} into the Netherlands when considering median values. For 0.95 percentile values, however, LT_N&I is by far the most cost-effective measure. SL_LOG is the least cost-effective for both output values used. The sensitivity analysis of the annual cost of preventive measures by increasing and decreasing values by 25% showed that the results of the cost-effectiveness analysis were robust. The absolute values of the cost-effectiveness ratios changed, but the ranking of measures based on these values did not change.

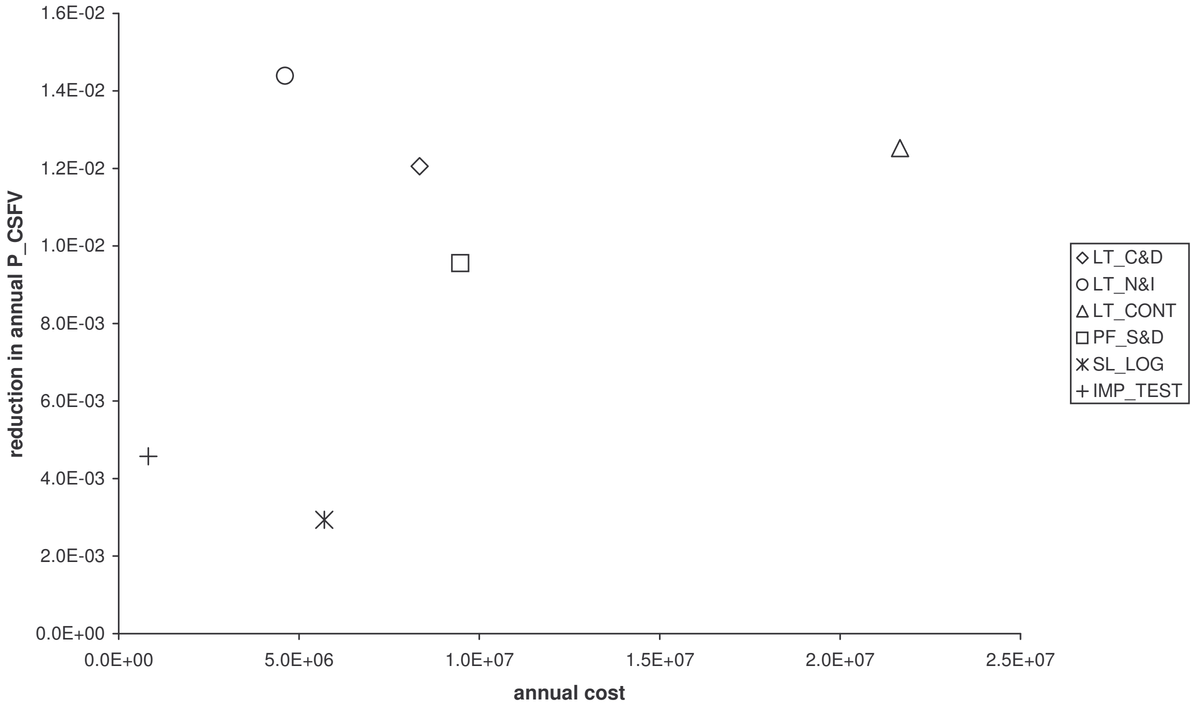

Fig. 5.8. Scatter plot showing the annual cost (ΔC) and reduction of the median annual P_{CSFV} ($\Delta P_{0.50}$) for six different measures aimed at preventing the introduction of CSFV into the country.

Table 5.6

Cost-effectiveness ratios for six different measures aimed at preventing the introduction of CSFV into the country

Preventive measure	Achieved reduction of the annual P_{CSFV}		Annual cost (million Euro)	Cost-effectiveness ratio ($euro^{-1}*10^{10}$)	
	$\Delta P_{0.50}$	$\Delta P_{0.95}$	ΔC	$CE_{0.50}$	$CE_{0.95}$
LT_C&D	0.0121	0.0777	8.34	14	93
LT_N&I	0.0144	0.0867	4.61	31	188
LT_CONT	0.0125	0.0713	21.66	6	33
PF_S&D	0.0096	0.0453	9.47	10	48
SL_LOG	0.0029	0.0054	5.70	5	9
IMP_TEST	0.0046	0.0075	0.82	56	91

5.4. DISCUSSION

5.4.1. Probability of CSFV introduction into the Netherlands

Fig. 5.3 and 5.4 presented a clear overview of the pathways and countries of origin contributing most to the annual P_{CSFV} into the Netherlands in the current situation. These model results were used to select tactical measures aimed at prevention of CSFV introduction. The effectiveness of these measures was calculated as the achieved reduction of the overall annual P_{CSFV} into the Netherlands (ΔP). For a comparative study like this, the annual P_{CSFV} was an adequate model output parameter, although its absolute value in the default scenario is quite low when compared with expert estimates (Horst et al., 1998; Meuwissen et al., 2000) and recent history (Elbers et al., 1999; De Vos et al., 2000). The model most probably underestimates the overall annual P_{CSFV} as not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries (see De Vos et al., 2004a).

Preventive measures directed at the pig transport sector (i.e. LT_C&D, LT_N&I, and LT_CONT) were most effective in reducing the annual P_{CSFV} into the Netherlands. These measures reduce the contribution of returning livestock trucks to the annual P_{CSFV}. Although separate supply and delivery routes on primary farms (PF_S&D) also affect the probability that CSFV is introduced by returning livestock trucks, this measure was less effective. A logistic supply of fattening pigs at slaughterhouses (SL_LOG) was as effective as testing piglets and breeding pigs by a quick and reliable PCR (IMP_TEST). The total number of batches of fattening pigs imported in 2003 was, however, much higher than the total number of batches of breeding pigs and piglets imported (Table 5.1). The effectivity per pathway-unit was thus higher for IMP_TEST. This is also illustrated by Fig. 5.7: SL_LOG reduced the relative contribution of the pathway import of fattening from 22% to 13%, whereas IMP_TEST reduced the relative contribution of the pathways import of breeding pigs and import of piglets from 14% to 2%, and from 7% to 1%, respectively. SL_LOG and IMP_TEST will continue to be less effective than the other preventive measures, as long as the Netherlands is a major exporter of pigs, and imports of pigs are only marginal compared to exports. It should be kept in mind, however, that the conclusions of this study are based on the current situation. Shifts in trade patterns – either pathways or countries of origin, or both – might lead to different conclusions with regard to the effectiveness of the preventive measures.

5.4.2. Cost-effectiveness of preventive measures

Based on effectiveness only, LT_CONT was quite a promising preventive measure (see Fig. 5.5). Its cost-effectiveness ratio is, however, quite low as implementing this measure incurs high annual cost (Table 5.6). On the contrary, IMP_TEST only attained a small reduction of the annual P_{CSFV} but had a high cost-effectiveness ratio due to its low annual cost. This is due to the small number of pigs imported for life by the Netherlands (17 640 pigs in 2003). In terms of cost per pig this measure is thus very expensive and despite its high cost-effectiveness ratio not attractive unless heavily subsidised. This illustrates that although the cost-effectiveness ratio provides good insight into the reduction in the annual P_{CSFV} gained per Euro invested, one should not focus only on cost-effectiveness ratios when deciding on preventive measures.

Sensitivity analysis of the annual cost of preventive measures demonstrated that the outcome of the cost-effectiveness analysis was robust, despite uncertainties involved in the cost calculations. This was not surprising given the large differences between the highest and lowest cost-effectiveness ratios (see Table 5.6). For median values, LT_N&I and IMP_TEST had much higher cost-effectiveness ratios than all other measures, whereas for the 0.95 percentile values LT_N&I was by far the most cost-effective measure. SL_LOG was the least cost-effective for both cost-effectiveness ratios and might even be less cost-effective in reality, as the costs of logistic supply were set at 0 Euro per pig due to lack of information (see Table 5.4).

The cost-effectiveness ratios based on the median annual P_{CSFV} assume risk neutrality. Risk-averse decision-makers will tend to reduce especially the risk of a high annual P_{CSFV}. The cost-effectiveness ratios based on the 0.95 percentiles of the annual P_{CSFV} indicate which preventive measures are most cost-effective in reducing the P_{CSFV} in ‘bad years’, i.e. in years with many large CSF epidemics in the EU. The calculations showed that under a risk-averse policy LT_N&I is by far the most cost-effective measure and that than LT_C&D is preferred over IMP_TEST.

For the 0.95 percentile values of the annual P_{CSFV}, the cost-effectiveness ratios of LT_C&D and IMP_TEST are almost equal. In such a case other criteria are needed to decide which preventive measure is preferred. If the ultimate goal of the preventive actions is to maximally reduce the annual P_{CSFV}, the effectiveness expressed as ΔP is the most important parameter and LT_C&D will be preferred. In case there is a fixed budget that can be spent on prevention of CSFV introduction, the annual cost (ΔC) of implementing the measures is the most important parameter. Then the preventive measure with the highest cost-effectiveness that fits in the budget will be preferred.

5.4.3. Selection of preventive measures

Preventive actions can either be directed at the number of pathway-units or at the probability of CSFV introduction per pathway-unit. Reducing the number of pathway-units can, however, not be attained by regulations imposed by policymakers. Intra-EU trade of pigs and pork products is no longer hampered by national borders since the establishment of the free internal market in 1993 (Anonymous, 1993). And even imports from outside the EU, although small, can only be prohibited on the basis of sanitary or phytosanitary arguments, i.e., if there is a proved risk that such imports pose a threat to human or animal health (WTO, 1995). Therefore only the cost-effectiveness of preventive measures aimed at reducing the probability of CSFV introduction per pathway-unit was considered in this study.

Under current EU law testing imported piglets and breeding pigs by a quick and reliable PCR is not allowed either. Nevertheless, this preventive measure was included in the cost-effectiveness analysis to investigate if it is worth considering when the goal is to reduce the annual P_{CSFV} into the Netherlands. Results showed that despite a high cost-effectiveness ratio this measure is not attractive due to its high cost per imported pig. Besides, implementing this measure causes difficulties. To prevent CSFV introduction the pigs should be tested at the border and remain in the lorries until test results are known (i.e. for a maximum period of 24 hours). With regard to animal welfare it would, however, be better to test the pigs at the farm in the country of origin before issuing the health certificate.

No preventive actions were directed at the pathways concerning the import of pork products and contacts with wild boar. In the scenario tree model, imported pork products can only result in a CSF infection of susceptible pigs if fed as swill. Although feeding of swill is forbidden in the EU (CEC, 2001), the model contains a small probability of infection by swill feeding to account for illegal practices. The contribution of imported pork products to the annual P_{CSFV} into the Netherlands is thus due to illegal swill feeding only and therefore it was impossible to direct preventive measures at these pathways. Measures to prevent CSFV introduction by direct or indirect contact with wild boar might be very effective if CSFV is present in the wild boar population. Previous model calculations showed that a 10% seroprevalence for CSFV in the Dutch wild boar population would increase the annual P_{CSFV} into the Netherlands by about 60% (De Vos et al., 2004a). In the default scenario these pathways did not however contribute to the annual P_{CSFV} into the Netherlands as the Dutch wild boar population is currently free of CSFV. Therefore it was impossible to calculate the effectiveness of measures directed at these pathways.

A more extensive analysis of the cost-effectiveness of the selected preventive measures was not possible due especially to the lack of information on the costs of measures. Implementing packages of preventive measures might, however, lead to different cost-effectiveness ratios, especially if the measures in a package intervene at the same pathway. Targeting a preventive measure at only one or a few countries of origin might achieve almost the same reduction of the annual P_{CSFV} at reduced cost. The default calculations showed that Germany contributed most to the annual P_{CSFV}. Targeting preventive measures only at this country of origin would thus result in a considerable reduction of the annual P_{CSFV}. This is, however, only possible for LT_C&D, LT_N&I, and IMP_TEST. Implementing the other preventive measures is only possible for all countries of origin simultaneously. Another option for reducing the expenses of preventive measures is to implement them only when it is known that CSFV is present in the country of origin, i.e. during the PostHRP[15]. For most countries of origin the probability of CSFV introduction is, however, highest during the HRP of an epidemic. The effectiveness of preventive measures will thus also be greatly reduced when applied only during the PostHRP.

