Economic optimization of surveillance in livestock production chains

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Thesis

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Contents

Chapter 1	General introduction	6
Chapter 2	A conceptual framework for economic optimization of single hazard surveillance in livestock production chains	18
Chapter 3	A conceptual framework for economic optimization of a surveillance portfolio	51
Chapter 4	Economic analysis of Classical Swine Fever surveillance in the Netherlands	72
Chapter 5	Economic optimization of the pig-hazard surveillance portfolio in a Dutch food company	130
Chapter 6	General discussion	157
	Summary	172
	Samenvatting	176
	Acknowledgement	180
	Training and supervision plan	182

Chapter 1

General introduction

1.1 Background

During the last decades, the world has regularly faced major crises in the field of livestock production and food safety. Examples include Classical Swine Fever (CSF) during the 1990s in the Netherlands, Belgium and Germany, Bovine Spongiform Encephalopathy (BSE) in the 1990s in the United Kingdom, recent Highly-Pathogenic Avian Influenza (HPAI) in China, and Foot and Mouth disease (FMD) in the United Kingdom and South Korea in 2001 and 2010 respectively. Such crises not only caused enormous socio-economic impacts (e.g., Meuwissen et al., 1999; Saatkamp et al., 2000; Anonymous, 2002; Mangen, 2002; Asseldonk et al., 2005), they resulted also in reduced public confidence in food production and products (Jonge et al., 2004).

The EU responded by new standards (e.g. introducing the new hygiene rules for foodstuffs, food of animal origin, etc.), the establishment of the European Food Safety Authority (EFSA) in 2002 and the subsequent establishment of Food Safety Authorities (FSAs) in individual member states (e.g. the Dutch Food and Consumer Product Safety Authority (VWA) founded in 2002). FSAs can be described as 'a body to coordinate and direct scientific research, risk analysis, monitoring and inspections and to communicate to the public on matters of food safety to restore consumer confidence in the safety of food' (Wit, 2003). Its mission is to provide scientific advice, technical support, risk assessment, monitoring, risk communication and collaboration with national actors (EFSA, 2008). One of the main activities of FSAs is surveillance to guarantee food safety in livestock production chains, ranging from visual inspection and blood sampling to second-line supervision (e.g. auditing) of surveillance by others (e.g. slaughterhouses). The aim of these surveillance activities is to provide information on livestock hazards to help decision makers make intervention strategies. Since the financial resource available to support governmental veterinary services become more and more limited (Stärk et al., 2006), increasing demands are posed on FSAs to improve the cost-effectiveness of their livestock hazard surveillance activities (FAO, 2006).

Surveillance in livestock production chains is highly essential for food producers (i.e. farmers) and food companies because it has major implications on their interests. As a result, both farmers and food companies pay more and more attention to livestock hazard surveillance to ensure livestock product's safety. In the Netherlands, a national animal health fund was created in the mid-1990s and funds disease surveillance and monitoring in peace time. The

contribution to this fund is totally from farmers, because policy makers believed that disease control (including surveillance) is an integral part of livestock production, and that hence the costs should be borne by farmers (Anonymous, 2008). Hence, it is self-evident that Dutch farmers are a major stakeholder for livestock hazard surveillance. Food companies put many resources in carrying out surveillance activities along their food supply chains and in conducting research to improve their current surveillance practice. Hence, food companies also have big interests in livestock hazard surveillance, and are therefore also a stakeholder.

Livestock hazard surveillance has become a more important topic in the scientific literature in the last decades, because more and more researchers have realized the importance of surveillance from both the theoretical and practical point of view. A large amount of research has been conducted for case studies (e.g., David et al., 2011; Kuiken et al., 2011; Pultorak et al., 2011; Robertson, et al., 2011) with regard to surveillance in livestock production chains, and only a few researchers have been engaged in conceptual development (e.g., Drewe et al., 2013; Hoinville et al., 2013; Häsler, 2011). Therefore, the scientific community is an important group of participants who have strong voices on livestock hazard surveillance.

Hence, surveillance in livestock production chains is an important managerial issue in many dimensions, and research to address this issue is relevant for various groups of stakeholders.

1.2 Problem Statement

Any surveillance organization, such as FSAs and food companies, has limited financial resources to conduct livestock hazard surveillance and is facing the challenge to maximize the surveillance performance under financial resource constraints, or alternatively, to minimize surveillance costs while guaranteeing a maximum surveillance performance. Although extensive research has been conducted to achieve surveillance optimization in livestock production chains, they overlooked aspects in terms of theoretical completeness (i.e. a standard complete framework to address the problem) and operational appropriateness (standard modelling approach to mimic the real-world behavior).

Existing research mainly addresses the problem from a technical point of view, i.e. by focusing on the technical performance of surveillance (e.g. Willeberg et al., 2011; Bruhn et al., 2014; Stevens and Pfeiffer, 2014). Economic aspects of livestock hazard surveillance have

been ignored in most previous surveillance studies (Drewe et al., 2012). Although having been overlooked for a long period, the importance of including economic aspects into livestock hazard surveillance evaluation has been increasingly stressed by the scientific community. As a result, research considering the economic dimensions of surveillance is increasingly observed in the literature. For example, Klinkenberg et al. (2005) investigated the cost-effectiveness of the current Dutch CSF surveillance system using Monte Carlo simulation. Prattley et al. (2007) evaluated the cost-effectiveness of bovine spongiform encephalopathy (BSE) surveillance. Hadorn et al. (2009) carried out a cost-effectiveness evaluation of bluetongue surveillance in Switzerland using scenario tree modelling. Häsler et al. (2012) conducted an economic evaluation of the surveillance and intervention program for bluetongue virus serotype 8 in Switzerland. Although such works included the economic aspects into their analyses, they mainly addressed the surveillance costs and avoided financial losses and ignored the non-financial mitigated impacts attributable to surveillance, e.g., avoided human health problems, animal welfare losses, and animal owners' psychological pressure (Hoinville et al., 2013). In addition, the asymmetrical allocations of surveillance costs and benefits to various stakeholders also have economic implications. For example, farmers bear largely the surveillance costs, while the benefits also accrue to other stakeholders such as processors, retailors, and consumers. Therefore, a successful approach for economic evaluation of surveillance needs to incorporate various stakeholders' preferences (to the benefits and costs of surveillance) into the analysis, which has not yet been studied by previous works in this area.

Moreover, some researchers have realized that the economics of livestock hazard surveillance not only depends on surveillance itself but also on intervention. Hence, they have conducted research to address the relationship between surveillance and intervention for economic analysis. Häsler et al., (2011) developed a conceptual framework for economic analysis by conceptualizing the relationship between disease surveillance, intervention and mitigation. Howe et al. (2013) further developed the theoretical foundation of this relationship. The essence of these works is that the mitigated losses from a livestock hazard rely on the quality of both surveillance and intervention. Without effective intervention programmes, even the best surveillance systems can not protect against major losses caused by the hazard. The focus of this dissertation is merely on the surveillance part, because I want to compare the economic efficiency of different surveillance programmes only. To serve this purpose, I assume a fixed

intervention strategy (e.g., taking the default intervention strategy as given). By doing so, all differences in costs and benefits are attributable to the surveillance programmes. A more comprehensive economic analysis of the joint effect of surveillance and intervention could yield different outcomes, but such an analysis would significantly increase the complexity of the research.

Yet another major limitation of existing research is that it analyses livestock hazard surveillance at a relatively aggregated level (e.g., Crauwels et al., 1999; Elbers et al., 2002). An appropriate analytical method or model should take into account the individual-level details in *hazard dynamics* (e.g. the development of hazard related symptoms, the transmission mechanism for the hazard, etc.) and *surveillance setup* (including various surveillance activities). What is most essential is it should successfully mimic the interactions between the detailed hazard dynamics within the animal population and the surveillance setup and derive the corresponding surveillance performance and costs. However, such an approach is not observed yet in the literature.

1.3 Objective

The overall research objective of this dissertation is to improve understanding of livestock hazard surveillance to achieve economic optimization, i.e., either increasing the surveillance performance with a limited budget or decreasing surveillance costs but still maintaining certain level of surveillance performance. In the conceptual dimension, it aims to obtain *knowledge* on economic implications of surveillance in livestock production chains, including the costs and benefits from conducting surveillance activities as well as the valuations of those costs and benefits by stakeholders. In the application dimension, it is to apply the obtained knowledge to address the financial resource allocation problem for livestock hazard surveillance to help surveillance organizations increase the efficiency of their surveillance activities. To realize the overall objective, four sub-objectives are proposed:

- To improve the scientific understanding of the livestock-hazard surveillance decision-making process by developing a standard conceptual framework for single-hazard surveillance system analysis;

- To improve the scientific understanding of the livestock-hazard surveillance decision-making process for surveillance portfolios by developing a conceptual framework for surveillance-portfolio analysis;
- To test the developed conceptual frameworks by applying the concepts to concrete case studies;
- To derive the practical results that can help the surveillance decision makers to improve their surveillance practice by applying the concepts to concrete case studies.

1.4 Outline of the thesis

This thesis is composed of six chapters: a general introduction (**Chapter 1**), four research chapters (**Chapter 2, 3, 4, 5**) and a general discussion (**Chapter 6**). An outline of the thesis structure is presented in Figure 1.1.

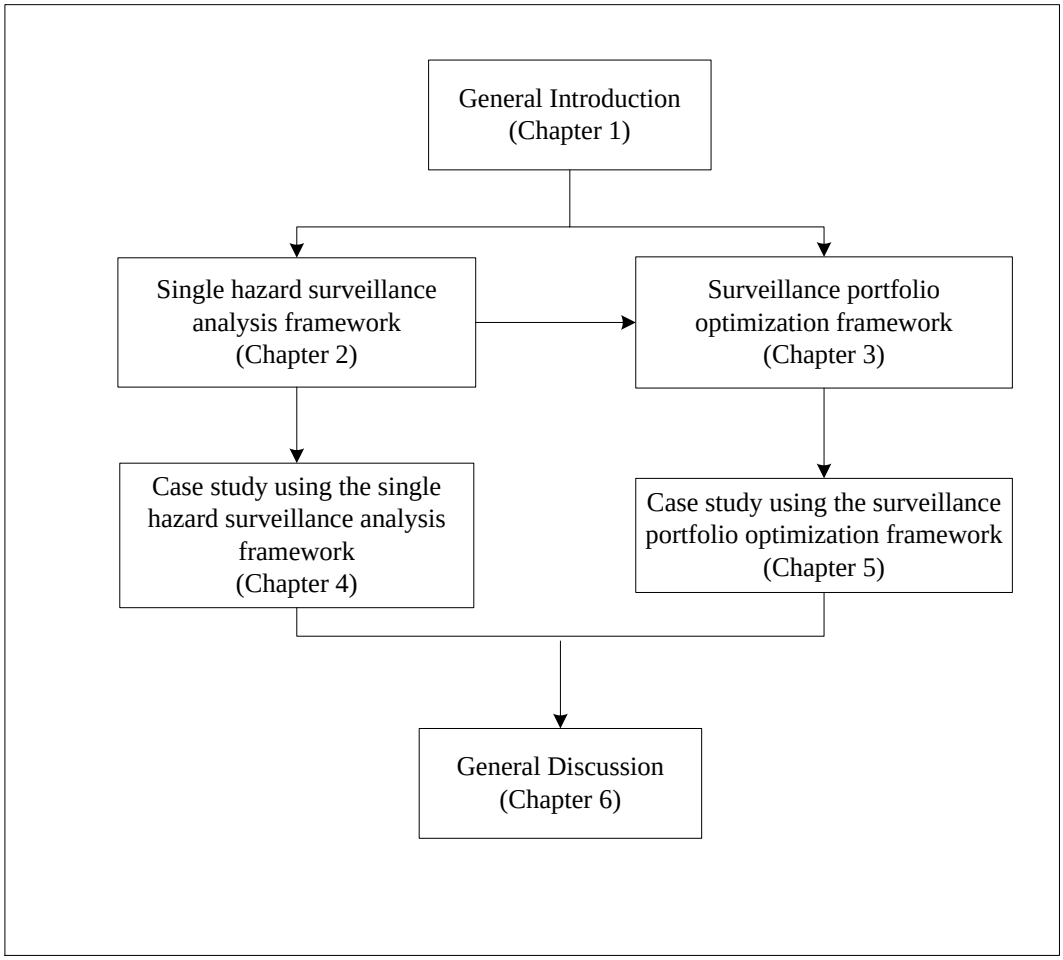

Figure 1.1 The outline of the dissertation

Chapter 2 presents a conceptual framework for the economic analysis of single-hazard surveillance systems in livestock production chains which differs from most of the previous research focusing on the technical aspect of livestock hazard surveillance (e.g., Ward et al., 1996; Bouma, et al., 2001; Paisley et al., 2011). This single-hazard analysis conceptual framework includes objective and subjective aspects of single-hazard surveillance system analysis considering the principles described by Häsler (2011) and Häsler et al. (2011). The objective analysis is a simulation model aimed at deriving an efficient set of surveillance setups based on the technical surveillance performance parameters and the corresponding surveillance costs, and the subjective analysis is a multi-criteria decision making model to evaluate the impacts of the hazard surveillance. This chapter also discusses the scientific validity of the conceptual framework and the availability of data in the framework's application.

Chapter 3 presents a conceptual framework for the economic optimization of a surveillance-portfolio consisting of multiple livestock hazards to survey. This framework applies the portfolio perspective to investigate the surveillance resource allocation problem, which is beyond the state of art that mainly focuses on single hazard surveillance analyses (e.g. Feld et al., 2000; Raulo and Lyytikainen, 2007; Martinez et al., 2011; Todd and Notermans, 2011; Chan et al., 2013; Dürr et al., 2013). A multi-criteria surveillance-portfolio optimization model is proposed which uses the outputs of the single hazard surveillance analysis as inputs. This chapter also discusses the scientific validity and data validity of the conceptual approach. The practical use of the conceptual approach is also discussed.

Chapter 4 applies the single-hazard surveillance framework to conduct a comprehensive economic analysis of CSF surveillance in the Netherlands. It takes into account the specialized structure of Dutch pig production, differences in virulence of CSF strains, and a complete list of possible surveillance activities. This chapter uses the current Dutch CSF surveillance system (i.e. the default surveillance setup) as the starting point, and investigates a number of alternative surveillance setups through cost-effectiveness and cost-benefit analyses. Managerial insights are obtained to facilitate the decision making of the policy makers.

Chapter 5 applies the surveillance-portfolio analysis framework to conduct economic optimization of a pig-hazard surveillance-portfolio, consisting of five pig-related hazards, in a

Dutch food company. In this chapter, each hazard is first analyzed by the single hazard surveillance analysis model to derive the technical surveillance performances and annual surveillance costs for each investigated surveillance setup. Then, the impact parameters corresponding to certain technical surveillance performance are estimated by relevant hazard experts. Together with the elicited stakeholder's weights, the surveillance portfolio optimization model is parameterized. Managerial implications are derived from the model's results to help the company improve its surveillance portfolio's performance.

Chapter 6 presents a synthesis of different chapters and also with the existing literature. It also discusses the implications for future research and the efforts required for further implementing the conceptual frameworks for single hazard surveillance and surveillance portfolio optimization. This chapter ends up with a summary of the main conclusions drawn from this PhD dissertation.