In this study only preventive actions directed at the pathways included in the scenario tree model could be analysed. Although the scenario tree model most probably contains those pathways contributing most to the annual P_{CSFV} (De Vos et al., 2004a), other pathways such as tourists, illegal imports, and laboratories working with CSFV can also lead to CSFV introduction. The relative importance of these pathways will increase if one or more of the preventive measures of this study are implemented. More insight into the underlying mechanisms of CSFV introduction by pathways not included in the model is then required to further reduce the overall annual P_{CSFV}.

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[15] HRP: high-risk period, i.e., the period from first infection with virus until first detection of disease; PostHRP: period from first detection of disease until eradication of disease.

5.4.4. Concluding remarks

The aim of this paper was to explore the cost-effectiveness of tactical measures aimed at prevention of CSFV introduction into the Netherlands. The results showed that, for cost-effectiveness, separation of national and international transport of pigs (LT_N&I) should be preferred. The logistic supply of fattening pigs at slaughterhouses (SL_LOG), on the contrary, is not worth the expense, given both its low effectiveness and low cost-effectiveness ratio. The sensitivity analysis confirmed the robustness of these conclusions. However, cost-effectiveness is not the only criterion when implementing a preventive measure. For a conscious decision the following issues should also be taken into account.

a) Ease of implementation of the measure, e.g. are small or large investments required, can a measure easily be introduced in the current situation or are significant adaptations required in farm management or the pig transport sector?

b) Allocation of costs and benefits over different actors, such as primary producers, pig transport sector, slaughterhouses, government, and consumers, i.e. who pays and who gains? LT_C&D, LT_N&I and LT_CONT mainly incur costs for the pig transport sector, PF_S&D and IMP_TEST for primary producers, and SL_LOG for slaughterhouses. Although IMP_TEST has a high cost-effectiveness ratio, this measure is far too expensive for primary producers. Such a measure can only be implemented when subsidised. Besides, costs of preventive measures carried out by, for example, the pig transport sector can be partly transferred to primary producers.

c) Cost-benefit ratio, i.e. is the measure worth its cost anyhow? A rough estimate of the monetary benefits of measures aimed at the prevention of CSFV introduction was obtained by multiplying the achieved reduction of the annual P_{CSFV} by the average cost of a CSF epidemic for the Netherlands (VWA, 2003). This indicated that the annual cost of preventive measures was higher than the expected annual benefits. However, the annual benefits of the preventive measures are most likely largely underestimated for two reasons. Firstly, calculation of benefits was based on the direct cost of an epidemic only, i.e. cost of controlling the epidemic. Indirect losses due to business standstill and especially export bans are in general much higher than the control cost of an epidemic (Mangen, 2002). Secondly, the annual P_{CSFV} calculated by the model is small when compared with recent history and expert estimates. This might result in an underestimation of the reduction in the annual P_{CSFV} by the measures.

d) Attributable cost, i.e. should all cost of implementing a measure be recovered by the reduction of the annual P_{CSFV} or can side-effects be expected resulting in additional benefits? All measures described in this study, except IMP_TEST, will also reduce the probability of introduction of other contagious pig diseases, such as FMD and African swine fever (ASF). Furthermore, LT_CONT and PF_S&D also reduce possible spread mechanisms during epidemics of contagious pig diseases. It was, however, impossible to quantify these reductions of disease introduction and spread and the accompanying benefits.

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Chapter 6

General discussion

6.1. INTRODUCTION

The research described in this thesis focused on a risk analysis of classical swine fever (CSF) introduction. The main objective of this study was to provide quantitative insight into the major risk factors contributing to the probability of CSF virus (CSFV) introduction (P_{CSFV}) to provide support for decision-making on the prevention of CSFV introduction. This objective was subdivided into three parts, which were dealt with in the various chapters of this thesis: an overview of all factors possibly contributing to the P_{CSFV} into the domestic pig population of a country (Chapter 2); the development of a model to quantitatively estimate the relative contribution of risk factors to the annual P_{CSFV} (Chapter 3 and 4); and a cost-effectiveness analysis of tactical measures aimed at preventing CSFV introduction (Chapter 5).

In this chapter the two critical steps of this risk analysis study – quantitative risk assessment and risk management – are discussed in more detail. The quantitative risk assessment of CSFV introduction into the Netherlands was carried out using a scenario tree model. This model is discussed with respect to the following four critical issues: definition of the system (Section 6.2.1), modelling approach (Section 6.2.2), model validation (Section 6.2.3), and model behaviour (Section 6.2.4). Then, risk management of CSFV introduction is discussed considering the definition of risk, which comprises both the probability and consequences of an adverse event. In this thesis emphasis has been placed on the (low) probability of CSFV introduction and not so much on the (high) consequences. Other studies have concentrated on the latter aspect, see for example the theses of Mangen (2002), Dewulf (2002), and Klinkenberg (2003). In Section 6.3.1 risk management through prevention of CSFV introduction is discussed. Next, some aspects of risk management through controlling the spread of CSFV during epidemics are described (Section 6.3.2). Then, important issues in balancing preventive and control measures to reduce the overall risk of CSFV introduction are highlighted (Section 6.3.3). The chapter ends with a list of the main conclusions of this thesis (Section 6.4).

6.2. SCENARIO TREE MODEL FOR CSFV INTRODUCTION

6.2.1. Definition of the system

The first step in a modelling study is to define the system of interest, which primarily depends on the objective of the research. As mentioned in the introduction, the main objective of this thesis focused on the introduction of CSFV. CSFV introduction was defined as the entrance of the virus into the *domestic pig population* of a region free of the disease, causing a primary outbreak. Virus introduction into the *wild boar population* was not considered since prevention and control strategies and the economic consequences of such an introduction are different (Anonymous, 1998; Anonymous, 1999; Laddomada, 2000; CEC, 2001; Schnyder et al., 2002).

The main aim of the model was to provide a better understanding of the importance of the different introduction routes of CSFV for a particular region. For this purpose, the model calculated the annual P_{CSFV} into this region, which was referred to as the target region. The scenario tree model was constructed such that all European Union (EU) member states could be chosen as a target region. In this study, model calculations were, however, only performed for the Netherlands, since most extensive data were available for this EU member state. The main determinants of the annual P_{CSFV} were (1) countries of origin (see Section 6.2.1.1) and (2) pathways, i.e. carriers and mechanisms that can transmit the virus from an infected animal to a susceptible one (see Section 6.2.1.2). The choice for, and implications of, modelling the P_{CSFV} at country level are discussed in Section 6.2.1.3.

6.2.1.1. Countries of origin

All 15 EU member states were included in the model as possible countries of origin[16]. No third countries were included for two reasons: (i) import of live pigs and pork products from third countries was marginal compared to trade within the EU (less than 5% of total imports) and (ii) information available on the occurrence of CSF in third countries was not sufficiently detailed. However, few imports does not mean that the probability of CSFV introduction from

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[16] The research described was carried out before the enlargement of the EU by 10 new member states on May 1, 2004.

third countries is, by definition, negligible. The P_{CSFV} per pathway-unit[17] imported from third countries might, for example, be relatively high. It was, however, not possible to determine these issues quantitatively.

An extension of the model to account for the enlargement of the EU as of May 1, 2004 might lead to different model outcomes. Such an extension would be a valuable exercise given the imperfect knowledge and uncertainties the Netherlands is facing with regard to the probability that CSFV may be introduced from these new member states. Up till 2004, trade in pigs – which accounts for more than 90 percent of the annual P_{CSFV} in the current situation – was only marginal with the new member states (PVE, 2004). However, this will most probably increase in the coming years as the new member states become part of the internal market. The new member states have not experienced large CSF epidemics in recent times (OIE, 2004a). It is, however, not fully clear to what extent CSFV is still present in the wild boar populations of some of these countries (Laddomada, 2000). Slovakia reported numerous outbreaks in wild boar during the last decade. The latest outbreaks reported by the other new member states date from before 2000. An objective and transparent quantitative risk assessment of the probability that CSFV will be introduced from these new member states is needed to confirm or deny the general feeling that these new member states are an important potential source of CSFV introduction. Calculations using the scenario tree model can furthermore indicate whether new priorities for preventing CSFV introduction need to be set.

6.2.1.2. *Pathways*

The pathway diagram of Chapter 2 showed all possible pathways for CSFV introduction. A selection of these pathways was made for inclusion in the scenario tree model. Two selection criteria were used: (i) expected importance for CSFV introduction on the basis of historical data and scientific literature and (ii) availability of knowledge and data to quantify the underlying probabilities. Although excluding some pathways from the model is somewhat contradictory to the main goal of the model, which was to analyse which risk factors contribute most to the annual P_{CSFV}, no other choice was available. For some pathways it was impossible to quantify the number of pathway-units and/or the probability of CSFV

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[17] Unit in which a pathway is measured, e.g., a batch of animals, a metric ton of animal products or a returning livestock truck.

introduction per pathway-unit. Therefore, the risk of all pathways was assessed qualitatively and only those pathways for which the risk was perceived to be high and for which data were available were included in the model for a quantitative risk assessment (Zepeda et al., 2001).

This procedure led to the inclusion of three exogenous pathways, viz. *import of pigs*, *import of pork products*, and *returning livestock trucks*, and one endogenous pathway, viz. *wild boar*. Recent history indicated that *transports of live pigs*, *contact with infected wild boar*, and *feeding of improperly heated swill* were the most important routes of CSFV introduction (De Vos et al., 2000). In areas where CSFV circulates in the *wild boar* population, the risk of introducing CSF into the domestic pig population is markedly higher than in areas where CSF problems in wild boar do not exist. An analysis of CSF outbreaks in Germany from 1993 to 1997 demonstrated that 80% of all primary outbreaks were in areas at risk from wild boar fever (Fritzemeier et al., 1998), whereas for 59% of all primary outbreaks, direct or indirect contact with wild boar was indicated as the causing risk factor (Fritzemeier et al., 2000). In the two major CSF epidemics in the EU in the 1990s, *transports of live pigs* played an important role in the spread of the virus from one region to another (Davies, 1994; Kramer et al., 1995; Teuffert et al., 1998; Elbers et al., 1999; De Vos et al., 2000). A *returning livestock truck* was presumed to be responsible for initiating the Dutch 1997/98 CSF epidemic (Elbers et al., 1999; Terpstra and De Smit, 2000; Stegeman et al., 2000a). In an expert consultation conducted before this epidemic, Dutch experts considered returning livestock trucks as an important risk factor for CSFV introduction into the Netherlands (Horst et al., 1998). Strictly speaking, the *import of pork products* cannot result in CSFV introduction into the Netherlands since swill feeding is prohibited. Nevertheless, this pathway was included in the model as CSFV can survive in pork and pork products beyond processing (Blackwell, 1984; Farez and Morley, 1997). Survival can be prolonged for several months if the meat is stored at cool temperatures, or even years if stored frozen (Van Oirschot and Terpstra, 1989; Terpstra, 1991; Edwards, 2000). Illegal swill feeding without adequate heat treatment can therefore easily result in a primary CSF outbreak (Edwards et al., 2000).

Although *illegal imports of pigs and pork products* constitute a similar or even greater risk for CSFV introduction than legal imports, it cannot easily be modelled, as by definition no quantitative data are available. The pathways *imports of genetic material*, *tourists*, *professional staff*, and *harbours and airports* were also not included due to a lack of quantitative data. It has recently been demonstrated that *artificial insemination* (AI) can be a route for introduction of CSFV into a pig herd when virus-contaminated semen is used (De Smit et al., 1999). This was also observed during the CSF epidemic in the Netherlands in

1997/98, although the number of farms infected by contaminated semen was small compared to the number of herds to which the semen was distributed (Elbers et al., 1999; Hennecken et al., 2000). In general, the risk of CSFV introduction through import of semen will be small, all the more since the probability of an AI centre becoming infected with CSF is rather small given its high bio-security level. *Tourists* might contribute to the probability of CSFV introduction through illegal import of animal products – the most likely source of CSFV introduction in the UK epidemic of 2000 was an infected pork product of unknown origin (Sharpe et al., 2001) – or by mechanical transmission, for example on clothing or footwear. This also applies to *professional staff*. Clothing and footwear seem, however, of little significance in the epizootiology of CSF (Terpstra, 1987; Terpstra, 1991; Laevens et al., 1998). Quantification of the probability that foot-and-mouth disease (FMD) is introduced into the Netherlands by tourists carrying animal products into the country resulted in an average annual probability of $2.5*10^{-3}$ (Van der Aa et al., 2000). This is a huge overestimation as it was assumed that each FMD-contaminated product would result in virus introduction into the livestock production sector. The probability of CSFV introduction will be even smaller, as a large share of the imported products did not originate from pigs. On the other hand, the probability that the virus is not detected and survives maturing, processing and transport is higher for CSFV than for FMD virus. Besides, introduction by mechanical transmission was not taken into account in this study. Nevertheless, based on this study it can be concluded that the probability of CSFV introduction by tourists will be relatively small, especially as personal imports of animal products from third countries have been largely forbidden since May 1, 2004 (CEC, 2004). *Harbours and airports* contribute to the P_{CSFV} due to the feeding of waste food that originates from international transports over land, sea or through the air. This can be very risky with respect to CSFV introductions, but is forbidden in the EU (CEC, 2001). Nevertheless, a model study by Horst et al. (1999) indicated that the P_{CSFV} due to swill feeding was highest for the western region of the Netherlands where both the main airport Schiphol and the harbour of Rotterdam are located.

Imports of manure, *birds, pets, arthropods and rodents*, and *air currents* are not likely to contribute to the P_{CSFV} (Terpstra, 1988; Van Oirschot, 1992; Terpstra, 1997; Elbers et al., 1999; Stegeman et al., 2000b; Dewulf et al., 2001), nor are *laboratories*. No CSFV introductions due to the escape of CSFV from laboratories through air currents or people carrying the virus were reported in the last decades. The negative pressure environment and bio-security protocols of laboratories working with contagious viral diseases make it unlikely that they will cause CSFV introduction into the pig production sector.

6.2.1.3. Regional level used in the model

The scenario tree model was constructed at country level since most data needed for the model were only available at this level. Animal movements are either registered in the European Animal Movement system (ANIMO) if national borders are crossed, or in national Identification and Recording (I&R) systems if the pigs remain in the same country. Data on import of pork products were available at the national level only. Furthermore, for preventive purposes the country level seemed more appropriate. Although the establishment of the free internal market in 1993 led to the abolishment of veterinary border checks between member states, national borders still play an important role in the prevention of contagious animal disease introduction. As soon as, for example, CSF or FMD outbreaks occur in the EU, member states take preventive measures at the national level and revert to national border controls. The country experiencing the epidemic, however, applies a regional approach. Only the installed control and surveillance zones are defined as infected areas, and export is usually still possible from the non-infected areas – regionalisation principle (Edwards et al., 2000; OIE, 2004b). It was, however, not possible to use these regions in the scenario tree model, as their definition depends on the course of an epidemic and is thus not static. Recently, the Netherlands has been divided into 20 fixed regions that can be used for regionalisation purposes (LNV, 2004b), but these regions are – again – only activated during an epidemic and can therefore not be used for preventive purposes.

Considering the huge differences between pig production areas within the EU member states with respect to, for example, herd and pig density, it might, however, be more sensible to evaluate the introduction of CSFV and its prevention at a lower regional level, such as province or department level. Most outbreaks of the major CSF epidemics of the 1990s occurred in what are referred to as densely populated livestock areas (DPLAs), which have an average pig density of more than 300 pigs/km^2 (Michel and De Vos, 2000). It was hypothesised that the concentration of pig production in these areas is correlated with the risk of introduction and spread of epidemic diseases (Dijkhuizen and Davies, 1995; Huirne and Windhorst, 2003). The qualitative risk assessment in Chapter 2 indicated that DPLAs generally have a higher probability of CSFV introduction than sparsely populated livestock areas (SPLAs), although this could not be attributed to pig density alone. This seems in contrast with the results of a study by Ferrè et al. (2003), who used a multiple attribute technique to rank DPLAs and SPLAs according to their risk of CSFV introduction and concluded that this risk is in general higher for SPLAs than for DPLAs. However, the calculations performed in this study did result in the risk of CSFV introduction per farm and not per region. Multiplying the risk ratios of Ferrè et al. (2003) by the total number of farms (see Table 2.2a of Chapter 2) will, in general, result in a higher risk per region for DPLAs. A quantitative risk assessment with the scenario tree model can give a more precise estimate of the P_{CSFV} into DPLAs and SPLAs. So far, this has not been possible, due to lack of data at the regional level. Nevertheless, it can be concluded that prevention of CSFV introduction deserves higher priority for DPLAs than for SPLAs, as the consequences of CSFV introduction are, in general, more severe (both epidemiologically and economically) for DPLAs (Mangen et al., 2002). If calculations with the scenario tree model could be performed at the regional level, it could be a useful tool for setting priorities for preventive measures in DPLAs.

6.2.2. Modelling approach

The scenario pathway approach, rather than simulation, was used to calculate the annual P_{CSFV}. The advantages and disadvantages of this approach have been discussed extensively in Chapter 3. One of the major advantages is that scenario tree model calculations can be performed rather quickly, whereas simulation requires many iterations to get just a few ‘hits’, i.e. virus introductions, since the probabilities calculated are very small. Using the techniques of rare event simulation or importance sampling (Heidelberger, 1995; Heegaard, 1997; Kleijnen, 1998) would have been an alternative for speeding up simulation model calculations. One of the major disadvantages of the scenario pathway approach is that the complex reality of CSFV introduction is reduced to a set of scenario tree calculations. Using simulation it would have been possible to follow each individual pathway-unit from origin to destination. Details on the number of pigs imported in each batch, including the number of infected pigs, for example, would have enabled calculations on the probability of detection, whereas in the scenario tree model only a general parameter for detection of CSFV infected pigs in a batch could be used. Simulation would, however, have required more detailed information and data to quantify input parameters, which is not all readily available. A simulation model might thus be a better representation of the complex real world than the scenario tree model, but at the expense of more uncertain input parameters, which can result in a false sense of accuracy. A third main difference is that the results of simulation are easier to visualise, showing exactly how often and in which years CSFV introduction occurs, and where the virus originates from. The scenario tree model provides insight into these issues by probabilities only, which are more difficult to interpret for people not familiar with quantitative risk analysis. The information provided by the scenario tree model was, however, very useful in analysing which countries of origin and pathways contributed most to the annual P_{CSFV} into the Netherlands, which was the main aim of the model.

6.2.3. Model validation

By definition, any model is a simplification of reality. Therefore, the art of model building is to determine what aspects of the complex real world should be included in the model. No matter how much effort is put in developing a model, it will always be an approximation of the real system and will, therefore, never be absolutely valid (Kleijnen, 1995; Law and Kelton, 2000). As a result, validation is one of the most critical steps in model building and can be defined as determining whether a model is an accurate representation of the system being studied to fulfil the purposes for which it has been developed (Dijkhuizen et al., 1997; Kleijnen 1999; Law and Kelton, 2000). No totally objective set of criteria is available to measure the validity of a model. In general, however, it can be stated that the more efforts put in validation, the higher the probability that major deficiencies are not overlooked.

A distinction is made between internal and external validation. Internal validation mainly refers to the design of the model, i.e., does the model perform as intended? External validation is concerned with determining whether the model is an accurate representation of the system under study (Kleijnen, 1995). In other words, internal validation deals with building the model right, whereas external validation deals with building the right model (Balci, 1998).

For internal validation of the model a what-if analysis was performed in Chapter 3 to check model structure and calculations. The outcome of the different scenarios resulted in a reasonable change of the mean annual P_{CSFV} with the beforehand expected sign. External validation of the model by comparing model output and data from the real system was impossible due to a lack of real-life data. Only CSFV introductions from 1990 onwards could be used for validation of the model as, by then, all EU member states had terminated prophylactic vaccination (Vandeputte and Chappuis, 1999). As such introductions are largely determined by chance, the number of observations was too small to determine the annual P_{CSFV} or to draw conclusions on the main causing factors (pathways and countries of origin). Face validation of absolute model output was also not possible since small probabilities are difficult to interpret, especially for people not familiar with quantitative risk analysis. In such situations, sensitivity analysis is considered an important step in the model validation process

(Kleijnen, 1999; Vonk Noordegraaf et al., 2003). An extensive sensitivity analysis was performed based on the techniques of group screening and Design of Experiments (DOE) and metamodelling (Watson, 1961; Kleijnen, 1998; Law and Kelton, 2000). Results indicated that only four out of 257 uncertain input parameters changed the ranking of risk factors contributing most to the annual P_{CSFV}. It was thus concluded that the scenario tree model is rather robust, despite many uncertain input parameters.

The scenario tree model was primarily built to analyse which pathways and countries of origin contributed most to the annual P_{CSFV} into the Netherlands. The sensitivity analysis indicated that for this purpose the scenario tree model was a valid tool. The annual P_{CSFV} into the Netherlands calculated using the model was, however, quite low when compared with recent history and expert estimates. The Netherlands experienced CSFV introductions in 1990, 1992, and 1997. Based on data from the Animal Disease Notification System (ADNS) for the period 1990-2003 the expected number of CSFV introductions per year is 0.43. Experts expected that the Netherlands would experience two CSF epidemics in a 5-year period (Meuwissen et al., 2003). However, the scenario tree model calculates that the Netherlands will experience CSFV introductions on average only once every 25 years. This is most probably an underestimation as not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries. Nevertheless, the current annual P_{CSFV} for the Netherlands might be lower than most experts would expect. After the 1997/98 CSF epidemic, additional preventive actions were taken to reduce the P_{CSFV}, especially with respect to returning livestock trucks. Besides, the repeated CSFV introductions during the 1990s might just have been ‘bad luck’. At the moment of writing, more than seven years have passed since the last introduction in 1997.

6.2.4. Model behaviour with respect to uncertainty and variability

The scenario tree model contained both uncertain and variable input parameters. By definition, uncertainty represents lack of knowledge of parameter values, which may be reduced by further measurement or study, whereas variability is the effect of chance and a function of the system studied (Anderson and Hattis, 1999; Nauta, 2000; Vose, 2000).

6.2.4.1. Uncertain input parameters

The scenario tree model contained 257 uncertain input parameters due to a limited availability of quantitative data. Point estimates were used for these parameters to avoid mixing uncertainty and variability. An extensive sensitivity analysis indicated that only four uncertain input parameters had significant impact on the ranking of risk factors, viz. the expected number of CSF epidemics in Germany, Belgium, and the United Kingdom, and the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km. The values of these input parameters were re-estimated before the model was used to explore the effectiveness of preventive actions aimed at reducing the annual P_{CSFV} into the Netherlands (Chapter 5). For the latter study, model input was also updated to account for the rapid changes in the EU pig production sector in recent years. These changes in numbers of pig farms, expected CSF epidemics, and trade figures might result in other uncertain input parameters influencing the ranking of pathways and countries of origin most. In 2003, the number of returning livestock trucks was even higher than in 1999. Therefore, it is likely that the impact of uncertain input parameters used in the calculations for this pathway is similar or even larger. In 2003, imports of breeding pigs from the United Kingdom made up only 4% of imports in 1999, resulting in a much lower annual probability that the United Kingdom is the source of CSFV introduction into the Netherlands. By contrast, in 2003 the number of livestock trucks returning from Spain was more than double the number in 1999, thereby increasing the importance of Spain as a source of CSFV introduction into the Netherlands. Therefore, it is likely that today the expected number of CSF epidemics in Spain will influence model results more than the expected number of CSF epidemics in the United Kingdom. Both values were, however, updated in the new version to represent the current situation best.