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Chapter 2

A conceptual framework for economic optimization of single hazard surveillance in livestock production chains

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Abstract

Economic analysis of hazard surveillance in livestock production chains is essential for surveillance organizations (such as food safety authorities) when making scientifically-based decisions on optimization of resource allocation. To enable this, quantitative decision support tools are required at two levels of analysis: (1) single-hazard surveillance system and (2) surveillance portfolio. This paper addresses the first level by presenting a conceptual approach for the economic analysis of single-hazard surveillance systems. The concept includes objective and subjective aspects of single-hazard surveillance system analysis: (1) a simulation part to derive an efficient set of surveillance setups based on the technical surveillance performance parameters (TSPPs) and the corresponding surveillance costs, i.e., objective analysis, and (2) a multi-criteria decision making model to evaluate the impacts of the hazard surveillance, i.e., subjective analysis. The conceptual approach was checked for (1) conceptual validity and (2) data validity. Issues regarding the practical use of the approach, particularly the data requirement, were discussed. It is concluded that the conceptual approach is scientifically credible for economic analysis of single-hazard surveillance systems and that the practicability of the approach depends on data availability.

Keywords: livestock hazard surveillance, economic analysis, conceptual framework

2.1 Introduction[1]

During the last decades, the European Union (EU) has regularly faced major crises in the fields of livestock production and food safety. Examples include classical swine fever (CSF) during the 1990s in the Netherlands, Belgium and Germany; bovine spongiform encephalopathy (BSE) in the 1990s in the United Kingdom; dioxins in 1999 in Belgium; and highly-pathogenic avian influenza (HPAI) in the 2000s in several EU countries. Such crises not only caused enormous socio-economic impacts (see, e.g., Anonymous, 2002; Asseldonk et al., 2005; Longworth et al., 2012ab), but they also resulted in reduced public confidence in food production and products (Jonge et al., 2004).

One of the EU's responses to improve the quality of both food production and products was the introduction of new standards to improve surveillance to guarantee the safety in food production chains, ranging from visual inspection and blood sampling to second-line

[1] A list of abbreviations is included in Appendix A.

supervision of surveillance by others, e.g., slaughterhouses. Surveillance [2] is commonly defined as: the systematic collection of data on the occurrence of specific hazards, the analysis and interpretation of these data, and the dissemination of consolidated and processed information to contributors to the program and other interested persons (Raska, 1966; Langmuir, 1971; Kelsey et al., 1986; Dufour and Audige, 1997). According to the World Animal Health Organization (OIE), a surveillance system is "a method of surveillance that may include one or more component activities that generates information on the health, disease or zoonosis status of animal populations". In agreement with these general definitions, and also to avoid terminology ambiguity, subsequent aspects were defined as follows:

- A single-hazard surveillance system (SHSS) is a surveillance system that aims to detect a single microbiological or chemical hazard in a livestock production chain, such as CSF or Salmonella surveillance.
- A surveillance system component (SSC) is a specific surveillance activity within a SHSS; for example, clinical diagnosis and routine serological tests in slaughterhouses. Hence, each SHSS consists of one or more SSCs.
- A surveillance setup of a SHSS is the combination of SSCs with their respective levels of intensity, e.g., sampling frequency and size.
- A Surveillance Portfolio (SP): the collection of a group of SHSSs operated by one single organization, e.g., a Food Safety Authority or a private slaughterhouse.

The overall optimization problem of any surveillance organization is to maximize surveillance performance within given or expected budget constraints. This economic surveillance optimization problem can be dealt with at two levels: (1) the SHSS, and (2) the surveillance portfolio. This paper focuses on the first level.

Surveillance is an important tool to manage complex system to avoid unfavorable damages. In the early stage, many studies on surveillance systems were conducted in military area (e.g., Cutrona et al., 1961; Easton and Fleming, 1960; Kaufman, 1964). Later, surveillance systems were extensively studied in the fields of engineering (e.g., Kuno, et al., 1996; Haritaoglu et al., 2000; Muller-Schneiders et al., 2005), human health (e.g., German et al., 2001; Chou et al., 2004) as well as animal health (e.g. De Vos et al., 2007; Häsler et al., 2012). With regard to

[2] Salman (2003) discussed the difference between monitoring and surveillance and used the term 'MOSS' (monitoring and surveillance system). For convenience reasons, we use the term "surveillance" interchangeably for both monitoring and surveillance.

the studies on surveillance system in livestock product chains, a considerable amount of literature is available on technical evaluation of SHSSs (Paisley et al., 2011; Willeberg et al., 2011). Drewe et al. (2012) performed a systematic review of evaluations of SHSSs, observing that there is a distinct lack of standardization with regard to such evaluation and only a few of these studies included some kind of economic aspect. Drewe et al. (2012) concluded that economic evaluation should be an integral part of the evaluation process of surveillance systems. Häsler et al. (2011) developed a practical framework for the economic evaluation of national SHSSs, with the main objective of guiding decision makers (DMs) in planning, designing, and conducting economic evaluations. They made a distinction between situations with and without legal or other constraints, and recommended cost-effectiveness analysis (CEA) for the former and cost-benefit analysis (CBA) for the latter. The framework presented by Häsler et al. (2011) provides important steps towards improvement and standardization of economic evaluation of SHSSs. However, it focuses primarily on financial evaluations and does not account for non-financial impacts such as social unrest and public health or the subjective valuation of these impacts. Moreover, the framework appears to be rather 'open'; that is, it leaves ample room for non-harmonization.

The aim of this article is to build further on the abovementioned studies and present a new conceptual approach for SHSS analysis. This provides a consistent conceptual basis for the development of quantitative tools for decision support, aimed at producing an economic evaluation of alternative surveillance options for a SHSS that explicitly emphasizes the benefits of hazard surveillance as well as the subjective evaluation by the stakeholders.

The remainder of this article is organized as follows. The SHSS analysis framework is elaborated in Section 2, followed by a numerical example for illustration purpose in Section 3 and a discussion in Section 4.

2.2 A conceptual framework for economic evaluation of single-hazard surveillance systems

In this section, a three-step evaluation framework for SHSS evaluation is presented (Figure 2.1).

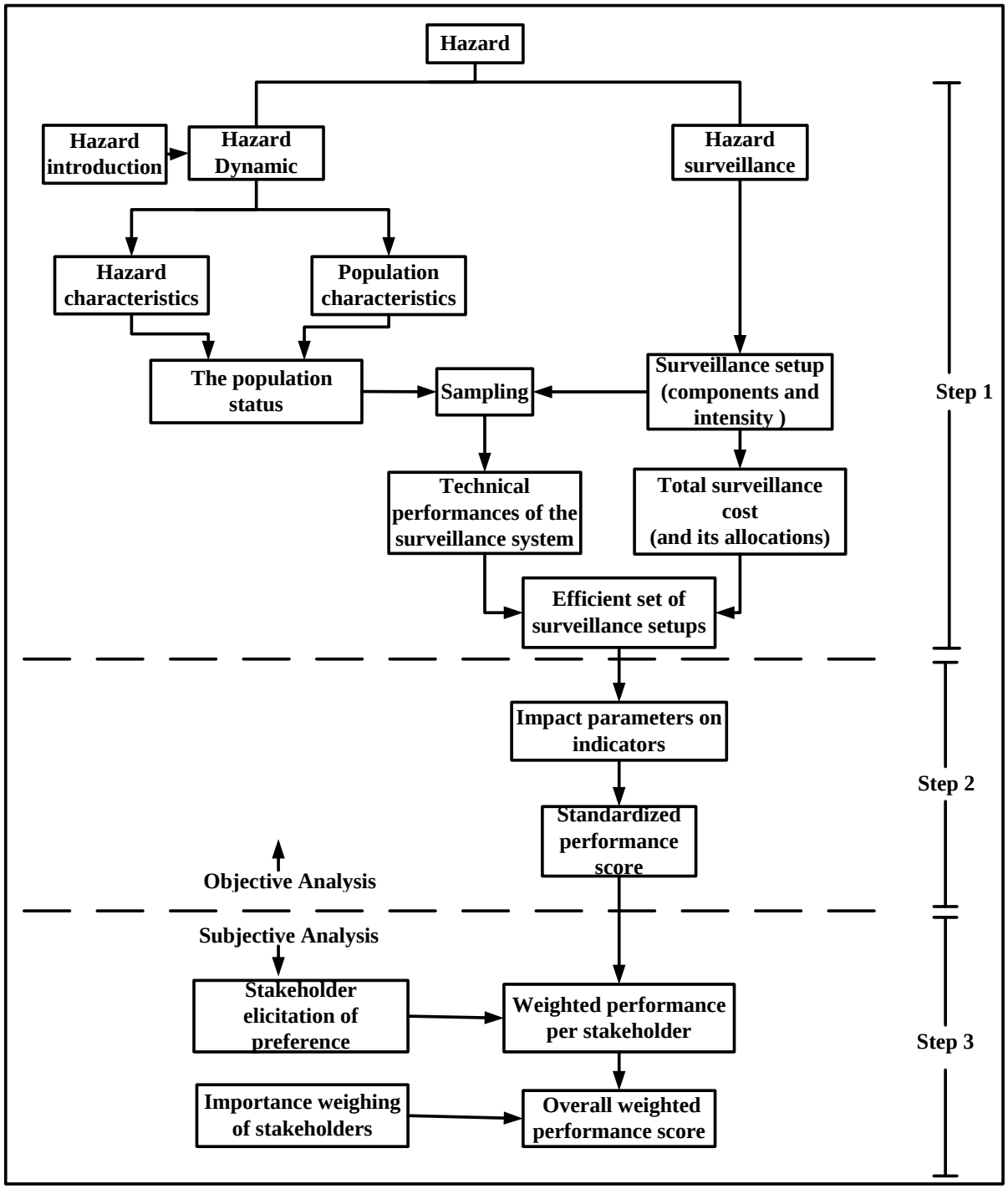

Fig.2.1. General evaluation framework for SHSS evaluation

Step 1 aims to obtain, from a variety of surveillance setups regarding a particular SHSS, the most efficient set of setups; that is, those that are not outperformed simultaneously by others on the two main criteria: technical surveillance performance parameters (TSPPs) and costs. To enable this, the hazard is subject to two distinct processes.

Firstly, the dynamics of the hazard within the population must be analyzed[3], taking the following two main features into account: the hazard characteristics (particular those influencing spread and expression of symptoms) and the population characteristics (such as production chain structure). Such an analysis can be performed using dynamic stochastic simulation modeling (see, e.g., CSF (Klinkenberg et al. 2005), BSE (Yamamoto et al. 2008) and Salmonella (Van der Gaag et al., 2004)). The model should include two main aspects: (1) the dynamics of the hazard as such (that is, the spread of the disease) and (2) the development of symptoms within individual animals. For the latter, a generic list of symptoms presented in Table 2.1 is proposed.

Table 2.1
A general list of hazard related expressions.

Categories of Expressions	Examples of Expressions
Clinical symptoms	
Non-specific clinical symptoms	Fever, Apathy, Loss of appetite
Suspicious clinical symptoms	Skin haemorrhage*
Specific clinical symptoms	Blue tongue**
Pathological findings	
In blood	Antigens, Antibodies, Chemical substances
In feces	Antigens, Chemical substances
In organs	Antigens, Chemical substances, lesions
In products	Antigens, Chemical substances
Other pathologies	Leukopenia***

*Suspicious clinical symptom for Classical Swine Fever and African Swine Fever
**Specific clinical symptom for Bluetongue Disease
***Pathological finding for Classical Swine Fever

The expressions are categorized into non-specific clinical symptoms, suspicious clinical symptoms, and pathological findings in blood and organs. After infection, expression of these symptoms occurs stochastically and time-dependent (see Appendix B). The symptom development (including "viraemia"), together with the within- and between-farm transmissions, should aim to provide a population matrix that includes the following three levels:

– Population: farms that are either infected or not infected

[3]Note: for zero-prevalence hazards, hazard introduction must be assumed,

- Farm: the distribution of animals according to varying states of infection
- Animal: the expression of the various symptoms within that animal.

This matrix is updated at each time-step of the simulation, and hence reflects the dynamics of the hazard within the entire population.

Secondly, the various surveillance setups can be analyzed by subsequently executing each setup through sampling of the population matrix at each time-step. This regular time-step sampling can include various issues simultaneously; for example, 100 percent daily sampling of clinical symptoms at each herd and blood sampling at the slaughterhouse. Depending on (1) the development of hazard features within the population, and (2) the intensity of the surveillance, at any given moment, sampling will result in an important event, depending on the hazard category: detection of the first infected farm, detection of a certain case, or observation of a trend change. Subsequently, for this run, the setup, the output parameters TSPPs, and costs can be calculated. Finally, analyzing the TSPP-cost combinations per surveillance setup can provide the efficient set.

Step 2. Regardless of its category, each hazard has impacts and the improved surveillance can decrease these impacts, therefore yielding benefits. For example, CSF has massive economic, socio-ethical, and other impacts. Reducing the duration of high risk period (HRP) as well as the number of infected farms at the end of the HRP for CSF results in a more favorable starting situation for control, and therefore reduced impacts (Burrell, 2002). Each type of impact is reflected by its hazard impact indicators (HIIs), e.g. for CSF, HIIs could be the number of infected herds in the epidemic, economic losses, and the number of culled animals. Given the above, the "impact differences" of various TSPPs on the TSPIs under different efficient surveillance setups can be analyzed using hazard impact simulation models (e.g. Mangen et al., 2002 (CSF); Longworth et al., 2012ab (HPAI)), provided that the TSPPs can explicitly be used as inputs. For example, Klinkerberg et al. (2005) use the number of infected farms at the end of the HRP to predict the direct costs of CSF epidemic using Mangen's impact simulation model. In the model of Longworth (2012ab), the link between the duration of HRP and different types of impacts can be found. In this way, we can derive the mitigated impacts because of the improved surveillance.

Finally, since each impact is measured differently, e.g., number of animals, monetary units, etc., different impacts can be made comparable by standardizing them to standardized performance scores (SPSs); this can be done using equation (1):

$$v_{i,s} = \begin{cases} 100 \times \left[P_i^{max} - P_{i,s}\right] / \left[P_i^{max} - P_i^{min}\right], & if\ P_i^{max} - P_i^{min} > 0 \\ 0, & if\ P_i^{max} - P_i^{min} = 0 \end{cases} \quad (1)$$

where

$v_{i,s}$ is the SPS on HII *i*, with surveillance setup *s*.

$P_{i,s}$ is the impact parameter on HII *i*, with surveillance setup *s*;

P_i^{max} is the maximum impact parameter on HII *i*;

P_i^{min} is the minimum impact parameter on HII *i*.

In this way, a SPS with values between 0 and 100 can be obtained. Because small values, such as monetary costs, are preferred in some cases and high values, such as an increase in consumer surplus, in others, a redirection is sometimes required (Mourits et al., 2010). This can be done using equation (2):

$$v_{i,s} = \begin{cases} 100 - 100 \times \left[P_i^{max} - P_{i,s}\right] / \left[P_i^{max} - P_i^{min}\right], & if\ P_i^{max} - P_i^{min} > 0 \\ 0, & if\ P_i^{max} - P_i^{min} = 0 \end{cases} \quad (2)$$

Step 3. The SPSs per impact obtained in Step 2 are *objective*; that is, value-free. However, each stakeholder *subjectively* evaluates each impact differently (Walshe and Burgman, 2010). Moreover, it is unlikely that the impact on each stakeholder is perceived as being of equal importance within society. Although this is ultimately a political decision, it will have an impact on the social welfare as such, and hence should be explicitly considered in the decision making process. Step 3 aims to obtain a single overall performance score for each surveillance setup, taking both above-mentioned issues into account. Firstly, a weighted performance score for each stakeholder group should be obtained using equation (3):

$$V_{g,s} = \sum_{i=1}^{I} w_{g,i} v_{i,s} \quad \text{for all } g \text{ and all } s \quad (3)$$

where

$V_{g,s}$ is the weighted performance score for stakeholder group *g* regarding surveillance setup *s*;

$w_{g,i}$ is the weight assigned by stakeholder group *g* to HII *i*, and $\sum_{i=1}^{I} w_{g,i} = 1$;

I denotes the number of HIIs considered.