6.2.4.2. Variable input parameters

In the model, two types of variable input parameters were distinguished: (i) parameters that were variable due to the inherent variability of CSF epidemics in the countries of origin and (ii) parameters that were variable due to yearly changes in the number of pathway-units present as described by, for example, trade figures. Probability distributions were used to model the parameters describing CSF epidemics in the countries of origin. Model calculations were iterated using Latin Hypercube Sampling (LHS) (Vose, 2000), resulting in a probability distribution for each output parameter. These probability distributions represented uncertainty about the true value of the output parameters due to yearly changes in the occurrence and course of CSF epidemics in the countries of origin. In years with few and smaller-scale CSF epidemics in the countries of origin, the annual P_{CSFV} will be at its minimum level whereas in years with many and larger-scale CSF epidemics in the countries of origin, the probability will be at its maximum level.

For the parameters describing the number of pathway-units present, single values were used based on the situation in 1999 (Chapter 3 and 4) and 2003 (Chapter 5). The model thus calculates the annual P_{CSFV} into the Netherlands for a real (historical) situation with regard to trade figures in which it is not known beforehand where and how many CSF epidemics will occur and how severe these will be. To explore model behaviour with respect to trade figures, model output based on trade figures of 1999 and 2003 was compared. Using the model version of Chapter 5 (i.e. including amendments made based on the sensitivity analysis), the median annual P_{CSFV} for 1999 was 0.0229, whereas for 2003 it was 0.0245. Recent changes in the Dutch pig production sector did thus not result in a lower annual P_{CSFV}. The relative contribution of returning livestock trucks was increased from 41% in 1999 to 50% in 2003. The relative contribution of pigs imported for life (breeding pigs and piglets) was decreased from 41% to 21%. In 1999, the countries of origin contributing most to the annual P_{CSFV} were Germany, Belgium, and the United Kingdom, whereas in 2003 Germany, Belgium, and Spain contributed most. Comparing model output of the first model version of Chapters 3 and 4 with the second version of Chapter 5 for trade figures of 1999, it was seen that the median P_{CSFV} was decreased from 0.0376 to 0.0229. Changes were mainly due to a higher value for the effectiveness of cleansing and disinfection of returning livestock trucks, and a lower value for the sensitivity of overall detection of imported pigs. Although this resulted in a lower relative contribution of returning livestock trucks (41% as opposed to 64%) and a higher relative contribution of imported pigs (piglets 14% as opposed to 7%, breeding pigs 27% as opposed to 18%, fattening pigs 15% as opposed to 10%), the ranking of pathways did not change. Furthermore, Germany, Belgium, and the United Kingdom remained the most important sources of CSFV introduction into the Netherlands. The conclusions based on the model calculations did not change therefore, although absolute values did.

To describe CSF infections in wild boar, the situation of a single year was also used in the model. As no CSF infections had occurred in Dutch wild boar populations in recent years (Elbers and Dekkers, 2000; A.R.W. Elbers, personal communication), the pathways direct and indirect contact with wild boar did not contribute to the annual P_{CSFV} into the Netherlands. It can, however, not be concluded that wild boar is an unimportant pathway. This only accounts for the situation in which the wild boar population is free of CSFV infections. In countries with infected wild boar populations, this pathway has, on the contrary, been one of the most important routes for CSFV introduction in the domestic pig population. In Germany, for example, 59% of all primary infections in the period 1993 to 1998 were due to direct or indirect contact with wild boar (Fritzemeier et al., 2000). Furthermore, contacts with wild boar have been a major cause of primary CSF outbreaks in Sardinia, Italy (Laddomada et al., 1994; Lowings et al., 1999; Laddomada, 2000; Biagetti et al., 2001). Although the Dutch wild boar population has been free of CSFV since 1985, this is no guarantee for the future. CSF is endemic in the wild boar populations of some areas in Germany (Laddomada, 2000; Artois et al., 2002). In Belgium too, CSF was detected in wild boar (OIE, 2004a). To evaluate the importance of this pathway for the Netherlands, a low (1%) and a high (5%) seroprevalence were assumed. Model calculations showed that the mean annual P_{CSFV} was increased by 14% and 69%, respectively. The relative contribution of direct and indirect contact with wild boar to the overall annual P_{CSFV} was 7% and 17%, respectively, when low seroprevalence was assumed, and 15% and 38%, respectively, when high seroprevalence was assumed. These figures indicate that infected wild boar is possibly an important source of CSFV introduction for the Netherlands too.

6.3. RISK OF CSFV INTRODUCTION

Risk is defined as the likelihood and magnitude of the occurrence of an adverse event (Ahl et al., 1993). Accordingly, the risk of CSFV introduction into the Netherlands comprises: (i) the annual P_{CSFV} into the Netherlands and (ii) the epidemiological consequences and economic losses caused by the resulting epidemic. In this thesis the annual P_{CSFV} was analysed, and measures aimed at the prevention of CSFV introduction were explored. The risk of CSFV introduction can, however, also be diminished by control measures reducing the subsequent spread of the disease. In Fig. 2.2 (Chapter 2), the relation between the risk of virus introduction on the one hand, and prevention and control measures on the other was illustrated.

6.3.1. Prevention of CSFV introduction

In principle, the annual P_{CSFV} is determined by (i) the occurrence of CSF in the countries of origin, (ii) the number of pathway-units present, and (iii) the P_{CSFV} per pathway-unit. Preventive actions can be directed at one or more of these items. Changing the CSF situation in the countries of origin is difficult, although the Netherlands has some influence through, for example, the standing veterinary committee (SVC) of the EU. As an illustration of the possible effects, the what-if analysis of Chapter 3 indicated that a real short high-risk period (HRP[18]) in the countries of origin would reduce the annual P_{CSFV} into the Netherlands by almost 50%.

In Chapter 5, scenario tree model calculations were performed for tactical preventive measures. These measures were directed at the P_{CSFV} per pathway-unit. Results showed that using livestock trucks for either national or international transports only (LT_N&I) was the most effective measure in terms of the achieved reduction of the annual P_{CSFV}. To reduce the number of pathway-units present, i.e. to reduce imports and/or exports of pigs, strategic preventive measures are needed. Such measures require structural changes in the pig production sector that cannot be enforced by legislation, but should be realised by the sector itself. Scenario tree model calculations were performed to explore the effectiveness of strategic measures that reduced the

(a) imports of live pigs by 50% (IMP_50);
(b) exports of live pigs by 50% (EXP_50);
(c) imports and exports of live pigs by 50% (TOT_50);
(d) imports of live pigs by 90% (IMP_90);
(e) exports of live pigs by 90% (EXP_90);
(f) imports and exports of live pigs by 90% (TOT_90).

In Fig. 6.1 the cumulative distribution function (cdf) of the annual P_{CSFV} for the default scenario and the above-mentioned scenarios is given. For comparison purposes also, the cdf of the most effective tactical preventive measure (LT_N&I) is shown. It is evident that for the worst-case scenarios (cumulative probability ≥ 0.9) reducing the imports of live pigs only (IMP_50 and IMP_90) is less effective than reducing the exports of live pigs. With respect to

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[18] HRP: period from first infection with virus until first detection of disease; PostHRP: period from first detection of disease until eradication of disease.

median values (cumulative probability = 0.5), however, EXP_50 is only slightly more effective than IMP_50. Reducing both imports and exports of live pigs by 90% (TOT_90) is by far the most effective measure and is the only strategic measure that is more effective than the tactical measure LT_N&I.

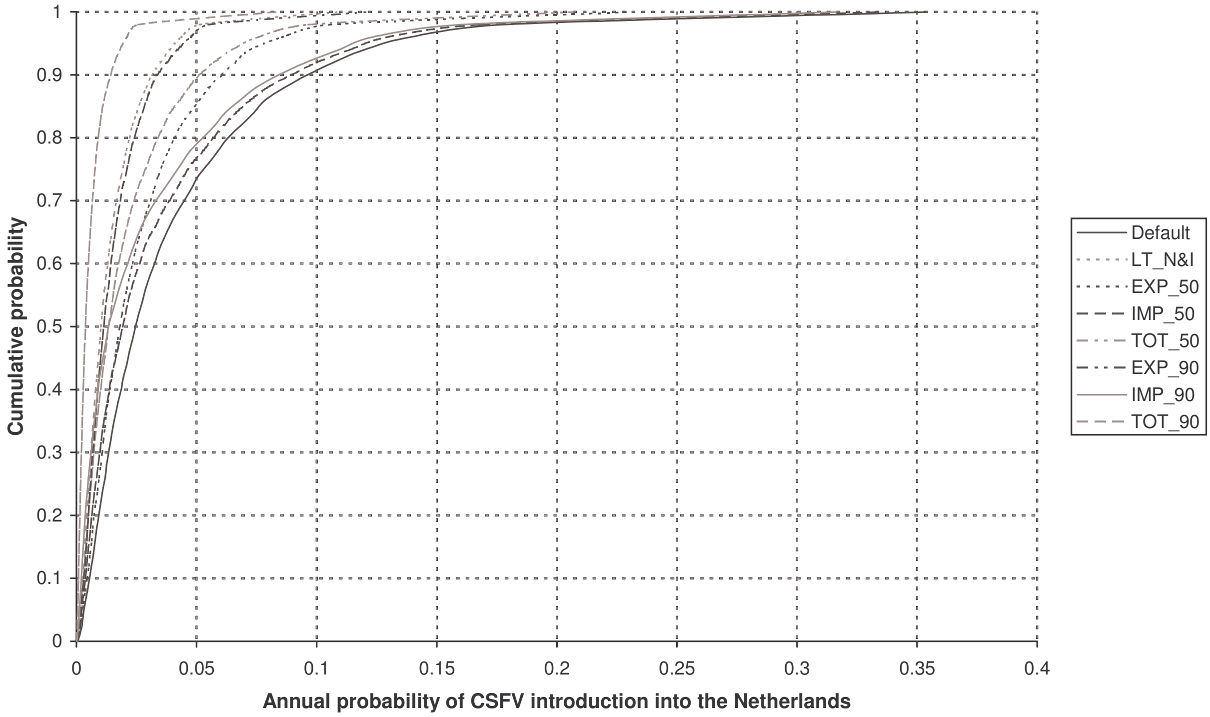

Fig. 6.1. Cumulative distribution function of the annual probability of CSFV introduction into the Netherlands for the default scenario (‘2003’) and when applying one tactical and six strategic measures aimed at prevention of CSFV introduction.

When deciding on measures aimed at reducing the annual P_{CSFV}, the cost of implementing these measures is equally important for decision-makers. In Chapter 5, the cost-effectiveness of tactical preventive measures was explored, showing that testing piglets and breeding pigs by a quick and reliable PCR (IMP_TEST) had the highest cost-effectiveness ratio for median values of the annual P_{CSFV}, whereas LT_N&I was by far the most cost-effective measure for 0.95 percentile values of the annual P_{CSFV}. The cost-effectiveness ratios of strategic preventive measures could, however, not be calculated. Estimating the cost incurred by structural changes in the pig production sector is rather complicated and was beyond the scope of this study. It is likely that, in the short term, costs of strategic preventive measures will be relatively high. In the long term, however, these measures can even result in reduced costs due to, for example, fewer pig transports. In addition, structural changes in the pig production sector do not only affect the P_{CSFV} but also the spread of disease after introduction, and hence the economic losses caused by CSFV introduction. Furthermore, the indirect losses due to export restrictions will be reduced if fewer pigs are exported. On the other hand, strategic preventive measures require substantial adaptations from both primary producers and other stakeholders in the pig production chain, such as pig transporters and slaughterhouses, and might therefore incur higher non-economic costs than costs associated with tactical preventive measures. Furthermore, the implementation of strategic preventive measures is irreversible, leaving less flexibility for reacting to future changes in the risk of CSFV introduction.

The cost-effectiveness analysis of Chapter 5 could not answer the question regarding whether preventive measures are worth the costs involved anyhow, i.e., does the achieved reduction in economic losses resulting from CSFV introductions outweigh the cost of preventive measures? The *average* cost of a CSF epidemic for the Netherlands was estimated at 128 million Euro (VWA, 2003), whereas the *annual* cost for implementing LT_N&I was 4.61 million Euro. Based on these figures, it can thus be concluded that this measure should prevent at least one CSFV introduction every 28 years. Calculations using the scenario tree model indicated that this measure achieved a reduction of the mean annual P_{CSFV} of 0.0254, indicating that, on average, it prevents only one outbreak per 39 years. The cost of implementing this measure is thus higher than the expected benefit. The absolute values calculated for the annual P_{CSFV} are, however, most probably an underestimation of the true value. Furthermore, indirect losses due to business standstill and especially export bans were not included in the average cost of a CSF epidemic, but are in general much higher than the direct costs of an epidemic (Mangen, 2002). Therefore, no conclusions on the cost-benefit ratio of this or other tactical preventive measures could be drawn.

6.3.2. Controlling spread of CSFV during an epidemic

The risk of CSFV introduction can also be reduced by limiting the consequences of CSFV introduction. Choosing the most effective control strategy during a CSF epidemic can reduce the size of an epidemic considerably, both in terms of the number of infected farms and the duration of the epidemic (Nielen et al., 1999; Mangen et al., 2002). Which strategy should be chosen to minimise the economic losses depends on, among other things, the location of the primary outbreak (i.e. is the first infected farm in a DPLA or SPLA) and the number of farms infected at the moment of first detection (Mangen, 2002). The development of marker vaccines with an accompanying discriminatory test (see e.g. Moormann, 2000) has opened up new perspectives for emergency vaccination as an additional control measure. Klinkenberg (2003) concluded that from an epidemiological perspective, emergency vaccination with E2 marker vaccines is a good alternative to preventive culling. Mangen (2002) concluded that, in economic terms, emergency vaccination is also an attractive tool to control CSF epidemics in DPLAs, provided that no trade restrictions are applied to vaccinated pigs and pork products. Despite broader political and public support, acceptance of vaccinated animals and their meat by EU trading partners, as well as by retailers and final consumers is still debatable (Anonymous, 2004).

Control strategies are only implemented after the detection of an infected herd, i.e., during the PostHRP. Simulation studies indicated, however, that the size of a CSF epidemic and the extent of its control costs are highly correlated with the number of farms infected during the HRP (VWA, 2003). If the number of infected farms at the moment of first detection can be kept equal to or less than 10, this results in a considerable reduction in control costs (VWA, 2003). Reducing the number of infected farms during the HRP can, for example, be achieved by monitoring programmes aimed at early detection of primary outbreaks, resulting in a shorter HRP (VWA, 2003). Another promising measure to reduce spread of CSFV during the HRP is the establishment of a quarantine period for individual farms after animals have been purchased. During this period it is not allowed to transport animals off the farm. After the FMD epidemic of 2001 such a quarantine measure came into force in the Netherlands, but until now only for the transport of ruminants. This is not allowed within 21 days after supply of cloven-footed animals onto the farm (including pigs) (LNV, 2004a). Simulation studies to evaluate the effectiveness of this measure with respect to spread of FMD virus, indicated that although the number of infected farms is not reduced by much, infected farms are, in general, concentrated in a smaller geographical area, resulting in fewer and smaller restricted areas and hence reduced economic losses (Greutink et al., 2002).

6.3.3. Preventive or control strategies to achieve risk reduction?

Based on the results of this thesis, it cannot be concluded that from an economic point of view prevention of CSFV introduction is by definition the best way to reduce the risk of CSFV introduction. Calculations showed that even the annual cost of the tactical preventive measure with the highest cost-effectiveness ratio, i.e. LT_N&I, was higher than the expected annual reduction of control costs. These calculations did not, however, take into account indirect losses due to business standstill and export bans. More research is needed to evaluate if preventive measures are worth the investment cost. The question that then should be addressed is whether to use the available resources for prevention of CSFV introduction or for controlling spread of CSFV during an epidemic, taking into consideration that each Euro can only be spent once. As discussed before, three types of measures can be distinguished that either prevent CSFV introduction or reduce the consequent spread of CSFV during the epidemic: (a) measures aimed at reducing the annual P_{CSFV} (PM), (b) measures aimed at reducing unnoticed spread of CSFV during the HRP (CM_HRP), and (c) measures aimed at controlling spread of CSFV after the detection of disease (CM_PostHRP). Their impact on introduction and/or spread mechanisms – and hence on the risk of CSFV introduction – expressed as the annual cost of CSFV introduction, is summarised in Fig. 6.2. To give an example, strategic preventive measures primarily influence the number of pathway-units present, and thus the annual P_{CSFV}. They will, however, also affect farm density and animal movement patterns and thus have side-effects on the spread of CSFV during both the HRP and PostHRP, and consequently on the economic losses of a CSF epidemic. The joint effect of strategic preventive measures on both the annual P_{CSFV} and the economic losses of a CSF epidemic determines the ultimate reduction of the annual cost of CSFV introductions, and thus the benefits of these measures. The ultimate goal of all three types of measures is to minimise the annual cost of CSFV introduction. Theoretically, for each type of measure, cost-benefit ratios can be determined and the economically most attractive measure selected. It should, however, be kept in mind that this is not a static decision, since the risk of CSFV introduction is not static. If, for example, the enlargement of the EU results in a higher annual P_{CSFV} into the Netherlands, this would favour the economic choice for preventive measures. If, on the other hand, emergency vaccination can be used as a control strategy, the size – and especially the economic losses – of future epidemics can be reduced, provided that no trade restrictions are applied to vaccinated pigs and pork products. This would make prevention less attractive from an economic point of view. Furthermore, if measures aimed at the early detection of CSFV infections and at reducing the spread of CSFV during the HRP can significantly reduce the economic losses incurred by a CSF epidemic at relatively low cost, these might be an economically attractive option to reduce the overall risk of CSFV introduction into the Netherlands.

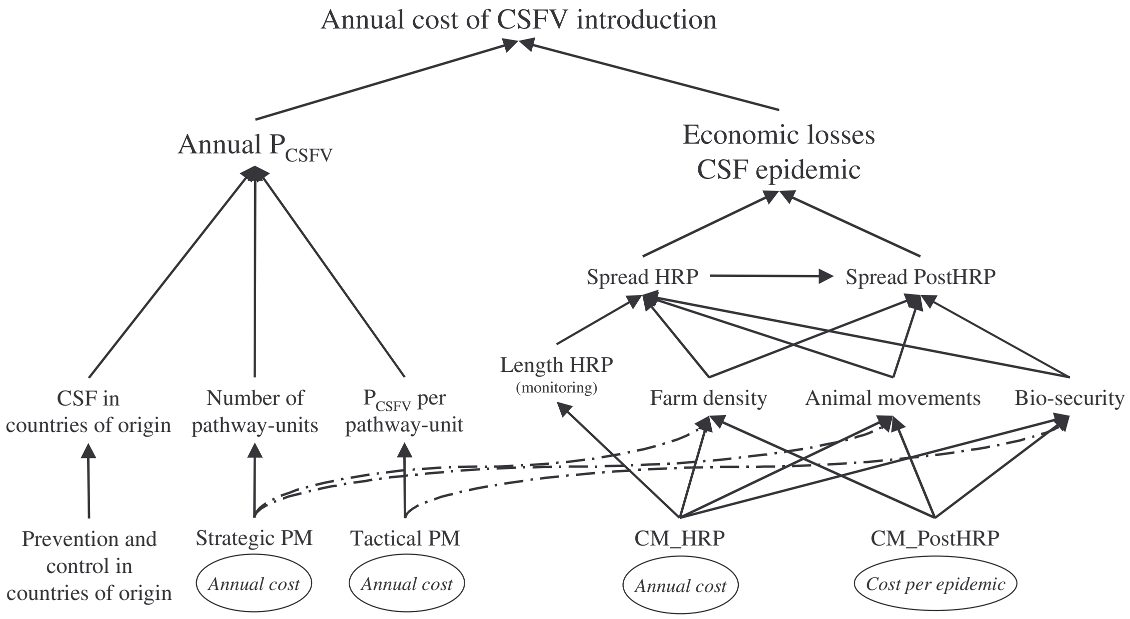

Fig. 6.2. The impact of preventive (PM) and control measures (CM[a]) on introduction and/or spread mechanisms and hence on the annual costs of CSFV introduction.

[a] CM_HRP: measures aimed at reducing unnoticed spread of CSFV during the high-risk period; CM_PostHRP: measures aimed at controlling spread of CSFV after detection of disease.

Considering socio-ethical factors, however, prevention of disease is preferred above controlling an epidemic. The animal welfare problems in restricted areas, the massive killing and destruction of healthy animals, the difficulties in selling meat originating from vaccinated animals, and the suffering of farmers caused by the loss of their animals plead for prevention of contagious animal disease epidemics, such as CSF and FMD. The risk of contagious animal disease introduction can, however, never entirely be reduced to zero, since some pathways simply cannot be excluded by taking preventive actions (MacDiarmid, 1997; Zepeda et al., 2001). Furthermore a zero-risk policy is not feasible anymore under the current WTO agreements (WTO, 1995). Risk managers must therefore decide on what is considered an ‘acceptable’ level of risk (Hathaway, 1993). The acceptability of risk is not only economically driven but will vary among stakeholders, particularly when the group benefiting from the imports differs from the group at risk by the imports (Wilson and Banks, 1993; MacDiarmid, 1997). This was clearly illustrated during the 2001 FMD epidemic in the Netherlands: whereas in general the pig production sector benefits most from the Dutch FMD free-without-vaccination status (PVE, 2004), dairy cattle farms were most severely hit during the epidemic (Abbas et al., 2002; Bouma et al., 2003).

6.4. MAIN CONCLUSIONS

- In spite of many uncertain input parameters, the scenario tree model is a useful and robust tool for carrying out quantitative risk assessment and risk management of CSFV introduction, which can easily handle small probabilities.
- Based on the situation of 2003 and the risk factors included, scenario tree model calculations indicated that the average annual P_{CSFV} into the Netherlands is approximately 0.04. This means that the Netherlands can expect CSFV introduction on average once every 25 years. This is most likely an underestimation since not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries.
- The most likely sources of CSFV introduction into the Netherlands are Germany and Belgium.
- Returning livestock trucks account for about 50% of the annual P_{CSFV} into the Netherlands. Contacts related to export of pigs are thus the most important cause of primary outbreaks in the Netherlands. By comparison, import of fattening pigs contributes 22% to the annual P_{CSFV}, whereas pigs imported for life (piglets and breeding pigs) contribute 21%.
- When a 1% and 5% seroprevalence of CSFV in the Dutch wild boar population are assumed, the annual P_{CSFV} is increased by 14% and 69%, respectively, indicating that prevention of CSFV introduction into the Dutch wild boar population is important from an epidemiological point of view.
- Using separate livestock trucks for national and international transport is a very promising tactical measure to prevent CSFV introduction into the Netherlands, both from an epidemiological and an economic point of view.
- Only strategic preventive measures resulting in a reduction of imports and exports of live pigs by 90% are more effective in reducing the annual P_{CSFV} into the Netherlands than the tactical preventive measure using separate livestock trucks for national and international transport.
- From a financial-economic point of view, implementing more measures to prevent CSFV introduction into the Netherlands than in the present situation is not, by definition, more attractive than taking the present risk of experiencing a CSF epidemic and the accompanying economic losses. However, inclusion of socio-ethical decision criteria

could justify a higher level of prevention than only from a financial-economic point of view.

- An integrated approach combining epidemiological and economic aspects of CSFV is required to support decision-makers in economically optimising (a) prevention of CSFV introduction, (b) reducing unnoticed spread of CSFV during the high-risk period, and (c) controlling CSF epidemics after detection of disease.
- Better availability of (existing) data on the actual CSF situation in the countries of origin, the number of pathway-units, and the probabilities of CSFV introduction per pathway-unit will improve the results of quantitative risk assessments of the annual P_{CSFV} and hence the basis for decisions on preventive measures.