For equation (3), two assumptions should hold: linear utility functions with respect to the SPSs of the HIIs and mutual preferential independency between HIIs. Clemen and Reilly (2001) and Mourits et al. (2010) have intensively justified the appropriateness of these two assumptions.

The weights are obtained per stakeholder group and reflect the preference of each stakeholder group on different HIIs. Various elicitation procedures can be used, including conjoint analysis (Green and Srinivasan, 1990) and the analytical hierarchy process (AHP) technique (Saaty, 2005).

After obtaining the weighted performance score per stakeholder group for the various surveillance setups, the final step is to account for differences in the importance of stakeholder groups through the weighting, as shown in equation (4):

$$V_s = \sum_{g=1}^{G} w_g V_{g,s} = \sum_{g=1}^{G} \sum_{i=1}^{I} w_g w_{g,i} v_{i,s} \quad \text{for all } s \qquad (4)$$

where

V_s is the overall weighted performance for implementing surveillance setup *s*;

w_g is the weight assigned by the decision maker to stakeholder group g (note: the sum of the weights w_g should be equal to 1);

G denotes the number of stakeholder groups.

The weights, w_g, should be obtained from the DM, using a similar elicitation technique as for $w_{g,i}$.

2.3 Numerical example

In this section, to illustrate the presented conceptual framework, a hypothetical case of a SHSS for CSF in the Netherlands is elaborated as a shortcut model. The at-risk population included 2300 farrowing, 5000 finishing and 360 farrow-to-finish pig herds (see Table 2.2).

Table 2.2
The distributions of farm types and animals

Farm type	Number of farms	Number of animals per farm		
		Piglet	Sow	Slaughter pigs
Farrowing	2300	2000	400	0
Finishing	5000	0	0	830
Farrow-to-finish	360	1090	220	800

A randomly selected herd was assumed to be the index premise. The within-farm and between-farm transmission parameters were derived from (Klinkenberg et al., 2003; Klinkenberg et al., 2005): β_w=0.21 and β_b=0.0024, respectively. The applied strain of CSF is assumed to be highly virulent and the expression-probability matrix for modelling CSF-related symptoms is presented in Table B1 (Appendix B). The matrix builds upon the literature, as indicated in the table, and was confirmed by the CSF expert from the Central Veterinarian Institute. By way of comparison, a low-virulent strain example is also shown with a different expression-probability matrix, as described in Table B2 (Appendix B).
The main features of the various SSCs included are described in Table 2.3.

Table 2.3
The SSCs that could be employed to detect CSF in the Netherlands

SSC	Sensitivities	Application frequency	Sampling size	Cost for Farmers	Cost for FSA
Daily clinical observation by the farmer	To call a veterinarian: 20% to 100%[ab] To submit an animal to AHS*: 20% to 100%[ab]	Every day	All animals	No	No
Veterinarian inspection	32%[ab]	After a call	All animals	70€/visit[a]	
		or once per four weeks	All animals	1175€/herd/year[ad]	
Pathology	50%[ab]	After the serevely diseased animal submitted to AHS	All animals submitted to AHS	50€/animal[ad]	350€/animal[ad]
Tonsil virology		After the serevely diseased animal submitted to AHS	All submitted animals		166000 €/year[ad]
Blood and tonsil analysis	100%[a]	In case of a CSF suspicion on farm	All animals with CSF suspicion		3170 €/case[ad]
Routine serology ELISA	99%[c]	A batch/week	5 animals/batch		8.8 €/test[e]
PCR on rendered animal	98%[b]	Dead animals	All dead animals		27 €/test[f]

[a]Klinkenberg et al., (2005)
[b] Backer et al., (2011)
[c]Colijn et al., (1997)
[d]VWA report, (2003)
[e]Anonymus, (2011)
[f]De Vos et al., (2005)
*Animal health service

Following Dutch protocol (VWA, 2003; Klinkenberg et al., 2005), the default setup (Def) included five SSCs: (1) clinical inspection by the farmer, (2) clinical inspection by a veterinarian, (3) pathology, (4) tonsil virology, and (5) blood and tonsil analysis (after CSF suspicion). In addition to Def, five alternative surveillance setups were also investigated, including Def+S5, Def+S10, Def+R20, Def+R33 and Def+R100. Def+S5 and Def+S10 denote the default surveillance setup plus routine serological testing in slaughterhouses with the sample size 5 and 10 animals per batch respectively. Def+R20, Def+R33 and Def+R100 indicate the default surveillance setup plus polymerase chain reaction (PCR) testing on rendered animals with the sample sizes, 20%, 33.3%, and 100% of the total dead animals respectively. Each simulation run included 1,000 iterations. The used TSPIs are the duration of the HRP and the number of infected farms at the end of the HRP.

2.3.1 Step 1: Obtaining the efficient set of surveillance setups

In Table 2.4, the simulation results for five surveillance setups are presented, taking account for both high- and low-virulent CSFV strains.

Table 2.4
Simulated results (percentiles) of technical performances for both high and low virulent CSF strains

Surveillance setup	Highly virulent strain						Low virulent strain					
	HRP duration (day)			The number infected farms at the end of HRP			HRP duration (day)			The number infected farms at the end of HRP		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Def[1]	27	36	50	1	4	14	51	76	113	1	4	9
Def + S5[2]	27	36	49	1	4	13	46	72	108	1	3	8
Def + S10[3]	27	36	48	1	4	13	41	68	103	1	3	8
Def + R20[4]	20	33	42	1	3	7	51	76	113	1	4	9
Def + R33[5]	20	21	34	1	2	4	51	76	113	1	4	9
Def + R100[6]	19	20	21	1	1	3	51	76	113	1	4	9

[1]Default surviellance setup

[2]Default surveillance setup + routine serological testing in slaughterhouses with the sample size 5 animal per batch

[3]Default surveillance setup + routine serological testing in slaughterhouses with the sample size 10 animal per batch

[4]Default surveillance setup + PCR testing on rendered animals with the sample size 20% of the total dead animals

[5]Default surveillance setup + PCR testing on rendered animals with the sample size 33% of the total dead animals

[6]Default surveillance setup + PCR testing on rendered animals with the sample size 100% of the total dead animals

For the high-virulent strain, the results show for Def a median HRP of 36 days with four infected farms at the end of the HRP. These figures increase to 50 days and 14 farms, respectively, with the 95th percentile. Additional serology in the slaughterhouses (Def+S5 and Def+S10) hardly affects these results: only a small reduction with the 95% percentile can be observed. In contrast, additional PCR testing on rendered animals (Def+R20, Def+R33 and Def+R100) does reduce HRP, which decreases with sampling size. For the low-virulent strain, the results show the opposite. The default HRP increased to 76 days at the median, while the number of infected farms at the end of the HRP remains more or less the same. In contrast to the high-virulent strain, however, the impact of PCR testing is virtually absent, whereas the impact of serology at the slaughterhouses does have a reducing impact, particularly on the HRP.

Table 2.5 presents the simulated daily surveillance costs for the respective surveillance setups and situations and lists the total costs, costs for the Food Safety Authority (FSA) and costs for the collective farmers.

Table 2.5
Simulated results (percentiles) of the daily average surveillance costs for both high and low virulent CSF strains (k€)

Surveillance setup	Highly virulent strain									Low virulent strain								
	Total average daily costs			Average daily costs for FSA			Average daily costs for farmers			Total average daily costs			Average daily costs for FSA			Average daily costs for farmers		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Def[1]	25.1	25.1	25.2	0.5	0.5	0.5	24.7	24.7	24.7	25.1	25.1	25.1	0.5	0.5	0.5	24.7	24.7	24.7
Def + S5[2]	58.6	58.8	59.1	33.9	34.2	34.4	24.7	24.7	24.7	58.7	58.8	59.0	34.0	34.2	34.3	24.7	24.7	24.7
Def + S10[3]	92.0	92.5	93.0	67.4	67.9	68.3	24.7	24.7	24.6	92.2	92.5	92.9	67.5	67.9	68.2	24.7	24.7	24.7
Def + R20[4]	40.4	40.4	40.5	15.8	15.8	15.9	24.7	24.7	24.7	40.4	40.4	40.5	15.8	15.8	15.8	24.7	24.7	24.7
Def + R33[5]	50.6	50.6	50.8	26.0	26.0	26.1	24.7	24.7	24.7	50.6	50.6	50.7	25.9	26.0	26.1	24.7	24.7	24.7
Def + R100[6]	101.6	101.7	102.1	76.9	77.0	77.5	24.7	24.7	24.7	101.6	101.7	101.9	76.9	77.0	77.3	24.7	24.7	24.7

[1]Default surviellance setup

[2]Default surveillance setup + routine serological testing in slaughterhouses with the sample size 5 animal per batch

[3]Default surveillance setup + routine serological testing in slaughterhouses with the sample size 10 animal per batch

[4]Default surveillance setup + PCR testing on rendered animals with the sample size 20% of the total dead animals

[5]Default surveillance setup + PCR testing on rendered animals with the sample size 33% of the total dead animals

[6]Default surveillance setup + PCR testing on rendered animals with the sample size 100% of the total dead animals

Large differences in costs between surveillance setups can be observed, ranging from total costs of 25 k€ for Def to 101 k€ for Def+R100. Differences within a setup between percentiles are virtually absent because routine costs are dominating. Moreover, quite some differences can be observed between the costs for the FSA and farmers. Since it was assumed that costs associated with additional serology and PCR testing would accrue to the FSA, costs for the latter increase with more intensified surveillance setups.

Mathematically, surveillance setups included in the efficient set will fulfil the following conditions:

s^* is an efficient surveillance setup, if there is no other setup s such that

$C(s) \leq C(s^*)$ (total daily surveillance costs)

and

$P(s) \leq P(s^*)$ (duration of HRP)

with at least one strict inequality (Ben-Israel et al., 1977).

Combining the median outcomes of the performance (Table 2.4) and the costs (Table 2.5), the efficient set of surveillance setups are circled in Figure 2.2.

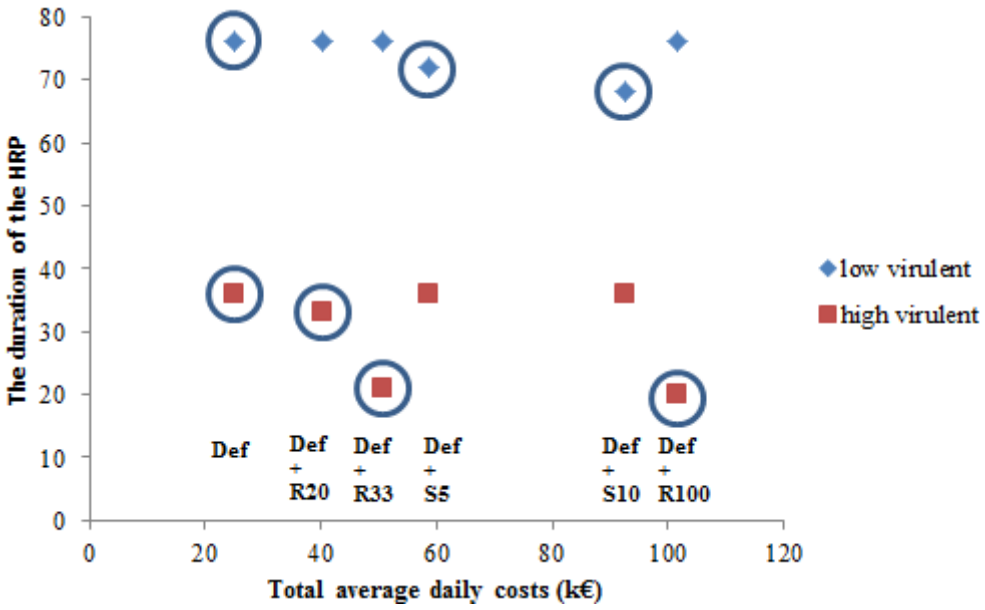

Fig.2.2. The efficient surveillance setups for the high and low virulent strains

In case of the high-virulent CSFV, Def+S5 and Def+S10 are dominated by the other setups; in case of the low-virulent CSFV, Def+R20, Def+R33 and Def+R100 are dominated by others.

2.3.2 Step 2: Obtaining standardized performance scores

For the surveillance setups included in the efficient set for the high-virulent CSFV, the impacts of the TSPPs on outbreaks of CSF were estimated. This was done using the CSF simulation approach described by Mangen et al. (2001) for Def, and estimations based on this for Def+R20, Def+R33 and Def+R100. Although diseases can have an impact on a range of HIIs (see, e.g., Mourits et al., 2010), only a few were included in the present analysis, for the sake of simplicity. The impact parameters on each HII for each efficient surveillance setup are presented in Table 2.6 (upper part).

Table 2.6

Impact parameters, standardized impact scores, weights on indicators and on stakeholders for each surveillance setup in the efficient set

Parameters and weights		Epidemiology		Economics			Human health
		The duration of the epidemic (day)	The number of infected farms in the epidemic (farm)	Total annual losses for farmers (k€)	Total annual losses for society (k€)	Total annual human infections (person)	Total annual human deaths (person)
Hazard Impact Indicators							
Def[1]		164*	99*	12,000*	11,8000*	0	0
Def + R20[2]		115	35	10,000	100,000	0	0
Def+ R33[3]		90	15	1,000	10,000	0	0
Def + R100[4]		76	5	800	8,000	0	0
Standardized performance scores:							
Def		0.0	0.0	0.0	0.0	0.0	0.0
Def + R20		55.7	68.1	17.9	16.4	0.0	0.0
Def+ R33		84.1	89.4	98.2	98.2	0.0	0.0
Def + R100		100.0	100.0	100.0	100.0	0.0	0.0
Weights on indicators:							
w_g:	$w_{g,i}$:						
Farmers (w_1=0.3)		$w_{1,1}$=0.21	$w_{1,2}$=0.09	$w_{1,3}$=0.45	$w_{1,4}$=0.05	$w_{1,5}$=0.04	$w_{1,6}$=0.16
Citizens (w_2=0.7)		$w_{2,1}$=0.1	$w_{2,2}$=0.1	$w_{2,3}$=0.04	$w_{2,4}$=0.16	$w_{2,5}$=0.12	$w_{2,6}$=0.48

*The impact parameters under the default situation (the default surveillance setup + non-vaccination and preventive-slaughter control strategy) are estimated based on Mangen, et al. (2001). The detailed estimation of the annual losses for farmers and society is presented in Appendix C.

[1]Default surviellance setup

[2]Default surveillance setup + PCR testing on rendered animals with the sample size 20% of the total dead animals

[3]Default surveillance setup + PCR testing on rendered animals with the sample size 33% of the total dead animals

[4]Default surveillance setup + PCR testing on rendered animals with the sample size 100% of the total dead animals

With Def, the largest impact was observed with 99 infected farms in 164 days. The associated costs for farmers and society were 12,000 and 118,000 k€, respectively (For the details see Appendix C). Since CSF is not a zoonosis, human casualties are absent. Improving the TSPPs (Table 2.4) of the surveillance reduced the impacts (Table 2.6).