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SUMMARY

Introduction

Since the early 1990s, classical swine fever (CSF) control in the European Union (EU) has been based on a strategy of non-vaccination and the stamping-out of infected and contact herds. As a consequence, the whole EU domestic pig population has become fully susceptible to CSF virus (CSFV). Combined with the existence of areas with dense pig populations, this has occasionally led to large epidemics, leading to high economic losses. Sporadic outbreaks of CSF continue to occur in the domestic pig population of the EU. In addition, CSF is endemic in wild boar populations in some areas of Germany, France, and Italy. Hence, introduction of CSFV remains a continuing risk to the pig production sector of the EU. The risk of CSFV introduction comprises: (i) the annual *probability* of CSFV introduction (P_{CSFV}) into a region and (ii) the epidemiological and economic *consequences* of the resulting epidemics. The research described in this thesis focused on the annual probability, i.e. P_{CSFV}. The main objective was to provide quantitative insight into the major risk factors contributing to the P_{CSFV} to provide support for decision-making on the prevention of CSFV introduction. This objective was subdivided into three parts:

1) overview of all factors possibly contributing to the P_{CSFV} into the domestic pig population of a region free of disease;
2) development of a model to quantitatively estimate the relative contribution of risk factors to the annual P_{CSFV};
3) cost-effectiveness analysis of tactical measures aimed at prevention of CSFV introduction.

Pathway diagram

Chapter 2 describes a pathway diagram presenting all possible causes of CSFV introduction, including their main events and inter-relations. A pathway diagram uses a tree-like approach to provide insight into all the possible causes of an adverse event. The pathway diagram for CSFV introduction comprises four levels. The first level shows all pathways for virus introduction into a region, i.e., all carriers and mechanisms that can transmit virus from an infected animal to a susceptible one. At the second level, it is determined whether any infected or contaminated pathway-unit[19] is present. The third level evaluates the effectiveness of preventive measures in detecting or deactivating the virus. The fourth level shows the two main routes of virus transfer to susceptible domestic animals, i.e. swill feeding and direct or indirect contact, ultimately resulting in a primary CSF outbreak. The underlying concept of a pathway diagram is that the adverse event – in this case, CSFV introduction – will only occur if the events of a certain pathway are true at all levels.

This pathway diagram was used to qualitatively assess the P_{CSFV} for densely and sparsely populated livestock areas (DPLAs and SPLAs, respectively) in five member states of the EU, viz. the Netherlands, Germany, Italy, Belgium, and France. It was concluded that DPLAs generally have a higher P_{CSFV} than SPLAs, although this cannot be attributed to pig density only.

The pathway diagram was furthermore used to qualitatively assess the reduction of the P_{CSFV} achieved by structural changes in the Dutch pig production sector. It was concluded that especially integrated chains of industrialised pig production will reduce the P_{CSFV} considerably. These are, however, difficult and costly to implement. Besides, these integrated chains will be extremely open to CSFV spread once the virus has been introduced, which might result in major economic losses.

Scenario tree model

Based on the pathway diagram, a scenario tree model was developed to calculate the annual P_{CSFV} into regions of the EU (Chapter 3). The main aim of this model was to analyse which pathways contribute most to the annual P_{CSFV} and to identify their origin. Pathways included in the model are import of pigs (subdivided into three subgroups: piglets, breeding pigs, and fattening pigs), import of pork products (subdivided into four subgroups: fresh/chilled, frozen, non-heat-treated, and heat-treated), returning livestock trucks, and contacts with wild boar (subdivided into direct and indirect contacts). All 15 EU member states[20] were included as regions of origin, i.e., as possible sources of CSFV introduction.

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[19] Unit in which a pathway is measured, e.g., a batch of animals, a metric ton of animal products or a returning livestock truck.

[20] The research described was carried out before the enlargement of the EU by 10 new member states on May 1, 2004.

The principles of the scenario pathway approach were used to construct the model for CSFV introduction. Using this approach, the sequence of events that would ultimately lead to CSFV introduction into the domestic pig population of a region was determined, starting with the event of a pathway-unit being infected or contaminated with the virus and ending with the event of an infective viral dose being transmitted to a susceptible pig in this region. For each pathway in the model, these events were ordered in a scenario tree. Each event in the scenario trees was assigned a probability of occurrence. To calculate the P_{CSFV} for a certain pathway, all probabilities along its scenario tree were multiplied. Combining the outcome of all scenario tree calculations gave insight into the relative contribution of pathways and countries of origin to the P_{CSFV}.

The scenario tree model is a stochastic model taking into account the inherent variability of CSF epidemics in the countries of origin. Probability distributions were used for the input parameters describing these epidemics. Model calculations were iterated using Latin Hypercube Sampling, resulting in a probability distribution for each output parameter.

Sensitivity analysis

Only limited data were available to quantify all input parameters required for the scenario tree model. Furthermore, data obtained from experiments or historic CSF epidemics are limited with respect to their utilisation value, due to, for example, low frequency of epidemics, differences in virus strains, and changes in preventive measures and control strategies used. As a result, the model contained many uncertain input parameters. Therefore, an extensive sensitivity analysis was performed to indicate which of the uncertain input parameters most influenced model results and thus required further (empirical) research (Chapter 4). Group screening combined with the statistical techniques of Design of Experiments (DOE) and metamodelling was applied to detect the most important uncertain input parameters among a total of 257. The response variable chosen was the annual P_{CSFV} into the Netherlands. Only 128 scenario calculations were needed to specify the final metamodel. Subsequently, a one-at-a-time sensitivity analysis was performed with the main effects of this metamodel to explore their impact on the ranking of risk factors contributing most to the annual P_{CSFV}.

The results indicated that only four uncertain input parameters changed the ranking of these risk factors, viz. the expected number of classical swine fever epidemics in Germany, Belgium, and the United Kingdom, and the probability that CSFV survives in an empty livestock truck travelling over a distance of 0-900 km. These parameters therefore required a more precise estimate of their values to make model outcome robust.

Cost-effectiveness of preventive measures

Chapter 5 describes a cost-effectiveness analysis of measures aimed at preventing CSFV introduction into the Netherlands. For all measures (i) scenario tree model calculations were performed and (ii) the annual costs were estimated. The scenario tree model used for this cost-effectiveness analysis slightly differed from the model version used in Chapters 3 and 4. Model input was updated to account for (i) the outcome of the sensitivity analysis and (ii) the rapid changes in the EU pig production sector during the previous years. Calculations were now based on trade figures of 2003.

Default calculations showed that the mean annual P_{CSFV} into the Netherlands was approximately 0.04, indicating that the Netherlands can expect CSFV introduction on average once every 25 years. This figure is most probably an underestimation since not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries. The most likely sources of CSFV introduction were Germany, Belgium, and Spain. Returning livestock trucks contributed most to the annual P_{CSFV} with 50%. Import of fattening pigs contributed next with 22%. Import of breeding pigs and piglets contributed 14% and 7%, respectively. Import of pork products contributed almost 7% and this could be attributed for 96% to fresh/chilled and frozen pork products. Direct and indirect contact with wild boar did not contribute to the annual P_{CSFV} into the Netherlands, since no CSF infections have occurred in Dutch wild boar populations in recent years.

Based on the results of the default calculations and expert consultation, six tactical preventive measures were selected for the cost-effectiveness analysis. The cost-effectiveness ratio of each measure was calculated as the achieved reduction of the annual P_{CSFV} (ΔP) divided by the annual cost for implementation (ΔC). Using separate livestock trucks for national and international transport appeared to be most effective in reducing the annual P_{CSFV}. This measure also had a high cost-effectiveness ratio, especially when a worst-case scenario was assumed (i.e. for 0.95 percentile values of the annual P_{CSFV}). Based on effectiveness only, livestock trucks with detachable containers was quite a promising preventive measure. Its cost-effectiveness ratio was, however, quite low since implementing this measure incurs high annual costs. By contrast, testing piglets and breeding pigs by a quick and reliable PCR only attained a small reduction of the annual P_{CSFV} but had a high cost-effectiveness ratio due to its low annual cost at sector level. In terms of cost per pig tested, this measure is, however, very expensive and therefore not attractive. Besides, implementing this measure is not allowed under current EU law, as it is trade restrictive.

Discussion

In Chapter 6 the two critical steps of this risk analysis of CSFV introduction – quantitative risk assessment and risk management – were discussed. First, the pathways and countries of origin not included in the scenario tree model used for the quantitative risk assessment were discussed with respect to their possible contribution to the annual P_{CSFV} into the Netherlands. Other issues of the quantitative risk assessment that were highlighted are: the regional level used in the model, the choice for the scenario pathway approach rather than simulation, the validation of the model, and model behaviour with respect to uncertainty and variability. Then, prevention as a tool for risk management of CSFV introduction was discussed. The effectiveness of strategic preventive measures that result in reduced imports and exports of pigs was explored with the scenario tree model and compared with the effectiveness of tactical preventive measures. Finally, the trade-off between preventive and control strategies to manage the risk of CSFV introduction was discussed, taking into account both economic and socio-ethical aspects. Three types of measures to reduce the risk of CSFV introduction were distinguished: (a) preventive measures aimed at reducing the annual P_{CSFV} (both tactical and strategic), (b) measures aimed at reducing unnoticed spread of CSFV during the high-risk period, and (c) measures aimed at controlling spread of CSFV after detection of disease.

Main conclusions

- In spite of many uncertain input parameters, the scenario tree model is a useful and robust tool for carrying out quantitative risk assessment and risk management of CSFV introduction, which can easily handle small probabilities.
- Based on the situation of 2003 and the risk factors included, scenario tree model calculations indicated that the average annual P_{CSFV} into the Netherlands is approximately 0.04. This means that the Netherlands can expect CSFV introduction on average once every 25 years. This is most likely an underestimation since not all pathways contributing to the P_{CSFV} were included in the model, nor were third countries.

- The most likely sources of CSFV introduction into the Netherlands are Germany and Belgium.
- Returning livestock trucks account for about 50% of the annual P_{CSFV} into the Netherlands. Contacts related to export of pigs are thus the most important cause of primary outbreaks in the Netherlands. By comparison, import of fattening pigs contributes 22% to the annual P_{CSFV}, whereas pigs imported for life (piglets and breeding pigs) contribute 21%.
- When a 1% and 5% seroprevalence of CSFV in the Dutch wild boar population are assumed, the annual P_{CSFV} is increased by 14% and 69%, respectively, indicating that prevention of CSFV introduction into the Dutch wild boar population is important from an epidemiological point of view.
- Using separate livestock trucks for national and international transport is a very promising tactical measure to prevent CSFV introduction into the Netherlands, both from an epidemiological and an economic point of view.
- Only strategic preventive measures resulting in a reduction of imports and exports of live pigs by 90% are more effective in reducing the annual P_{CSFV} into the Netherlands than the tactical preventive measure using separate livestock trucks for national and international transport.
- From a financial-economic point of view, implementing more measures to prevent CSFV introduction into the Netherlands than in the present situation is not, by definition, more attractive than taking the present risk of experiencing a CSF epidemic and the accompanying economic losses. However, inclusion of socio-ethical decision criteria could justify a higher level of prevention than only from a financial-economic point of view.
- An integrated approach combining epidemiological and economic aspects of CSFV is required to support decision-makers in economically optimising (a) prevention of CSFV introduction, (b) reducing unnoticed spread of CSFV during the high-risk period, and (c) controlling CSF epidemics after detection of disease.
- Better availability of (existing) data on the actual CSF situation in the countries of origin, the number of pathway-units, and the probabilities of CSFV introduction per pathway-unit will improve the results of quantitative risk assessments of the annual P_{CSFV} and hence the basis for decisions on preventive measures.