These impact parameters on HIIs were transformed into SPSs using equation (1), and results are presented in Table 2.6 (middle part). The lowest impact parameter on each HII was given an SPS value of 100. On all HIIs, Def performed the worst and therefore the SPSs were 0.

Finally, subjective weights of the respective HIIs, $w_{g,i}$, are presented in Table 2.6 (lowest part). These weights were hypothetically generated, with the underlying assumption that farmers have a higher preference for economic losses, while citizens put a higher weight on human health-related HIIs, especially on "total annual human deaths".

2.3.3 Step 3: Subjective evaluation of the impacts

The SPSs are transformed into the weighted performance score per stakeholder group by multiplying the SPSs and the respective weights on corresponding HIIs, $w_{g,i}$, of Table 2.6 in equation (3); then, multiplying the DMs' weights, w_g, in equation (4) provides the overall weighted performance score. All of the results are presented in Table 2.7.

Table 2.7
The weighted performance score per stakeholder group and the overall weighted perfromance

Stakeholder group	Surveillance setup	Weighted performance
Farmers	Def[1]	0.0
	Def + R20[2]	26.7
	Def + R33[3]	74.8
	Def + R100[4]	80.0
Citizens	Def	0.0
	Def + R20	15.7
	Def + R33	37.0
	Def + R100	40.0
Overall	Def	0.0
	Def + R20	19.0
	Def + R33	48.3
	Def + R100	52.0

[1]Default surviellance setup

[2]Default surveillance setup + PCR testing on rendered animals with the sample size 20% of the total dead animals

[3]Default surveillance setup + PCR testing on rendered animals with the sample size 33% of the total dead animals

[4]Default surveillance setup + PCR testing on rendered animals with the sample size 100% of the total dead animals

According to the weighted performance scores for two stakeholder groups, farmers have a higher level of preference than citizens, because the impact on human health (which has a high preference with citizens) does not apply to CSF and therefore to the overall impact. Moreover, it can be seen that farmers have a slightly higher preference for Def+R100 over Def+R33 (80 versus 74.8), and citizens have even closer preference for the two setups (40 versus 37).

2.4 Discussion and conclusion

This paper presents a conceptual approach for economic analysis of single-hazard surveillance system. Unlike the existing literature, the approach not only considers various socio-economic impacts due to hazard surveillance, but also includes subjective valuation of such impacts by different stakeholders. In so doing, it provides an improved basis for conducting quantitative modeling research on SHSS evaluation and enables in-depth, cost-effectiveness analysis of SHSS that accounts for the preferences of stakeholders. To judge whether the approach could fulfill its intended purpose, insights should be obtained regarding the scientific credibility and the practicability of the approach.

2.4.1 Scientific Credibility of the approach

It is self-evident that the internal validation has been conducted extensively. Therefore, this section only discusses the conceptual validity and data validity.

2.4.1.1 Conceptual validity

The developed approach attempts to tackle the SHSS analysis problem in three steps (see Fig. 2.1). In step 1, a simulation model is developed with two separate modules: (1) simulation of hazard dynamic and (2) simulation of the sampling process (subject to a surveillance setup) on the referred animal population. For dynamic hazard simulation, the hazard expression-probability matrix (see Appendix B) is proposed to more realistically model the symptoms development for infected animals. The classical SIR model (e.g., Stegeman et al., 2004 (HPAI) and Klinkenberg et al., 2005 (CSF)) is used to model the within- and between-farm hazard spread. The development of the hazard, in terms of symptom occurrence and hazard spread, results in a three-level population matrix that mimics the real-life situation of the hazard status in the animal population: (1) infected farms in the country, (2) infected animals on the infected farms, and (3) symptoms in the infected animals. Compared to existing models for disease surveillance (e.g., Klinkenberg et al., 2005; Backer et al., 2011), the proposed simulation model makes a conceptual improvement in that it makes more biological sense and mimics the real life better (Taylor, 2003); this is particularly the case with sampling on the three-level population matrix, which is close to the real-life situation. However, the main drawback of the proposed model is that it is quite data-intensive to construct. After obtaining the technical performances and the associated costs for various possible surveillance setups, an efficient set of surveillance setups are derived based on the commonly used Pareto Efficiency Principle (e.g., Ben-Israel et al., 1977). Eliminating the dominated surveillance setups can save a large amount of work for the following analysis.

In step 2, the efficient surveillance setups of the SHSS will be analyzed further on its socio-economic impacts, that is, the benefits of the SHSS. Häsler (2011) noted that economic assessment of surveillance can be conducted at two levels: (1) cost-effectiveness assessment and (2) cost-benefit assessment; one important drawback of the cost-effectiveness assessment is that it cannot quantify the benefits of the SHSS. To the best knowledge of the authors, the present study is the first to explicitly incorporate the benefits from surveillance to SHSS analysis in the field of animal health studies. In this sense, it represents an advance for cost-

benefit assessment of the SHSS in that field. To enable the cost-benefit assessment, a list of HIIs is selected to measure different types of impacts, such as the duration of the epidemic, monetary losses for the farmers, etc. The impact parameters on HIIs can be obtained using the impact assessment models. Such models have been presented by, e.g. classical swine fever (Mangen et al., 2002), salmonella (Goldbach and Alban, 2006), and avian influenza (Longworth et al., 2012 (HPAI)). However, such extensive impact assessment models are not available for all hazards. Where such models are lacking, the impact parameters should be estimated by experts (e.g., Asseldonk et al. (2005) for epidemiological impacts of CSF, FMD, and HPAI, and Senturk and Yalcin (2005) for financial impacts of FMD). Once obtained, the impact parameters are standardized using equations (1) or (2), a typical normalization method (e.g., Sorace and Zhan, 2003; Ginevicius, 2008), to make the impact parameters comparable between HIIs. Hereby, it is necessary to point out that since this is a conceptual article, only the most commonly used benefits were considered. In the real application of the concept, more types of benefits can be included and tailor-made to need of the analysis for specific hazards, e.g., including the mitigation of public uneasiness, physiological problem for animal owners, etc.

In the third step, multi-criteria decision making is used to incorporate stakeholders' preferences to evaluate different types of impacts, e.g. monetary values versus human deaths, comparable. Each type of impact is captured by a HII and the weighted sum of the impact parameters on HIIs is used to measure the weighted performance of a surveillance setup (see equation (3)). These kind of multi-criteria decision making models have been broadly used for multi-criteria decision analysis, in the animal-health-related field (e.g., Ohashi et al., 2010; Mourits, et al., 2010) and in other disciplines (e.g., Mendoza and Martins, 2006; Vaidogas and Sakenaite, 2011). Well-defined elicitation techniques such as conjoint analysis (Green and Srinivasan, 1990) and analytical hierarchy process (Saaty, 2005) can be used to derive the "importance weights" on different HIIs and stakeholder groups.

Finally, the overall appropriateness of the concept has been confirmed by relevant experts[4] who did not identify any serious omissions or problems. Therefore, from a conceptual point of view, it is concluded that there is no reason to invalidate the approach.

[4] Experts from the Dutch FSAs (NVWA and PVE), the food company VION and Central Veterinary Institute (CVI) are consulted.

2.4.1.2 Data validity

Various types of data are required at each step of the conceptual approach. In step 1, two types of data are important to parameterize the simulation model: (1) the data for hazard spread, that is, the within- and between-farm transmission parameters, and (2) the data for expression development, that is, the symptoms' occurrence probabilities in the expression-probability matrix. Some hazards' transmission parameters can be obtained directly from the literature, e.g., HPAI (Stegeman et al., 2004) and CSF (Klinkenberg et al., 2005). However, it is more difficult to obtain the probabilities of symptom occurrences. Firstly, an extensive literature study is required to retrieve the raw data from a range of sources, such as infection experiments and epidemiological surveys. Then, given that the conditions (e.g. the types and ages of the animals) to derive the raw data may vary from one source to another, it is impossible to obtain the directly suitable information to fill in the expression-probability matrix. Therefore, relevant experts should be consulted in order to translate the raw data into a form that exactly fits the expression-probability matrix. Here, it must be noted that this data is not available for all hazards. It is relatively easy to obtain such data for diseases such as CSF and HPAI, but may not be for other diseases, which can raise the problem of approach application.

In step 2, the data, that is, the impact parameters on HIIs for implementing each efficient surveillance setup is required. This data can be obtained using impact assessment simulation models (e.g., Mangen et al., 2002 (CSF); Goldbach and Alban, 2006 (salmonella); Longworth et al., 2012 (HPAI)). When such models are lacking for a less-studied hazard, expert options can be used to obtain the impact parameters (e.g., Asseldonk et al., 2005; Senturk and Yalcin, 2005).

In step 3, the preferences, reflected by weights, on different HIIs and stakeholder groups are required. These weights can be derived through stakeholder and decision-maker elicitation using the well-defined preference elicitation techniques such as conjoint analysis and AHP.

Hence, the data for the approach can be obtained through a variety of scientifically accepted methods and the data validity of the conceptual approach can be asserted.

2.4.2 Practicability of the approach

The full practicability of the approach overall relies heavily on the data availability for the studied hazard, including the data for disease spread and expression development (step 1), the data for impact parameters derived from the impact assessment models (step 2), and the data for the elicited weights on HIIs (step 3). Firstly, for the well-studied hazards such as CSF, FMD, and AI, the data required in all three steps are available, which enables the thorough application of the approach to surveillance assessment. Secondly, for the less-studied hazards, the required data may only be partly available, e.g., the data for spread and expression development for swine vesicular disease can be obtained from the literature (Dekker et al., 1995; Hakhverdyan et al., 2006). However, the data for the socio-economic impacts of swine vesicular disease are missing. In such cases, using expert knowledge is the only alternative to estimate the impact parameters so that the developed approach can still be applied in a semi-quantitative way. Finally, if the hazard is less studied and no required data exists, the approach will still have merit as a guideline to facilitate qualitative reasoning.

2.4.3 Conclusion

From a conceptual perspective, it can be concluded that the proposed approach has scientific credibility; that is, its credibility cannot be invalidated. From a practical viewpoint, applicability relies heavily on the availability of data, which varies among hazards. Nevertheless, even in the absence of the data for one or more steps of the framework, the proposed concept provides a good scientific rationale for economic analysis of the SHSS.

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Appendix A

Abbrevations

Term	Meaning
AHP	Analytical Hierarchy Process
BSE	Bovine Spongiform Encephalopathy
CBA	Cost-benefit Analysis
CEA	Cost-effectiveness Analysis
CSF	Classical Swine Fever
DALY	Daily Adjusted Life Year
Def	Default Surveillance Setup
DM	Decision Maker
EFSA	European Food Safety Authority
EU	European Union
FMD	Foot and Mouth disease
FSA	Food Safety Authorities
HII	Hazard Impact Indicator
HPAI	Highly-pathogenic Avian Influenza
HRP	High Risk Period
OIE	World Animal Health Organization
PCR	Polymerase Chain Reaction
R	PCR Testing on Rendered Animals
S	Serological Tests in Slaugherhouses
SHSS	Single Hazard Surveillance System
TSPI	Technical Surveillance Performance Indicator
TSPP	Technical Surveillance Performance Parameter
SPS	Standardized Performance Scores
SSC	Surveillance System Component

Appendix B

Table B1
The expression matrix for disseased animals infected by the highly virulent CSF strain

Expressions	Days post infection																						
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	References
	Daily probability of showing expressions for infected individual animals																						
Clinical symptoms																							
Non-specific symptoms:																							
Fever	0	0	0	0	0.1	0.3	0.5	0.7	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	a, b, c, d, e, f, g, h, i, j, n
Apathy	0	0	0	0	0.1	0.3	0.5	0.7	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	d, e, f, g, h, j, n
Loss of appetite	0	0	0	0	0.1	0.3	0.5	0.7	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	d, e, f, g, h, j, n
Respiratory disease	0	0	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	i, n
Constipation	0	0	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	d, g, h, n
Diarrhoea	0	0	0	0	0	0	0	0	0	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	d, e, g, h, j, n
Death	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0.03	0.05	0.07	0.1	0.5	0.7	0.9	1	d, g, h, n
Suspicious symptoms:																							
Conjunctivitis	0	0	0	0	0	0	0	0	0.09	0.1	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	
Skin haemorrhage	0	0	0	0	0	0	0	0	0.08	0.09	0.19	0.24	0.29	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.69	0.74	j, n
Blue ear / tail	0	0	0	0	0	0	0	0	0.07	0.08	0.18	0.23	0.28	0.33	0.38	0.43	0.48	0.53	0.58	0.63	0.68	0.73	g, j, k, n
Hind leg weakness	0	0	0	0	0	0	0	0	0.06	0.07	0.17	0.22	0.27	0.32	0.37	0.42	0.47	0.52	0.57	0.62	0.67	0.72	g, j, n
Pathological findings																							
In blood:																							
Antigen/virus(infectious)	0	0	0	0	0.1	0.2	0.4	0.6	0.8	1	1	1	1	1	1	1	1	1	1	1	1	1	f, h, l, n
Antibodies	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	m, n
In organs:																							
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.65	0.65	n
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	n
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	n
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	n

[a]Summerfield et al. (1998)

[b]Kaden et al. (2007)

[c]Sainz et al. (2008)

[d]Prodanov et al. (2007)

[e]Wang et al. (2008)

[f]Handel et al. (2004)

[g]Núñez et al. (2005)

[h]Terpstra (1991)

[i]Depner et al. (1999)

[j]Polaček et al. (2007)

[k]Li, et al. (2010)

[L]Weesendorp et al. (2009a)

[m]Colijn et al. (1997)

[n]Expert opinion

Table B2

The expression matrix for disseased animals infected by the low virulent CSF strain

Expressions	Days post infection																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Reference
	Daily probability of showing expressions for infected individual animals																													
Clinical symptoms																														
Non-specific symptoms:																														
Fever	0	0	0	0	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.2	0.2	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0	0	0	a, b, c, g, k
Apathy	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0	0	0	a, b, c, g, k
Loss of appetite	0	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0	0	0	a, b, c, g, k
Respiratory disease	0	0	0	0	0	0	0	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0	0	0	a, b, c, g, k
Constipation	0	0	0	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0	0	0	a, b, c, g, k
Diarrhoea	0	0	0	0	0	0	0	0	0	0.09	0.1	0.11	0.12	0.13	0.14	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0	0	0	a, b, c, g, k
Death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	d, e, k
Suspicious symptoms:																														
Conjunctivitis	0	0	0	0	0	0	0	0	0	0.06	0.07	0.08	0.09	0.1	0.11	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0	0	0	a, b, c, g, k
Skin haemorrhage	0	0	0	0		0	0	0	0	0.05	0.06	0.07	0.08	0.09	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	a, b, c, g, k
Blue ear / tail	0	0	0	0	0	0	0	0	0	0.04	0.05	0.06	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	a, b, c, g, k
Hind leg weakness	0	0	0	0	0	0	0	0	0	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	0	a, b, c, g, k
Pathological findings																														
In blood:																														
Antigen/virus(infectious)	0	0	0	0	0.2	0.22	0.24	0.26	0.28	0.3	0.32	0.34	0.36	0.38	0.4	0.4	0.38	0.36	0.34	0.32	0.3	0.28	0.26	0.24	0.22	0.2	0	0	0	a, b, k
Antibodies	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	0.84	0.89	0.93	0.95	0.97	0.98	1.00	f, k
In organs:																														
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0.07	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	0	0	k
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.03	0.04	0.04	0.03	0.02	0.01	0	0	0	0	0	0	0	0	0	0	k
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	k
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	k

[a]Weesendorp et al. (2009a)

[b]Weesendorp et al. (2009b)

[c]Floegel-Niesmann et al. (2003)

[d]Terpstra (1991)

[e]Liess (1988)

[f]Colijn et al. (1997)

[g]Mittelholzer et al. (2000)

[k]expert opinion

Appendix C

The annual costs for the farmers and society under the default surveillance setup are estimated as follows: first, according to Mangen et al. (2001), the costs for farmers (including the preventive slaughter costs and consequential costs for farmers) is 120 million euros per epidemic. We assume the annual introduction probability of CSF to the Netherlands is 0.1. Therefore, the annual costs for farmers because of the CSF is 120*0.1=12 million euros.

Second, according to Mangen et al. (2001), the total direct costs and direct consequential costs are 590 million euro per epidemic. Moreover, there are also the costs because of the trade ban due to CSF. Hence, we assume the same amount of trade-loss costs (590 million euros per epidemic) are incurred. Therefore, the annual costs because of CSF for the society is approximately 118 million euros ((590+590)*0.1).

Chapter 3

A conceptual framework for economic optimization of a surveillance portfolio

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Abstract

Decision making on hazard surveillance in livestock product chains is a multi-hazard, multi-stakeholder, and multi-criteria process that focuses on a variety of decision alternatives. The multi-hazard aspect means that the allocation of the scarce resource for surveillance should be optimized from the point of view of a surveillance portfolio (SP) rather than a single hazard. In this paper, we present a novel conceptual approach for economic optimization of a surveillance portfolio to address the resource allocation problem for a surveillance organization from a theoretical perspective. This approach has been checked for conceptual validity and data validity, and the practicability of the approach was also discussed.

Keywords: hazard surveillance, surveillance portfolio optimization, conceptual framework, economic analysis

3.1 Introduction [5]

A surveillance organization, such as a Food Safety Authority (FSA), often has multiple hazards to survey with limited surveillance resource (i.e. budget). Therefore, the allocation of the scarce surveillance resource should be optimized from the perspective of a surveillance portfolio (SP) rather than a single hazard. To avoid terminology ambiguity, we present the following terms that have been defined in Guo et al. (2014) at the beginning of this paper:

- A single-hazard surveillance system (SHSS) is a surveillance system that aims to detect a single microbiological or chemical hazard in a livestock production chain, such as Classical Swine Fever (CSF) or Salmonella surveillance.
- A surveillance system component (SSC) is a specific surveillance activity within a SHSS; for example, clinical diagnosis and routine serological tests in slaughterhouses. Hence, each SHSS consists of one or more SSCs.
- A surveillance setup of a SHSS is the combination of SSCs with their respective levels of intensity, e.g., sampling frequency and size.
- A Surveillance Portfolio (SP): the collection of a group of SHSSs operated by one single organization, e.g., a Food Safety Authority or a private slaughterhouse.

[5] A list of abbreviations is included in the appendix.

Many studies have been conducted to analyze the performance of SHSS (e.g., Feld et al., 2000; Raulo and Lyytikainen, 2007; Häsler et al., 2011; Martinez et al., 2011; Todd and Notermans, 2011; Häsler et al., 2012; Chan et al., 2013; Durr et al., 2013). In contrast, only two studies on SP are available. Prattley et al. (2007) and Prattley (2009) presented an approach of risk-based resource allocation for surveillance on exotic livestock diseases in New Zealand. The authors demonstrated the potential of portfolio theory for prioritizing between various surveillance options and optimizing resource allocation between these options. They also identified issues for further research, such as the risk attitude of decision makers, weighing of risks and impacts, and the problem of increasing the complexity of decision support with increased portfolios. However, the authors did not offer a suggestion for how these issues should be tackled in a consistent way. Moreover, the authors restricted their attention to exotic livestock diseases only, not including other types of hazards (e.g. endemic diseases, chemical hazards). To the best of our knowledge, there is no other literature on economics of SP.

The aim of this paper is to build further on Prattley's studies and present a conceptual approach for SP optimization that provides a consistent conceptual basis for the development of quantitative tools for decision support, aimed at the economic optimization of a SP. The framework is elaborated from the FSA's point of view, but it can be also used by other surveillance organizations, such as private companies. The SHSS framework that has been elaborated in Guo et al., (2014) serves as the basis of the SP optimization framework: the analytical results of each SHSS are used as the inputs of the SP optimization model.

The remainder of the paper is organized as follows. Section 2 briefly puts the role of FSAs into perspective, and Section 3 provides hazard categorization. This is followed by elaborations for the framework of SP optimization (Section 4) and a discussion (Section 5).

3.2 Food safety authorities and surveillance optimization as a multi-criteria, multi-stakeholder problem

An FSA is a public body founded to serve the interests of the general public. Its primary role in this respect is to allocate resources to surveillance activities in order to contribute to the maximization of social welfare or the minimization of social dis-welfare. This includes not only its own (public) resources, but also involvement of private resources (such as farms and

slaughterhouse labor and mandatory test costs). Trade-offs can exist between public and private resources (e.g. in the case of control-of-control), as well as an asymmetric distribution of these resources between stakeholders. The latter is even more prominent when the benefits of improved surveillance are concerned. For example, a reduced impact of an avian influenza (AI) epidemic because of "early detection of the virus" includes mitigated human health burden, fewer animals being culled, a reduced impact on animal welfare and socio ethics, and less disruption of social life. All of these criteria are subjectively evaluated by the stakeholders involved (Mourits et al., 2010). Hence, there is a large asymmetry between stakeholders regarding both resources (that is, costs) and benefits, which could cause conflicts of interest. The prime decision maker (DM) role of a FSA or any surveillance organization is to allocate the surveillance resources in such a way that all stakeholders collectively evaluate the ultimate outcome (that is, total surveillance performance) as maximal.

An arbitrary distinction can be made between those stakeholders that are directly and indirectly affected by surveillance. The directly affected stakeholders, which include farmers, the processing industry, and retailers, can be actively involved in surveillance (e.g. required labor), will be directly affected by changes in surveillance performance (e.g. increased or reduced risks of CSF outbreaks) and will have their production costs directly affected by (changes in) surveillance costs. Indirectly affected stakeholders include the general public and non-governmental organizations: changes in surveillance costs and/or performance could, through the livestock production chain, result in higher/lower prices and/or higher/lower risks.

3.3 Hazard categorization

Any FSA, and in fact most surveillance organizations, operate SHSSs for various hazards, all of which have specific features with regard to hazard type, surveillance objectives and occurrence possibilities. Figure 3.1 presents an overview of a hazard categorization.

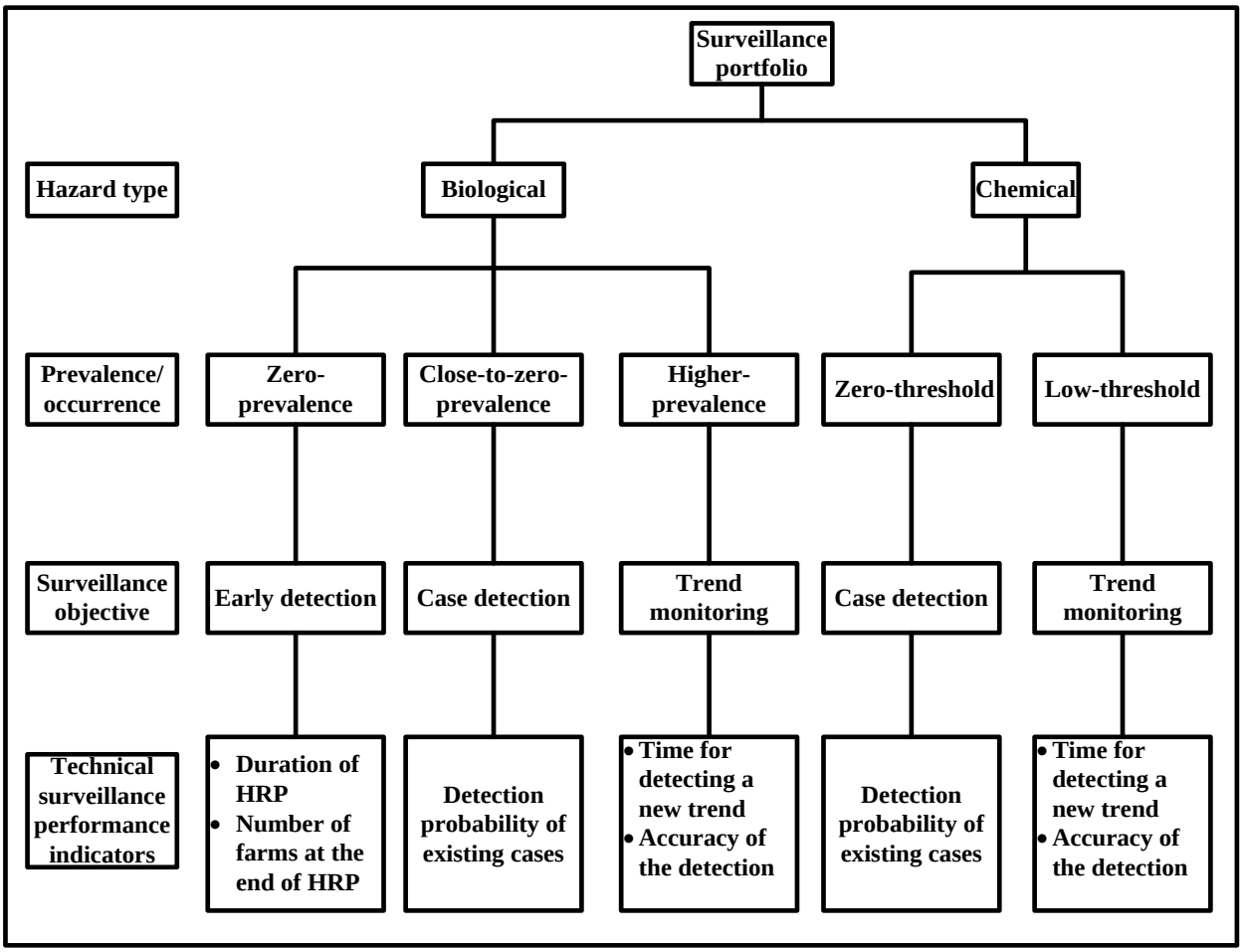

Fig.3.1. SHSS categorization scheme

Starting with all hazards that can, in principle, be surveyed, an initial distinction can be made between biological (viruses, bacteria, prions, etc.) and chemical (contaminants, toxins, etc.) hazards. The main reason for this distinction is the different dynamics of these hazards in an animal population. Biological hazards in principle multiply and spread between infected animals, resulting in an increasing number of affected animals over time. Chemical hazards dilute after entering the livestock production chains (assuming only one entrance, such as a contaminated batch of feed): once entered, the concentration will reduce due to growth of the animal and/or through vertical dilution (e.g. dioxin from a sow to its offspring).

A subsequent categorization feature is prevalence. Biological hazards can be either absent in normal conditions (that is, epidemic or zero-prevalence hazards such as CSF and FMD), while prevalence cannot be excluded but is extremely low (that is, close-to-zero prevalence hazards, such as BSE) or have a higher prevalence (e.g. endemic hazards such as salmonella).

For chemical hazards, higher prevalence is assumed to be non-hazardous and hence disregarded, leaving zero-prevalence (that is, not allowed, such as added hormones) and low-prevalence (that is, having a very low threshold, such as residuals of pesticides) hazards. However, it is noteworthy that this difference is partially artificial, caused by the current technical inability to detect.

From the prevalence situation, the ultimate surveillance objective can be derived, together with the associated technical surveillance performance indicator (TSPI). The aim of zero-prevalence hazard surveillance is to detect hazards such as CSF or FMD as soon as possible from the moment of introduction in the population. This is reflected by minimizing the so-called High-Risk Period (HRP). Therefore, important TSPIs are the length of the HRP and the number of infected farms at the end of this HRP (as a measure for disease spread during the HRP). For close-to-zero hazards, detection of all existing cases before they pose a danger to the general public is the main objective; hence, the detection probability is an important TSPI. Higher-prevalence hazards are and will be endemic for some time. Therefore, reliable trend monitoring could be a main goal, e.g. to monitor the impact of control and reduction measures. Hence, the time-lag until detection of important changes in prevalence levels and trends in this area, as well as the reliability and accuracy of this detection, are important TSPIs. Similar objectives and TSPIs can be defined for both zero- and low-prevalence chemical hazards.

3.4 A conceptual framework for economic optimization

Surveillance organizations operate various SHSSs with limited resources. The (economically) optimal SP includes (1) those SHSSs with (2) their respective setups that combine to achieve maximum surveillance performance with limited resources and other constraints. Hence, a surveillance organization must make choices at two levels: (1) between SHSSs and (2) between surveillance setups of a SHSS. Figure 3.2 illustrates this decision problem. Including a SHSS in the SP automatically implies that a particular setup must be chosen.

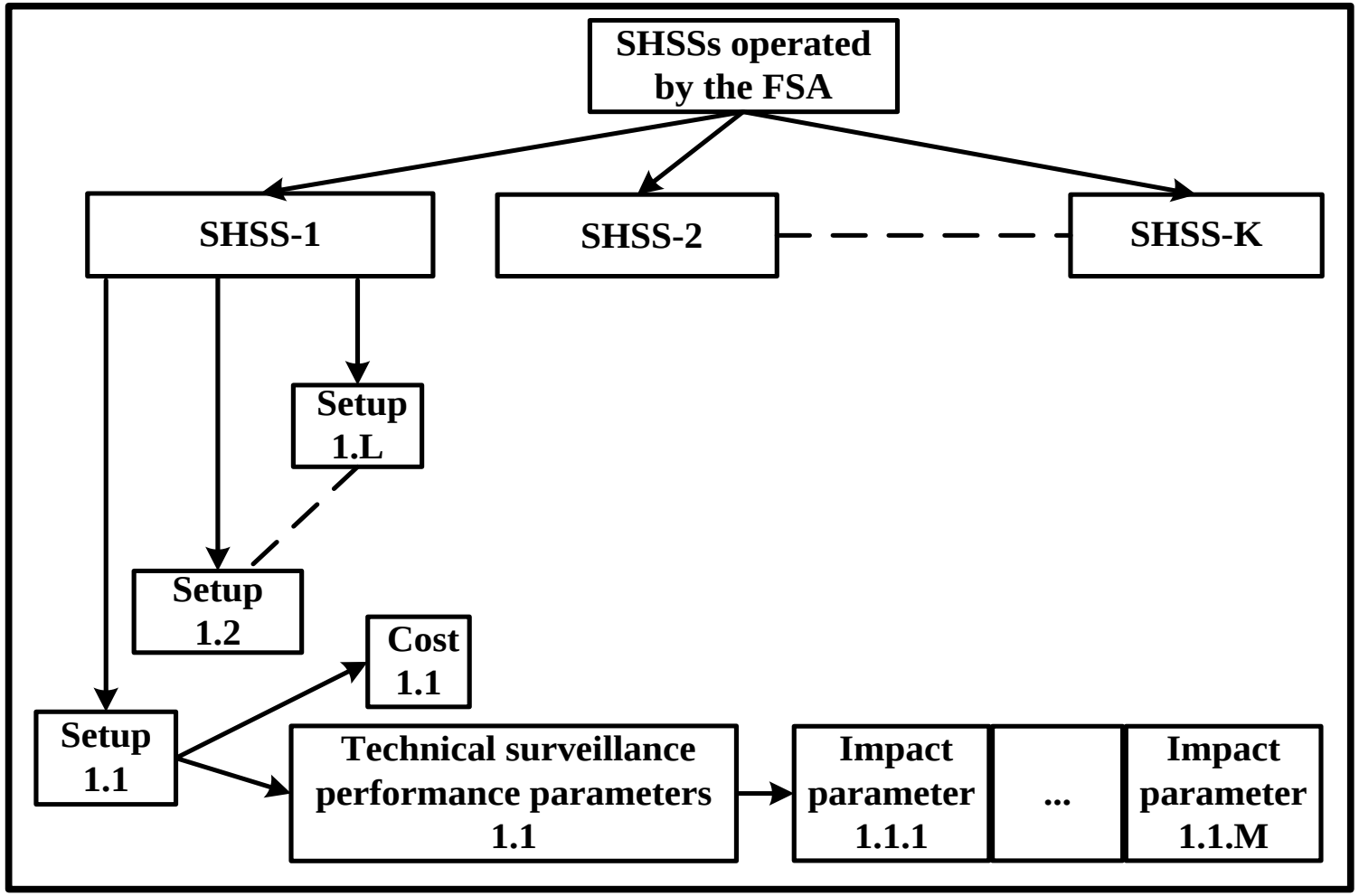

Fig.3.2. The conceptual framework for SP optimization

This choice results in technical surveillance performance parameter (TSPPs), such as duration of the High Risk Period (HRP), and in turn, a consequent (reduction in) impacts (e.g. economic losses, human health impact). Moreover, surveillance costs are incurred from applying this setup. Similarly, other hazards (that is, SHSS) must be considered, as well as the subjective valuation by the stakeholders.