SAMENVATTING

Inleiding

Sinds het begin van de negentiger jaren is het in de Europese Unie (EU) niet langer toegestaan om varkens preventief in te enten tegen klassieke varkenspest (KVP). De huidige bestrijding van KVP epidemieën is gebaseerd op (i) het ruimen van besmette bedrijven (afmaken en vernietigen van alle aanwezige varkens) en (ii) het instellen van beschermings- en toezichtsgebieden waarin vervoer van varkens verboden is. Als gevolg van dit non-vaccinatiebeleid is de hele gedomesticeerde varkenspopulatie in de EU vatbaar voor KVP virus (KVPV). Dit heeft, mede door de aanwezigheid van gebieden met een zeer hoge varkensdichtheid, enkele malen geleid tot zeer grootschalige epidemieën met extreem hoge economische schade. Uitbraken van KVP komen nog steeds voor in de EU. Bovendien is KVP endemisch in een aantal wilde zwijnen populaties van Duitsland, Frankrijk en Italië. Insleep van KVPV is dus een voortdurend risico voor de varkenssector van de EU. Het risico van KVPV insleep omvat (i) de jaarlijkse *kans* op insleep van KVPV en (ii) de epidemiologische en economische *gevolgen* van de epidemieën die daardoor geïnitieerd worden. Het onderzoek beschreven in dit proefschrift richt zich op de jaarlijkse kans op insleep. De belangrijkste doelstelling was om kwantitatief inzicht te verkrijgen in de risicofactoren die bijdragen aan de kans op KVPV insleep, ter ondersteuning van beleidsvorming op het gebied van preventie van KVPV insleep. Daartoe zijn de volgende subdoelstellingen geformuleerd:

1) geven van een overzicht van alle factoren die mogelijk bijdragen aan de kans op KVPV insleep in de gedomesticeerde varkenspopulatie van een regio die vrij is van de ziekte;
2) ontwikkelen van een model om de relatieve bijdrage van risicofactoren aan de kans op KVPV insleep kwantitatief te berekenen;
3) uitvoeren van een kosten-effectiviteit analyse van tactische maatregelen ter preventie van KVPV insleep.

Insleepdiagram

In hoofdstuk 2 wordt een insleepdiagram (Engels: pathway diagram) beschreven dat een overzicht geeft van alle mogelijke oorzaken van KVPV insleep, hun onderlinge relaties en de belangrijkste gebeurtenissen die hierbij een rol spelen. Het insleepdiagram heeft de structuur van een analyseboom en bestaat uit vier lagen. De eerste laag bevat alle insleeproutes (Engels: pathways) waarlangs KVPV in een regio geïntroduceerd kan worden, met andere woorden, alle vectoren en mechanismen die kunnen leiden tot virus overdracht van een geïnfecteerd op een vatbaar dier. In de tweede laag wordt bepaald of er voor een insleeproute één of meer geïnfecteerde of gecontamineerde eenheden[21] aanwezig zijn. In de derde laag wordt de effectiviteit van preventieve maatregelen geëvalueerd ten aanzien van het ontdekken of onschadelijk maken van het virus. De vierde laag geeft de twee belangrijkste manieren van overdracht van virus van geïnfecteerde op vatbare dieren – voeren van swill en directe of indirecte contacten –, die uiteindelijk kunnen leiden tot een (primaire) uitbraak van KVP. De achterliggende gedachte van dit insleepdiagram is dat KVPV insleep alleen plaatsvindt als de gestelde vragen voor een insleeproute in alle lagen met ja beantwoord kunnen worden.

Het insleepdiagram is gebruikt om een kwalitatieve schatting te geven van de kans op KVPV insleep voor gebieden met een hoge varkensdichtheid en voor gebieden met een lage varkensdichtheid in vijf lidstaten van de EU: Nederland, Duitsland, Italië, België en Frankrijk. De conclusie is dat gebieden met een hoge varkensdichtheid over het algemeen een grotere kans op insleep van KVPV hebben, maar dat dit niet alleen aan de dierdichtheid toegeschreven kan worden.

Voorts is het insleepdiagram gebruikt om een kwalitatieve schatting te geven van het effect van structurele veranderingen in de Nederlandse varkenssector op de kans op KVPV insleep. De conclusie is dat met name geïntegreerde ketens van grootschalige varkensbedrijven op een industrieterrein de kans op KVPV insleep aanzienlijk verkleinen. Het verwezenlijken van zulke ketens is echter een moeilijke en kostbare aangelegenheid. Bovendien zullen deze ketens extra kwetsbaar zijn voor verspreiding van KVPV als insleep eenmaal heeft plaatsgevonden, wat aanzienlijke economische schade tot gevolg kan hebben.

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[21] Eenheid waarin een insleeproute kan worden gemeten, bijvoorbeeld een lading dieren, een ton dierlijke producten of een terugkerende veewagen.

Insleepmodel

Het insleepdiagram is gebruikt als basis voor het ontwikkelen van een model dat de kans op KVPV insleep berekent voor regio's in de EU (Hoofdstuk 3). Het doel van dit insleepmodel (Engels: scenario tree model) is om te analyseren welke insleeproutes het meest bijdragen aan de kans op KVPV insleep en waar deze insleeproutes vandaan komen. Het model bevat de volgende insleeproutes voor KVPV: import van varkens (onderverdeeld in drie groepen: biggen; fokvarkens; slachtvarkens), import van varkensproducten (onderverdeeld in vier groepen: vers/gekoeld; bevroren; bewerkt, maar niet verhit; bewerkt en verhit), terugkerende veewagens en contact met wilde zwijnen (onderverdeeld in direct en indirect contact). Alle 15 EU lidstaten[22] zijn in het model opgenomen als herkomstregio's, i.e. als mogelijke bronnen van KVPV insleep.

Het insleepmodel is gebaseerd op de principes van de zogeheten 'scenario pathway methode'. In deze methode wordt de volgorde van gebeurtenissen die uiteindelijk leidt tot een ongewenste gebeurtenis – hier: insleep van KVPV in de gedomesticeerde varkenspopulatie van een regio – beschreven in een zogeheten scenarioboom (Engels: scenario tree). Aan iedere gebeurtenis in zo'n scenarioboom wordt vervolgens een kans van optreden toegekend. Deze kansen worden met elkaar vermenigvuldigd om de uiteindelijke kans op de ongewenste gebeurtenis te berekenen. Voor alle insleeproutes die in het model opgenomen zijn, is zo'n scenarioboom opgesteld. Iedere boom start met de gebeurtenis dat één of meerdere eenheden geïnfecteerd of gecontamineerd zijn met KVPV en eindigt met de gebeurtenis dat een infectieuze dosis KVPV wordt overgebracht op een vatbaar dier. Om de jaarlijkse kans op KVPV insleep te berekenen, zijn de uitkomsten van alle scenarioboom berekeningen samengevoegd. Dit geeft tevens inzicht in het relatieve belang van de verschillende insleeproutes en herkomstregio's.

Het insleepmodel is een stochastisch model, dat rekening houdt met de inherente variatie in het optreden en de omvang van KVP epidemieën in de herkomstregio's. Voor de input parameters die deze epidemieën beschrijven, zijn kansverdelingen gebruikt. Om resultaten te genereren met het model moeten de berekeningen daarom een aantal keer herhaald worden. Dit resulteert in een kansverdeling voor iedere output parameter.

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[22] Het beschreven onderzoek is uitgevoerd voor de uitbreiding van de EU met 10 nieuwe lidstaten op 1 mei 2004.

Gevoeligheidsanalyse

De beschikbaarheid van gegevens om de input parameters van het insleepmodel te kwantificeren, was beperkt. Daarnaast is de gebruikswaarde van gegevens afkomstig uit experimenten en KVP epidemieën in het verleden beperkt vanwege, bijvoorbeeld, de lage frequentie waarin epidemieën voorkomen, verschillen in virusstammen en veranderingen in de strategieën ter preventie en bestrijding van KVP. Het insleepmodel bevat derhalve een groot aantal onzekere input parameters. Daarom is een uitgebreide gevoeligheidsanalyse uitgevoerd om na te gaan welke onzekere input parameters de meeste invloed hebben op de modeluitkomsten en dus nader (empirisch) onderzoek behoeven (Hoofdstuk 4). Een combinatie van de technieken van groepscreening, experimentele proefopzet en metamodellen is gebruikt om de belangrijkste onzekere input parameters uit een totaal van 257 op te sporen. De jaarlijkse kans op KVPV insleep in Nederland is als afhankelijke variabele gebruikt in deze gevoeligheidsanalyse. In totaal zijn 128 scenario's doorgerekend om het uiteindelijke metamodel te definiëren. Om het effect van de onafhankelijke variabelen uit dit metamodel op de rangorde van insleeproutes te bepalen, is vervolgens een 'traditionele' gevoeligheidsanalyse uitgevoerd, waarbij slechts één parameter tegelijk werd veranderd.

De resultaten van deze gevoeligheidsanalyse laten zien dat slechts vier onzekere input parameters de rangorde van insleeproutes beïnvloeden. Dit zijn: het verwachte aantal KVP epidemieën in Duitsland, België en het Verenigd Koninkrijk, en de kans dat KVPV overleeft in een lege veewagen die een afstand aflegt van 0-900 km. Voor deze parameters is derhalve een nauwkeurigere schatting nodig om de modeluitkomsten robuust te maken.

Kosten-effectiviteit van preventieve maatregelen

Hoofdstuk 5 beschrijft een kosten-effectiviteit analyse van maatregelen gericht op preventie van KVPV insleep in Nederland. Voor alle maatregelen zijn (i) berekeningen uitgevoerd met het insleepmodel en (ii) schattingen gemaakt van de jaarlijkse kosten. Het insleepmodel dat gebruikt is voor deze kosten-effectiviteit analyse verschilt enigszins van de modelversie gebruikt in hoofdstuk 3 en 4. De model input is herzien om rekening te houden met (i) de uitkomsten van de gevoeligheidsanalyse en (ii) de snelle veranderingen in de Europese varkenssector van de afgelopen jaren. De nieuwe berekeningen zijn gebaseerd op handelsgegevens van 2003.

Standaard berekeningen laten zien dat de gemiddelde kans op KVPV insleep per jaar voor Nederland ongeveer 0,04 is. Dit geeft aan dat Nederland gemiddeld eens in de 25 jaar insleep van KVPV kan verwachten. Hoogstwaarschijnlijk is dit een onderschatting, aangezien het model niet alle insleeproutes die bijdragen aan de kans op KVPV insleep bevat en evenmin niet-EU lidstaten. De meest waarschijnlijke herkomstregio's van het virus zijn Duitsland, België en Spanje. Met zo'n 50% dragen terugkerende veewagens het meest bij aan de jaarlijkse kans op KVPV insleep in Nederland. Import van slachtvarkens, fokvarkens en biggen dragen respectievelijk 22%, 14% en 7% bij aan de kans op KVPV insleep. Import van varkensproducten draagt bijna 7% bij en dit kan voor 96% toegeschreven worden aan verse/gekoelde en bevroren producten. Directe en indirecte contacten met de wilde zwijnen dragen niet bij aan de jaarlijkse kans op KVPV insleep, daar zich de laatste decennia geen KVP infecties voorgedaan hebben in de Nederlandse wilde zwijnen populatie.

Op basis van de resultaten van de standaard modelberekeningen en expert consultatie zijn zes tactische preventieve maatregelen geselecteerd voor de kosten-effectiviteit analyse. De kosten-effectiviteit ratio van iedere maatregel is berekend als de verlaging van de jaarlijkse kans op KVPV insleep (ΔP) gedeeld door de jaarlijkse kosten voor het uitvoeren van de maatregel (ΔC). Scheiding van het nationale en internationale transport van varkens blijkt het meest effectief in het verlagen van de insleepkans. Deze maatregel heeft ook een hoge kosten-effectiviteit ratio, in het bijzonder wanneer een worst-case scenario wordt verondersteld (i.e. voor de 0,95 percentiel waarden van de jaarlijkse kans op KVPV insleep). Op basis van effectiviteit alleen is het gebruik van veewagens met losse laadbakken een veelbelovende maatregel. De kosten-effectiviteit ratio van deze maatregel is echter laag, doordat de uitvoering ervan hoge jaarlijkse kosten met zich meebrengt. Het testen van biggen en fokvarkens met een snelle en betrouwbare PCR resulteert daarentegen slechts in een kleine verlaging van de kans op KVPV insleep, maar heeft wel een hoge kosten-effectiviteit ratio dankzij de lage jaarlijkse kosten op sectorniveau. Uitgaande van de kosten per getest varken is deze maatregel echter zeer duur en daarom niet aantrekkelijk. Bovendien is het uitvoeren van deze maatregel niet mogelijk onder de huidige EU wetgeving, aangezien het handelsbelemmerend werkt.

Discussie

Hoofdstuk 6 bevat een algemene discussie van de twee cruciale stappen in deze risico analyse van KVPV insleep: de kwantitatieve risico inschatting en het risico management. Als eerste worden de insleeproutes en herkomstregio's die niet opgenomen zijn in het insleepmodel, dat gebruikt is voor de kwantitatieve risico inschatting, besproken voor wat betreft hun mogelijke bijdrage aan de jaarlijkse kans op KVPV insleep in Nederland. Andere aspecten van de kwantitatieve risico inschatting die bediscussieerd worden, zijn: het regionale niveau dat gebruikt is in het insleepmodel, de keuze voor de scenario pathway methode in plaats van simulatie, validatie van het insleepmodel en het gedrag van het insleepmodel met betrekking tot onzekerheid en variatie. Daarna wordt preventie als strategie voor risico management van KVPV insleep besproken. De effectiviteit van strategische preventieve maatregelen die leiden tot minder import en export van varkens is bestudeerd en vergeleken met de effectiviteit van tactische preventieve maatregelen. Tenslotte wordt de afweging tussen preventie en bestrijding als het gaat om de beheersing van het risico van KVPV insleep besproken, rekening houdend met zowel economische als sociaal-ethische aspecten. Drie typen maatregelen die het risico van KVPV insleep kunnen verlagen, worden onderscheiden: (a) preventieve maatregelen gericht op het verlagen van de jaarlijkse kans op KVPV insleep (zowel tactisch als strategisch), (b) maatregelen gericht op het verminderen van onopgemerkte verspreiding van KVPV tijdens de hoog-risico periode van een epidemie en (c) maatregelen gericht op bestrijding van KVPV na detectie van de ziekte.

Belangrijkste conclusies

- Ondanks een groot aantal onzekere input parameters is het insleepmodel een bruikbaar en robuust instrument voor kwantitatieve risico inschatting en risico management van KVPV insleep, waarmee eenvoudig kleine kansen berekend kunnen worden.
- De berekeningen met het insleepmodel geven aan dat, op basis van de situatie in 2003 en de risicofactoren in het model, de gemiddelde kans op KVPV insleep per jaar voor Nederland ongeveer 0,04 is. Dit betekent dat Nederland gemiddeld eens in de 25 jaar insleep van KVPV kan verwachten. Hoogstwaarschijnlijk is dit een onderschatting, aangezien het model niet alle insleeproutes die bijdragen aan de kans op KVPV insleep bevat en evenmin niet-EU lidstaten.
- De meest waarschijnlijke herkomstregio's van KVPV insleep in Nederland zijn Duitsland en België.
- Terugkerende veewagens nemen ongeveer 50% van de jaarlijkse kans op KVPV insleep in Nederland voor hun rekening. Contacten gerelateerd aan de export van varkens zijn dus de belangrijkste oorzaak van primaire uitbraken in Nederland. Ter vergelijking, import

van slachtvarkens draagt 22% bij aan de jaarlijkse kans op KVPV insleep, terwijl varkens geïmporteerd voor het leven (biggen en fokvarkens) 21% bijdragen.

- Wanneer een 1% en 5% seroprevalentie van KVPV in de Nederlandse wilde zwijnen populatie wordt verondersteld, stijgt de jaarlijkse kans op KVPV insleep met respectievelijk 14% en 69%. Dit laat zien dat het voorkómen van KVPV insleep in de Nederlandse wilde zwijnen populatie belangrijk is vanuit epidemiologisch oogpunt.
- Scheiding van het nationale en internationale transport van varkens is zowel vanuit epidemiologisch als economisch oogpunt een veelbelovende tactische maatregel om insleep van KVPV in Nederland te voorkomen.
- Alleen strategische preventieve maatregelen die leiden tot een vermindering van de import en export van levende varkens met 90% zijn effectiever in het verlagen van de jaarlijkse kans op KVPV insleep in Nederland, dan de tactische maatregel die zorgt voor een scheiding van het nationale en internationale transport van varkens.
- Vanuit financieel-economisch perspectief is het nemen van extra maatregelen ter preventie van KVPV insleep in Nederland niet per definitie aantrekkelijker dan het nemen van het huidige risico op een KVP epidemie en de bijbehorende economische schade. Het toevoegen van sociaal-ethische besluitvormingscriteria zou echter wel eens een hoger niveau van preventie kunnen rechtvaardigen dan op basis van enkel financieel-economische criteria.
- Een geïntegreerde aanpak die epidemiologische en economische aspecten van KVPV combineert, is nodig om beleidsmakers te ondersteunen bij het zoeken naar het economische evenwicht tussen (a) preventie van KVPV insleep, (b) verminderen van onopgemerkte verspreiding van KVPV tijdens de hoog-risico periode en (c) bestrijding van KVP epidemieën na detectie van de ziekte.
- Betere beschikbaarheid van (bestaande) gegevens over de huidige KVP situatie in de herkomstregio’s, het aantal eenheden per insleeproute en de kans op KVPV insleep per eenheid, zal de resultaten van de kwantitatieve risico inschatting van de jaarlijkse kans op KVPV insleep verbeteren en derhalve de basis voor besluitvorming over preventieve maatregelen.

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CURRICULUM VITAE

Clazina Johanna de Vos-de Jong werd op 6 september 1974 geboren in Woerden. In 1992 behaalde zij het VWO-diploma aan het Christelijk Lyceum Almelo. In datzelfde jaar begon zij met de studie Tropisch Landgebruik aan de toenmalige Landbouwuniversiteit Wageningen. In augustus 1997 werd deze studie cum laude afgerond met als afstudeervakken Tropisch Grasland en Dierlijke Productiesystemen. De periode augustus 1995 – februari 1996 bracht zij door bij het Tropical Forages Program van het CIAT (International Centre for Tropical Agriculture) in Colombia. Van oktober 1997 tot en met maart 1998 werkte zij als toegevoegd onderzoeker bij de leerstoelgroep Agrarische Bedrijfseconomie van Wageningen Universiteit aan de economische aspecten van mastitis en mastitisbestrijding. In april 1998 kreeg zij een aanstelling als Assistent In Opleiding (AIO) bij deze leerstoelgroep, eerst voltijds, later in deeltijd. Dit resulteerde in het voor u liggende proefschrift. Het beschreven onderzoek maakte deel uit van een groot Europees onderzoeksproject naar de diergezondheidsproblemen van dichtbevolkte diergebieden in de Europese Unie (EU Research Project FAIR5-CT97-3566). Sinds april 2005 is ze aangesteld als Postdoc bij de leerstoelgroep Bedrijfseconomie van Wageningen Universiteit.

TRAINING AND SUPERVISION PLAN

Training and Supervision Plan			**Graduate School WIAS**
Name PhD student	C.J. de Vos		
Project title	Risk analysis of classical swine fever introduction		
Group	Business Economics		
Daily supervisor(s)	H.W. Saatkamp		
Supervisor(s)	R.B.M. Huirne		
Project term	from April 1998	until February 2005	
Submitted	17 January, 2005	first plan / midterm / **certificate**	

EDUCATION AND TRAINING (minimum 21 cp, maximum 42 cp)		
The Basic Package (minimum 2 cp)	year	cp
WIAS Common Course (mandatory)	1999	2.0
Course on philosophy of science and/or ethics (mandatory)	1998	1.0
Subtotal Basic Package		**3.0**
Scientific Exposure (conferences, seminars and presentations, minimum 5 cp)	year	cp
International conferences *(minimum 2 cp)*		
Annual congress of the European Society of Risk Analysis	1999	0.6
Conference of the International Society for Veterinary Epidemiology and Economics	2000	1.0
Annual meeting of the Society for Veterinary Epidemiology and Preventive Medicine, 2000 & 2001	2000-2001	1.2
Seminars and workshops		
GSAH - seminar on classical swine fever	1998	0.1
Mansholt Institute – Interdisciplinair debat: Perspectieven voor de varkenshouderij in Nederland	1998	0.1
Studiedag bij het afscheid van Prof. J.A. Renkema: Nieuwe bedrijfsontwikkelingsstrategieën: uidagingen voor de toekomst	1998	0.2
Second Intervet Symposium: Prevention of viral diseases by vaccination: vaccination versus non-vaccination	1999	0.2
Meeting of EU National Swine Vesicular Disease Laboratories	1999	0.1
Lecture by Prof. Mark Woolhouse, entitled "Foot-and-mouth disease: from epidemiology to epitopes”	2000	0.1
WIAS Science Day: Adaptive capacity and enivronment	2000	0.2
Mini Symposium: FMD prevalence, control and research	2000	0.1
WIAS Seminar ("Plus"): Organic farming: a challenge for animal production systems research	2000	0.3
VEEC – Annual meeting of the Dutch Society for Veterinary Epidemiology and Economics	2000	0.2
BSE: feiten en fictie	2001	0.2
Bijeenkomst voor stafmedewerkers CIDC: “Van expert opinion naar risico analyse, is dit anders?”	2002	0.1
VEEC – Annual meeting of the Dutch Society for Veterinary Epidemiology and Economics	2003	0.2
WIAS Science Day: DecAnimalS	2003	0.2
Presentations *(minimum 4 original presentations of which at least 1 oral, 0.5 cp each)*		
Annual congress of the European Society of Risk Analysis (oral presentation)	1999	0.5
Meeting of EU National Swine Vesicular Disease Laboratories (oral presentation)	1999	0.5
Annual meeting of the Society for Veterinary Epidemiology and Preventive Medicine (oral presentation)	2000	0.5
Conference of the International Society for Veterinary Epidemiology and Economics (2 oral presentations)	2000	1.0
Annual meeting of the Society for Veterinary Epidemiology and Preventive Medicine (poster presentation)	2001	0.5

Bijeenkomst voor stafmedewerkers CIDC: “Van expert opinion naar risico analyse, is dit anders?”(oral presentation)	2002	0.5
VEEC – Annual meeting of the Dutch Society for Veterinary Epidemiology and Economics (oral presentation)	2003	0.5
WIAS Science Day: DecAnimalS (oral presentation)	2003	0.5
Subtotal International Exposure		**9.6**
In-Depth Studies (minimum 4 cp)	year	cp
Disciplinary and interdisciplinary courses		
Mansholt PhD course. Stochastic simulation: the design of simulation experiments (Prof. Kleijnen)	1998	0.5
PHLO course Animal Health. Management, Principles and Applications	1998	1.0
Mathematical modelling of infectious diseases	1998	1.0
Animal Import Risk Analysis Course (David Vose)	1998	2.0
PHLO course Risk management: principles and applications	1999	1.0
Delphi 4 Foundations Course	1999	1.0
PhD students' discussion groups (optional)		
Discussion on two books: Handbook of simulation by Banks; Simulation modelling and analysis by Law and Kelton	1999	1.0
Undergraduate courses		
Economische modellering van dierziekten (D200-210)	1998	3.0
Dynamische beslissingsmodellen (A100-232)	1999	2.0
Subtotal In-Depth Studies		**12.5**
Professional Skills Support Courses (minimum 2 cp)	year	cp
WIAS Course Techniques for Scientific Writing (advised)	1998	0.5
Course Supervising MSc thesis work (advised when supervising MSc students, 0.5 cp)	1998	0.5
Comunication skills I (Tweegesprekken) and II (Groepsgesprekken)	1999	1.0
Giving oral presentations (Quintrix)	2000	0.5
Career perspectives	2005	1.0
Subtotal Professional Skills Support Courses		**3.5**
Education and Training Total (minimum 21 cp, maximum 42 cp)		**28.6**

One credit point (cp) equals a study load of approximately 40 hours.

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