In order to elaborate the optimization problem, the following problems must be solved:

- the various impacts each hazard has must be made comparable and additive;
- differences in valuation of stakeholders of different impacts must be allowed, as well as interest differences between stakeholders.

Below, an attempt has been made to solve this problem in a conceptual manner in order to enable economic optimization of a SP.

Step 1. Each SP consists of a set of SHSSs, so a list of potential hazards and associated SHSSs must first be identified. Next, for each SHSS the efficient set of surveillance setups must be identified (details has been presented in Guo et al., 2014). Thereafter, for each hazard impact indicator (HII) *i*, the standardized portfolio performance should be calculated using equation (1):

$$v_i(X) = 100 \times \frac{\sum_{h=1}^{H}\sum_{s=1}^{S_h}(P_{h,i}^0 - x_{h,s}P_{h,i,s})}{\sum_{h=1}^{H}(P_{h,i}^0 - P_{h,i}^{max})} \quad \text{for all } i \tag{1}$$

where only one or no surveillance setup for each hazard *h* is implemented (see constraint (3));

$v_i(X)$ denotes the *standardized portfolio performance* (SPP) on HII *i* , which is actually the performance deviation on HII *i*, compared to the performance of the maximum portfolio performance on HII *i*;

X is the decision variable matrix of $x_{h,s}$.

$x_{h,s}$ denotes the binary *decision variable* to judge whether, for hazard *h*, surveillance setup *s* is selected to compose the SP.

S_h denotes the number of the alternative surveillance setups for hazard *h*.

H denotes the number of hazards.

$P_{h,i,s}$ denotes the impact parameter (e.g. disease costs, number of human deaths) for hazard *h*, on HII *i*, for implementing surveillance setup *s*;

$P_{h,i}^0$ denotes the *baseline performance* for hazard *h*, on HII *i*;

$P_{h,i}^{max}$ denotes the maximum performance technically possible (or artificially set by the relevant expert) for hazard *h* on HII *i*;

$\sum_{h=1}^{H}(P_{h,i}^0 - P_{h,i}^{max})$ denotes the theoretically maximum portfolio performance on HII *i*.

Step 2. Having obtained the overall performance of the entire SP for each HII *i*, two subjective weightings must be performed: (1) the differences in preference between the stakeholders involved, and (2) the differences in importance of the various stakeholders viewed by the final decision maker. This 'double weighting', as well as the final optimization statement, is expressed in (2) to (5):

$$Max\ PV = \begin{pmatrix} w_1 & \cdots & w_G \end{pmatrix} \times \begin{pmatrix} w_{1,1} & \cdots & w_{1,I} \\ \vdots & \ddots & \vdots \\ w_{G,1} & \cdots & w_{G,I} \end{pmatrix} \times \begin{pmatrix} v_1(X) \\ \vdots \\ v_I(X) \end{pmatrix} \quad (2)$$

s.t. various constraints, such as

$\sum_{s=1}^{S_h} x_{h,s} \leq 1$ for all *h*, (3)

$\sum_{h=1}^{H} \sum_{s=1}^{S_h} c_{g,h,s} x_{h,s} \leq B_g$ for all *g*, (4)

$x_{h,s} \in (0,1)$ for all *h*, *s* (5)

where

PV is the overall weighted portfolio performance (OWPP);

$\begin{pmatrix} w_1 & \cdots & w_G \end{pmatrix}$ is the weights the decision maker puts on the various stakeholders 1 to *G*;

$\begin{pmatrix} w_{1,1} & \cdots & w_{1,I} \\ \vdots & \ddots & \vdots \\ w_{G,1} & \cdots & w_{G,I} \end{pmatrix}$ are the preference weights stakeholders 1 to *G* put on HII 1 to *I*.

$\begin{pmatrix} v_1(X) \\ \vdots \\ v_I(X) \end{pmatrix}$ is the standardized portfolio performance (SPP) on each HII from equation (1);

B_g denotes the total annual budget available for stakeholder group, *g* (*g*=0,1,..,*G*), to carry out the surveillance activities (to simplify the formulation, the decision maker (the FSA) is treated as a stakeholder group, *g*=0).

$c_{g,h,s}$ is the annual surveillance costs for stakeholder group *g*, when, for hazard *h*, surveillance setup *s* is implemented.

The set of constraints (3) ensure that a maximum of one surveillance setup for each hazard will be included in the SP; constraints (4) ensure that the total annual surveillance costs for stakeholder group *g* cannot exceed the annual available surveillance budget; and definitions (5) defines $x_{h,s}$ as binary variables. Additional constraints can be included to establish more complex models according to the specific situation; such as the minimum required surveillance performance for some hazards.

To derive the weight matrix that reflects shareholders' preferences, a stakeholder panel, analogous to the consumer panel in marketing (e.g., Dynan, 2000; Carpenter et al., 2001; Booth et al., 2003) will be established to elicit stakeholder preference.

3.5 Quantitative elaboration of the concept of SP optimization

To illustrate the concept of optimization of a surveillance portfolio, we use a hypothetical numerical example. Three different hazards were selected as potential surveillance target within the portfolio: classical swine fever (CSF), avian influenza (AI), and salmonella (Sal). Impact Parameters for Dutch conditions were assumed taking into account previous studies: Mangen et al. (2001) for CSF, Backer et al. (2011) and Koopmans et al. (2003) for AI, and Valkenburgh et al. (2007) for Sal respectively. These impact parameters, which mimic the results of SHSS analysis, are presented in Table 3.1.

Table 3.1

Impact parameters, P_{his}, for hazard h, on indicator i, for implementing surveillance setup s as well as weights for indicators and stakeholders

All possible surveillance setups for each hazard h		Total annual losses for farmers (k€)	Total annual losses for the society (k€)	Total annual cases of human infections (Person)	Total annual cases of human (Person)	Annual surveillance costs for FSA (k€)
Hazard Impact Indicators	P_{his}	i=1	i=2	i=3	i=4	C_{hs}
h=1 (CSF)						
s=1	$P_{1,i,1}=P_1^0$	12,000	118,000	0	0	200
s=2	$P_{1,i,2}$	10,000	100,000	0	0	5800
s=3	$P_{1,i,3}$	1,000	10,000	0	0	9500
s=4	$P_{1,i,4}=P_1^{max}$	800	8,000	0	0	28100
h=2 (AI)						
s=1	$P_{2,i,1}=P_2^0$	6,200	62,000	10	0.1	200
s=2	$P_{2,i,2}$	6,100	61,000	7	0.08	3,000
s=3	$P_{2,i,3}$	5,800	58,000	6	0.05	10,000
s=4	$P_{2,i,4}=P_2^{max}$	5,000	50,000	4	0.03	80,000
h=3 (Salmonella)						
s=1	$P_{3,i,1}=P_3^0$	0	10,000	50,000	50	0
s=2	$P_{3,i,2}$	0	7,000	35,000	39	2,000
s=3	$P_{3,i,3}$	0	5,500	20,000	20	30,000
s=4	$P_{3,i,4}=P_3^{max}$	0	5,000	18,000	15	50,000
Weights on indicators assigned by stakeholders						
Farmers		w_{11}=0.4	w_{12}= 0.2	w_{13}= 0.1	w_{14} = 0.3	
Citizens		w_{21}=0.1	w_{22}= 0.1	w_{23}= 0.2	w_{24} = 0.6	
Weights on stakeholders assigned by the decision maker		Scenario 1	Scenario 2	Scenario 3		
Farmers : Citizens		$w_1 : w_2$=0 : 1	$w_1 : w_2$=1 : 0	$w_1 : w_2$=0.4 : 0.6		

Impact parameters are fictively generated referring to the works of Backer et al. (2011), Koopmans et al. (2003), Mangen et al., (2001), Valkenburgh et al., (2007) under the non-vaccination and pre-slaughter control strategy.

Four surveillance setups are included for each hazard. For each, respective surveillance costs for an FSA and the impact on disease costs and human health are listed according to the framework in Figure 3.2. Table 3.1 lists the weights for each HII and for farmers and citizens.

Step 1: Table 3.2 lists the SPPs, v_i, of the possible SPs. It is assumed here that one surveillance setup must be selected for each hazard, which means there are a total of 64 SPs available. For ease of demonstration, only four of these SPs are explicitly shown in Table 3.2.

Table 3.2
Standardized portfolio performance per indicator

SP	Total annual losses for farmers	Total annual losses for the society	Total annual cases of human infections	Total annual cases of human	Total annual surveillance costs for Dutch FSA (k€)
(1, 1, 1)	0.0	0.0	0.0	0.0	400
(1, 1, 2)	0.0	2.4	46.9	31.4	2,400
(1, 1, 3)	0.0	3.5	93.7	85.5	30,400
...	...	...	...	...	...
(4, 4, 4)	100.0	100.0	100.0	100.0	158,100

Step 2: Through the "double weighing" on v_i, the OWPPs for all 64 possible SPs are obtained and graphically depicted in Figure 3.3.

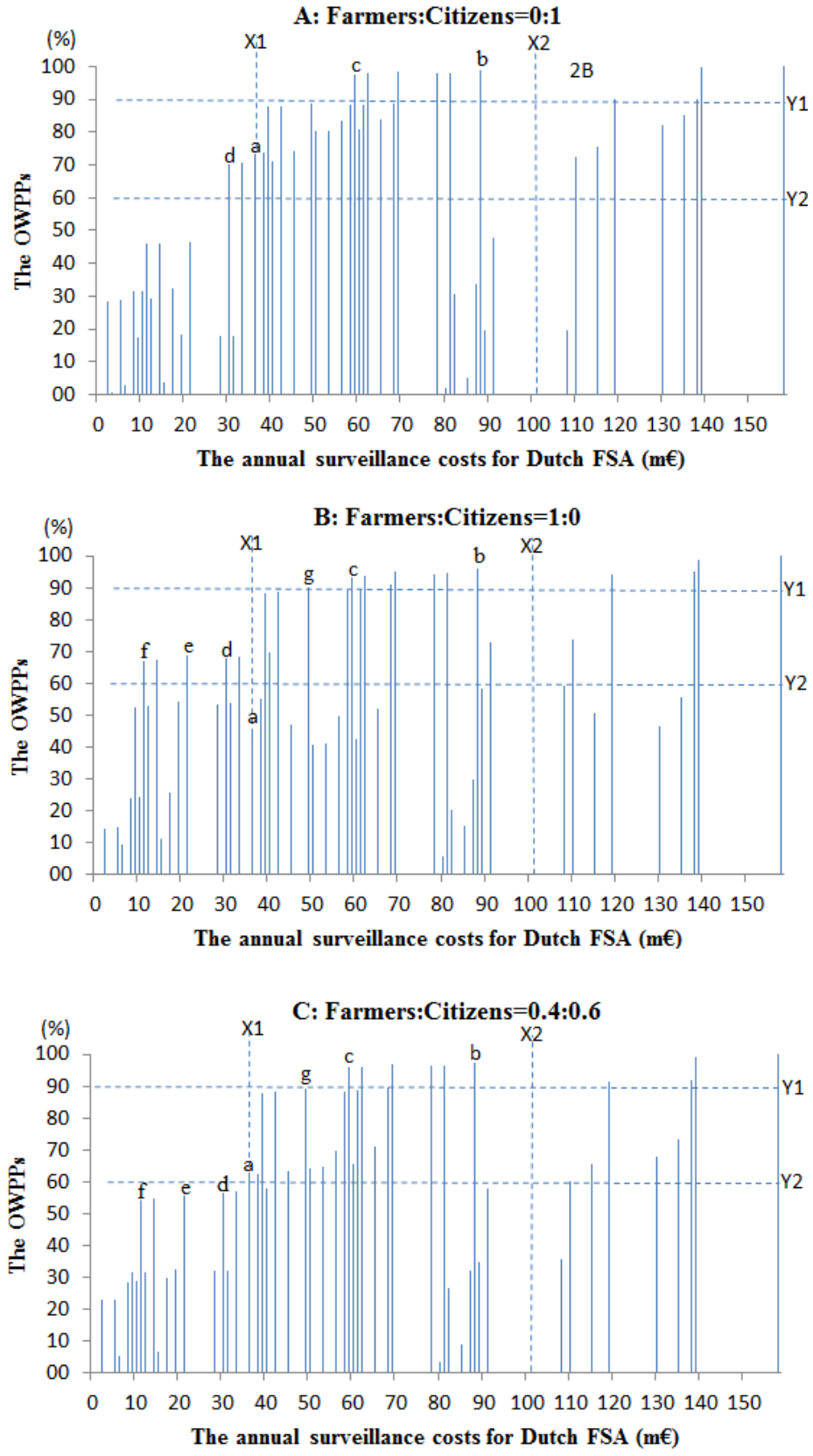

Fig.3.3. The OWPPs with three different sets of decision makers' weights on two stakeholder groups

The horizontal axis represents the annual surveillance costs for Dutch FSA to operate the SP and the vertical axis represents the OWPPs. Each SP is defined by (1) the annual surveillance costs and (2) the OWPPs. Clearly, there is no proportional relationship between the OWPPs and the costs, which articulates the need for economic optimization of surveillance resource allocation. Figure 3.3A, 3.3B and 3.3C present the results with three different settings of decision makers' (DMs') weights on farmers and citizens. Two levels of budget constraints (X1=36 m€ or X2=100 m€) are considered and only the SPs that expense less than the budget are feasible options. Similarly, two minimum performance constraints (Y1= 60% or Y2= 90%) are also considered to ensure an acceptable level of OWPP; in other words, only those SPs that guarantee the minimum OWPP are feasible.

Figure 3.3A shows the results solely from a citizen's point of view, where the DMs' weights on farmers and citizens are 0 and 1, respectively. In terms of cost-effectiveness, and taking into account only the preference of the citizens, SP-*a* is to be preferred in case budget constraint X1 is considered. An increase of this budget to X2 results in a switch in preference to SP-*b*. A subsequent step could be to treat the cost-effective SPs (that is, SP-*a* and SP-*b*) as a starting point for cost-efficient analysis. For budget constraint X1, from the cost-efficient perspective, SP-*d* can also be an attractive option because it delivers slightly lower overall OWPPs than SP-*a* but saves on surveillance costs. For budget constraint X2, SP-*c* is even more attractive than SP-*b* because it saves almost one-third on surveillance costs but still ensures almost the same OWPPs as SP-*b*. Such an analysis has practical implications for DMs to efficiently allocate surveillance budgets. Another approach could be to take the minimum performance as a constraint. For example, if the minimum required OWPP is Y1, SP-*d* is the cheapest choice to fulfill the requirement, while if the minimum required OWPPs increases to Y2, the least expensive SP to fulfill that requirement becomes SP-*c*.

Conducting the same analysis purely from a farmer's standpoint (Figure 3.3B) produces different results. Considering budget constraint X1, SP-*e* is preferred over SP-*a*. Moreover, the OWPP under SP-*a* becomes smaller, indicating that farmers have a lower overall preference for this surveillance setup. Similarly, with constraint Y1, SP-*f* rather than SP-*d* is the cheapest SP for ensuring the minimum performance, while with Y2, SP-*g* rather than SP-*c* is the cheapest SP. Only with budget constraint X2 do both farmers and citizens prefer SP-*b*.

Figure 3.3C shows the results from a simultaneous viewpoint of both stakeholder groups based on the importance judgment of the DMs. The preferred SP-*a* and SP-*b* under budget constraints X1 and X2 are the same as in Figure 3.3A because the DM assigns a larger weight on citizens, which means that their preference is relatively dominant. Moreover, the cheapest SP under the minimum performance constraint Y1 is SP-*a*, which is different from its counterparts in Figure 3.3A (SP-*d*) and 3B (SP-*f*). The same as in Figure 3.3A, SP-*c* is the cheapest option for satisfying constraint Y2. This compromise-based result provides the scientific basis for DMs to make their decisions.

For surveillance organization such as a FSA, it should be realized that the complexity of the SP optimization problem increases with (1) the number of hazards, (2) the level of surveillance setups for each hazard, and (3) the number of stakeholder groups involved.

3.6 Discussion

Decision making on hazard surveillance in livestock production chains is a multi-hazard, multi-stakeholder, and therefore multi-criteria problem between different surveillance alternatives. Therefore, the resource allocation should be tackled from a surveillance portfolio (SP) point of view. Currently, a suitable conceptual basis for such a SP is not available. Hence, this paper presents such a conceptual approach for the economic optimization of a SP. The approach was elaborated from a pure theoretical point of view, with the intention of addressing the resource allocation problem for a surveillance organization.

In order to judge whether this approach is a credible tool for economic optimization of a SP, two issues should be addressed: (1) the scientific credibility of the concept, and 2) the practical use of the approach.

3.6.1 The scientific credibility of the concept

3.6.1.1 Conceptual validity

As presented in Fig. 3.2, the concept builds further on the SHSS analysis (Guo et al., 2014) with the aim of tackling the multiple hazards surveillance problem. Using the SHSS analysis approach, for each SHSS in the SP, an efficient set of surveillance setups can be obtained, accompanied by the corresponding TSPP, surveillance costs, and the impact parameters on a list of HIIs. The surveillance costs and impact parameters are used as the inputs of a multi-

criteria portfolio optimization model described in function (2) to derive the optimal SP that maximizes the OWPP. The multi-criteria optimization model has been widely applied in the area of resource allocation optimization (e.g., Hallerbach et al., 2004; Montibeller et al., 2009; Wabiri and Amusa, 2010; Ballestero et al., 2012).

Hence, the concept synchronizes the SHSS analysis approach (Guo et al., 2014) and the existing multi-criteria portfolio optimization model. Furthermore, experts[6] in this field were consulted to validate the concept, and concluded it to be relevant and reasonable.

3.6.1.2 Data validity

The proposed approach requires different types of data, particularly: (1) data for each SHSS analysis (that is, the data for hazard spread and expression and the data for impact parameters) and 2) the data for weighting different HIIs. The way to derive the data for SHSS analysis was described in Guo et al. (2014). Obtaining stakeholders' preferences to weigh the HIIs is important. The stakeholder panel method could be used to elicit stakeholders' preferences. This method can refer to the consumer panel approach, which is predominantly used in the marketing field to analyze consumer preference (e.g., Dynan, 2000; Carpenter et al, 2001; Booth et al., 2003). Compared to the single-interview approach, the consumer panel approach has two advantages: (1) it provides a more accurate measure and (2) it lowers the probability of omitting relevant information from analysis (Frank and Strain, 1972). Hence, although laborious, varied and valuable data can be obtained to parameterize the models.

3.6.1.3 Operational validity

An illustrative example was elaborated to reveal the operational validity of the approach. Because there is no published research for comparing results, we can only justify the operational validity of the approach based on rational reasoning on the observed results in the illustrative example. The example shows that the proposed approach can discriminate the cost-effectiveness and cost-efficiency of different SPs based on the mitigated impacts and the corresponding surveillance costs, subject to various practical constraints. Moreover, it has also been shown that different stakeholders can have different preferences on the same SP, which fulfills the intended purpose of the approach; namely, to show the impact of stakeholders' subjectivity on SP selection.

[6] Experts from the Dutch FSAs (NVWA and PVE), the food company VION, and Central Veterinary Institute (CVI) are consulted.

Therefore, the operational validity of the approach can be concluded.

3.6.2 The practical use of the approach

To apply the proposed approach (that is, build the decision support models upon the concept), it is essential to have two types of data available. Firstly, the data for the inputs of the SHSS simulation models and for the impact parameters on HIIs are required and can be obtained using the SHSS analysis approach (Guo et al., 2014). Such data are available for some well-studied hazards (e.g. CSF, AI, Sal); however, they are difficult to obtain for some less studied hazards. Secondly, the data for stakeholders' preferences is required as the inputs of the multi-criteria SP optimization model. As mentioned above, the second type of data can be derived using the stakeholder panel approach.

Depending on the availability of these data, the approach can be applied on three levels accordingly. Firstly, if all required data is available for the hazards in the SP, the full model can be completely formulated to optimize the SP in a quantitative way. Secondly, if part or all of the data is missing for some hazards in the SP, expert knowledge can be used to estimate the missing data so that the approach can still be used in a semi-quantitative way. Thirdly, in case the SP consists of so many hazards for which the two types of data are missing, the concept of the approach can still be used as a guideline for qualitative reasoning.

In addition to data availability, applying the approach requires extensive use of OR techniques. Firstly, the Monte Carlo simulation technique will be applied to derive the TSPPs of different surveillance setups in various SHSSs. Secondly, to elicit the stakeholders' preferences, the analytical hierarchy process (Saaty, 2005) and conjoint analysis techniques (e.g., Green and Srinivasan, 1990) are required. Thirdly, solving the SP optimization problem with the proposed model requires the application of optimization techniques. As shown here, for the reasonably small numerical example as presented, it is already laborious to obtain the results through numeration approach (Figure 3.3). As the number of hazards involved and the associated levels of surveillance setups increases, finding the optimal SP could become computationally complex. Therefore, optimization techniques such as linear programming should be applied to solve the problem.

Finally, in practice, decision makers may not want to express their real preferences on different stakeholder groups for political reasons, which could have a huge impact on the final selection of SP (see: Figure 3.3). This implies that one must carefully use the obtained decision maker's weights on stakeholders, and sensitivity analysis may be necessary to test the sensitivity of the results responding to the decision maker's weights.

3.6.3 Concluding remarks

This paper presents a novel approach to improve multi-hazard surveillance assessment. It investigates all relevant aspects that must be taken into account when addressing the food hazard surveillance problem on the surveillance portfolio level. Although its practicability is more restricted by data availability, compared to existing approaches (e.g., Prattley, 2009; Häsler et al., 2011), the proposed approach makes the following important improvements: (1) it makes conceptual contributions to SP optimization, and (2) it provides a credible basis for quantitative modeling. The SP approach proposed here will then be used to optimize a small-scale SP in a food company, which consists of several SHSSs.

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Appendix

Abbreviations

Term	Meaning
AHP	Analytical Hierarchy Process
AI	Avian Influenza
CSF	Classical Swine Fever
DM	Decision Maker
FSA	Food Safety Authorities
HII	Hazard Impact Indicator
HRP	High Risk Period
OWPP	Overall Weighted Portfolio Performance
Sal	Salmonella
SHSS	Single Hazard Surveillance System
SP	Surveillance Portfolio
SPP	Standardized portfolio performance
TSPI	Technical surviellance performance indicator
TSPP	Technical surviellance performance parameter

Chapter 4

Economic analysis of Classical Swine Fever surveillance in the Netherlands

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Abstract

Classical Swine Fever (CSF) is a highly contagious pig disease that causes economic losses and impaired animal welfare. Improving the surveillance system for CSF can help to ensure early detection of the virus, thereby providing a better initial situation for controlling the disease. Economic analysis is required to compare the benefits of improved surveillance with the costs of implementing a more intensive system. This paper presents a comprehensive economic analysis of CSF surveillance in the Netherlands, taking into account the specialized structure of Dutch pig production, differences in virulence of CSF strains, and a complete list of possible surveillance activities. The starting point of the analysis is the current Dutch surveillance system (i.e. the default surveillance setup), including the surveillance activities "daily clinical observation by the farmer", "veterinarian inspection after a call", "routine veterinarian inspection", "pathology in AHS", "PCR on tonsil in AHS", "PCR on grouped animals in CVI", and "confirmatory PCR by NVWA". Alternative surveillance setups were proposed by adding "routine serology in slaughterhouses", "routine serology on sow farms" and "PCR on rendered animals". The costs and benefits for applying the alternative surveillance setups were evaluated by comparing the annual mitigated economic losses because of intensified CSF surveillance with the annual additional surveillance costs.

The results of the cost-effectiveness analysis show that the alternative surveillance setups with "PCR on rendered animals" are effective for the moderately virulent CSF strain, whereas the surveillance setups with "routine serology in slaughterhouses" or "routine serology on sow farms" are effective for the low virulent strain. Moreover, the current CSF surveillance system in the Netherlands is cost-effective for both moderately virulent and low virulent CSF strains. The results of the cost-benefit analysis for the moderately virulent CSF strain indicate that the current surveillance system in the Netherlands is adequate. From an economic perspective, there is little to be gained from intensifying surveillance.

Keywords: classical swine fever; surveillance system; cost-effectiveness analysis; stochastic simulation modelling

4.1 Introduction

Classical Swine Fever (CSF) is a highly contagious pig disease that causes economic losses (Meuwissen et al., 1999; Saatkamp et al, 2000; Moennig, 2000) and impaired animal welfare (Mangen, 2002). The Netherlands experienced a large epidemic in 1997-1998, but has since been free of CSF. Nevertheless, the risk of CSF introduction remains (Backer et al., 2011). Two key factors which determine the impacts of a CSF epidemic are the early detection and rapid eradication of the disease. These factors are influenced by the quality of the surveillance system or programme and the effectiveness of the control strategy, respectively. The main aim of pre-epidemic surveillance is therefore to achieve early detection; more specifically, it is to minimize the duration of the High Risk Period (HRP) and the number of infected farms at the end of this period (Klinkenberg et al., 2005; Guo et al., 2014). An analysis of CSF surveillance should focus on these two performance parameters. Moreover, resources available to support government veterinary services are becoming more and more limited in many countries worldwide (Stärk et al., 2006), including the Netherlands (i.e. Dutch Food safety authorities faces an increased pressure on optimally allocating their surveillance resource due to budget cut). Therefore, an analysis should also address the economic aspects of surveillance, such as the cost of surveillance activities and the potential economic benefits provided by improved surveillance. The importance of incorporating economic aspects in the evaluation of surveillance has been addressed by Drewe et al. (2012), Häsler (2011) and Häsler et al. (2011). A few studies have incorporated economic aspects in the evaluation of surveillance systems; these studies generally use cost-effectiveness as the economic evaluation method. Prattley et al. (2007) developed a model for the cost-effective evaluation of bovine spongiform encephalopathy (BSE) surveillance. The authors claimed that the model could be used as a standard tool to evaluate and compare alternative BSE surveillance strategies. Hadorn et al. (2009) conducted a cost-effective evaluation of bluetongue surveillance in Switzerland using scenario tree modelling. They concluded that an improved passive clinical surveillance in cattle and sheep combined with a targeted bulk milk testing strategy in high-risk dairy cattle herds should be implemented. Häsler et al. (2012) conducted an economic evaluation of the surveillance and intervention program for bluetongue virus serotype 8 in Switzerland. The authors concluded that the programs were economically beneficial in the period of 2008-2009, and not beneficial in 2010-2012. The reason for the "unbeneficial situation" in 2010-2012 is that the average intervention costs are kept the same as in period 2008-2009, while the mean total benefits are reduced in 2010–2012 due to the

reduced occurrence of disease in a fully vaccinated population. For CSF surveillance, only Klinkenberg et al. (2005) included an economic evaluation (cost-effectiveness analysis).

Aspects of CSF surveillance in the Netherlands have been studied several times, and can be categorized into *ex post* analysis (i.e. statistical analysis of past epidemics) and *ex ante* analysis (i.e. simulation studies of choice options). Crauwels et al. (1999) and Elbers et al. (2002) both conducted *ex post* analyses of the 1997-1998 Dutch CSF epidemic. Crauwels et al. (1999) concluded that routine serological tests would not have shortened the HRP during this epidemic; Elbers et al. (2002) found a significant effect of clinical-sign-based surveillance on the early detection of CSF. The studies of Klinkenberg et al. (2005) and Backer et al. (2011) are *ex ante* studies. Klinkenberg et al. (2005) investigated the cost-effectiveness of the current Dutch CSF surveillance system using the Monte Carlo simulation technique. They concluded that the current system are capable of preventing very expensive epidemics with high probability. They also found that excluding the four-weekly veterinarian inspection increased the median of the HRP from 35 days to 36 days. Backer et al. (2011) analysed the potential use of additional PCR testing of rendering animals as a surveillance activity to ensure early detection of CSF. The authors estimated a two-day gain in detection time and concluded that this was too small to demonstrate a substantial effect of the new early detection system based on mortality data, considering the variation in outcome and the uncertainty in some model assumptions. However, the authors also stated that the new activity might be useful in long CSF-free periods, when farmers and veterinarians tend to become less aware of CSF. These Dutch studies are accompanied by studies in other European countries, particularly with regard to demonstration of CSF-freedom (Feliziani, et al., 2005; Martin et al., 2007; Boklund et al., 2013), Monte Carlo simulations (Karsten et al., 2005ab), syndromic surveillance (Raulo and Lyytikainen, 2007), and CSF awareness and risk-based surveillance (Dürr et al., 2013).

These studies have made important contributions to the body of knowledge on CSF surveillance in the Netherlands. However, they all lack one or more of the following aspects: specialized structure of Dutch pig production chain, coverage of different surveillance activities, consideration of different virulent strains, a cost-benefit analysis, and/or trade-offs between surveillance performance and costs from a national decision making point of view. The current paper attempts to address these limitations. With a special attention to the

economic aspect of CSF surveillance in the Netherlands, we compared different surveillance setups consisting of most surveillance system components (SSCs) available by cost-effectiveness and cost-benefit analysis based on the general principles proposed by Häsler (2011) and Häsler et al. (2011). We considered a more specific structure of Dutch pig production chain (compared to previous studies), and considered two different virulence stains for evaluating CSF surveillance in a Dutch setting. We also derived new managerial insights from the modelling results which can support the decision making of Dutch Government concerning CSF surveillance.

4.2 Materials and methods

4.2.1. General model features

In this paper, the following terms and definitions are used, as defined in Guo et al. (2014):

- A single-hazard surveillance system (SHSS) is a surveillance system that aims to detect a single microbiological or chemical hazard in a livestock production chain, such as CSF or Salmonella surveillance.
- A surveillance system component (SSC) is a specific surveillance activity within a SHSS; for example, clinical diagnosis and routine serological tests in slaughterhouses (hence, each SHSS consists of one or more SSCs).
- A surveillance setup of a SHSS is the combination of SSCs with their respective levels of intensity, e.g., sampling frequency and size;

The simulation model is stochastic and dynamic, and captures the specialized structure of the Dutch pig production chain by distinguishing three different types of farms: farrowing, finishing and farrow-to-finish. In Figure 4.1, the interrelations between the different farm types are presented.

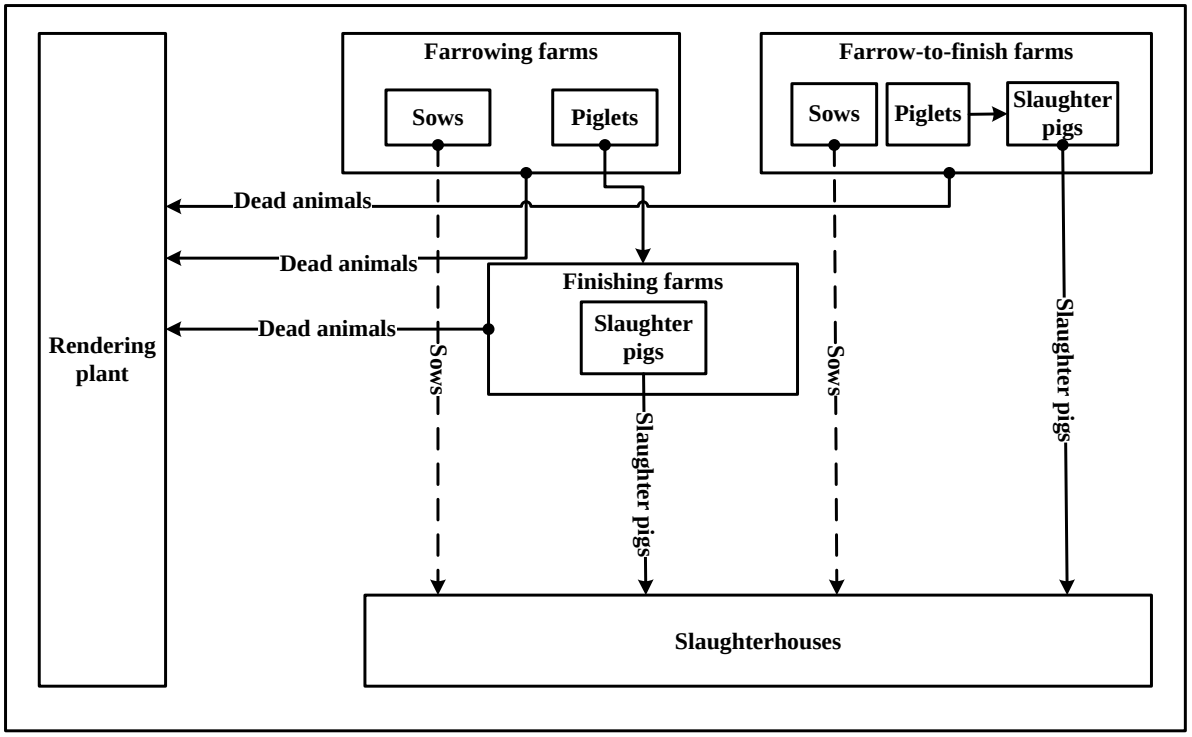

Fig. 4.1. The simplified Dutch pig production chain. The dotted lines are used to denote the flows of sows to the slaughterhouses, which are disregarded in the model because of the low submission rate.

Specific breeding farms were not included because their number is relatively small and they have a high level of bio-security. Standard surveillance of CSF on these breeding farms is likely to have little impact on both the technical performance and the total surveillance costs of the surveillance system, and therefore on the choice of the surveillance setup. Dotted lines are used to denote the flow of sows to the slaughterhouses, which are disregarded in the model because of the low submission rate.

A simplified distribution of animals and farm types is presented in Table 4.1, which is estimated from a dataset of Dutch pig farms in 2010 provided by Dutch Animal Health Service (GD) together with expert opinions. It combines the data in the Dutch Farm Registration System (BRBS) and in the Dutch Identification and Registration (I&R) system, including unique farm identifiers, farm classes, and the number of animals per farm type for the year 2010 (Hop et al., 2014).

Table 4.1
The distribution of farms and animals (averages) estimated from the Dutch pig farm database 2010 provided by the Animal Health Service

Farm type	Number of farms	Number of animals		
		Piglet	Sow	Hog
Farrowing	2300	2000	400	0
Finishing	5000	0	0	830
Farrow-to-finish	360	1090	220	800

The numbers of animals per farm in Table 4.1 are the averages estimated from that dataset, and there exists a large variation in the farm sizes (i.e. farms containing from only several animals to above 10000 animals). Using the averages of animals is a simplification of the reality. However, compared to the previous studies (e.g., Crauwels et al., 1999; Klinkenberg et al., 2005) which considered one type of homogeneous animals, the assumed structure of Dutch pig production chain in our work is already closer to the real life situation. Moreover, incorporating the variation in farm sizes will significantly increase the complexity of the simulation model, thus we decided to use the average numbers of animals on the farms.

The main structure of the model is presented in Figure 4.2 and consists of four linked modules.

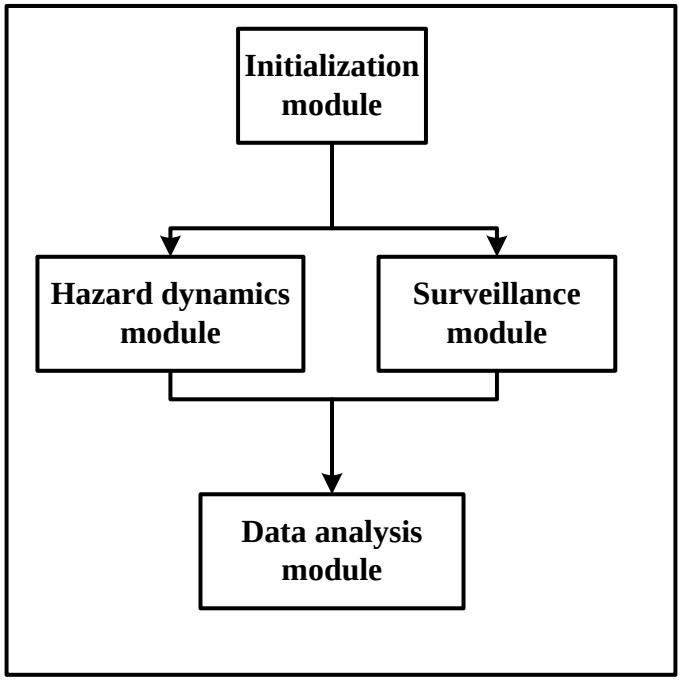

Fig. 4.2. The main structure of the CSF surveillance simulation model

The Initialization module loads and initializes different sets of input parameters and matrices (for more details see Figure A17 in the Supporting Information). The CSF dynamics module simulates the development of CSF in the Dutch pig population at three interrelated levels: (1) CSF symptoms (i.e. the symptoms in diseased animals) within individual animals, (2) disease spread between animals within farms and (3) disease spread between farms. Parallel to this, the surveillance module simulates the daily surveillance activities in the pig population. Finally, the simulated and stored data are analysed in the data analysis module (for more details see Figure A18 in the Supporting Information).

4.2.2. Classical swine fever dynamics and surveillance modules

In Figure 4.3, an outline of the hazard dynamic and surveillance modules (i.e. the core of the CSF surveillance simulation model) is presented.

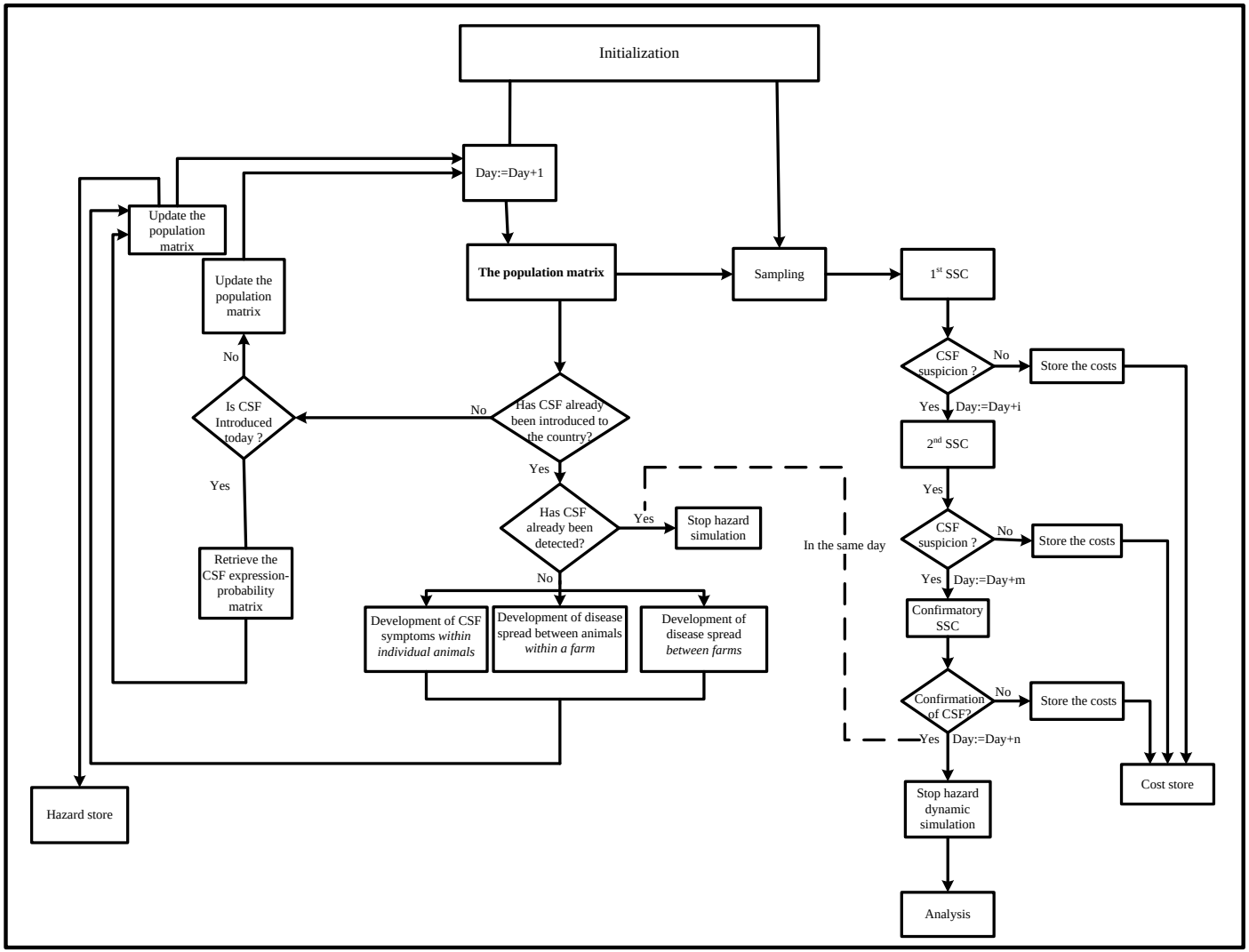

Fig. 4.3. The outline of the hazard dynamic and surveillance modules (i.e. the core of the CSF surveillance simulation model). The dotted line indicates that the hazard dynamics simulation stops in the same day of hazard detection.

After initialization, the population matrix is updated each day. This matrix describes the distribution of animals with symptoms on farms in the Netherlands, which includes (1) the number of infected farms in the country, (2) the number of infected animals on the infected farms, and 3) the number of infected animals with certain symptoms on the infected farms. Prior to CSF introduction, updating is done using the daily probabilities of showing background symptoms for individuals animals (see Table 4.2).

Table 4.2
Daily probability of showing the background symptoms and mortalities for individual animals in the CSF-free period

symptoms	Daily probabilities of showing the background symptoms and mortalities	
	Piglets	Slaughter pigs and sows
Non-specific clinical symptoms*	0.01	0.0025
Suspicious clinical symptoms*	0.0003	0.0001
Mortalities**	0.0016	0.0002

*The probabilities of clinical symptoms were estimated by comparing the model results for the number of false positives per year to the historical data confirmed by expert opinions.
**The mortalities in the CSF-free period were derived from a database of all commercial pig enterprises in the Netherlands in the period 2001–2005, estimated from Backer et al. (2011) combined with expert opinions.

The background symptoms are symptoms similar to those caused by CSF, but which are attributable to hazards other than CSF. These are included to model 'false positive animals' in the CSF-free period. For clinical symptoms, the probabilities for individual animals were estimated by comparing the model results for the number of false positives per year, to the historical data confirmed by expert opinions, because of the lack of literature data. The mortality was derived from a database of all commercial pig enterprises in the Netherlands in the period 2001–2005, estimated from Backer et al. (2011) combined with expert opinions.

An annual default probability of CSF introduction of 0.06 was used (De Vos et al., 2004), which means that on average around one outbreak in 16 years is expected. The index farm was randomly selected, and each infection started with three infected animals. In the default situation, a moderately virulent strain was assumed.

After CSF introduction, the model uses the CSF symptom matrices for piglets, slaughter pigs and sows to update the population matrix. The complete CSF symptom matrices can be found in Table A1 and Table A2 in the Supporting Information. In Table 4.3, a simplified version is presented for explanation purposes.

Table 4.3
Daily probability of showing CSF-related symptoms for individual piglets infected by moderately virulent CSF

symptoms	Days post infection																			
	0	1	...	9	10	11	12	13	14	15	16	17	18	19	20	21	...	28	References
	Daily probability of showing CSF-related symptoms for infected individuals																		
Clinical symptoms																			
Non-specific symptoms:																			
Fever	0	0	...	0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.7	...	0	a, h , c, d, k
Apathy	0	0	...	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.64	0.59	0.54	0.49	0.44	0.39	...	0	c, d, k
Loss of appetite	0	0	...	0.33	0.38	0.43	0.48	0.53	0.58	0.63	0.63	0.58	0.53	0.48	0.43	0.38	...	0	c, d, k
Respiratory disease	0	0	...	0.32	0.37	0.42	0.47	0.52	0.57	0.62	0.62	0.57	0.52	0.47	0.42	0.37	...	0	k
Constipation	0	0	...	0.31	0.36	0.41	0.46	0.51	0.56	0.61	0.61	0.56	0.51	0.46	0.41	0.36	...	0	c, d, k
Diarrhoea	0	0	...	0.29	0.34	0.39	0.44	0.49	0.54	0.59	0.59	0.54	0.49	0.44	0.39	0.34	...	0	a, c, k
Death	0	0	...	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0	c, d, e, b, k
Suspicious symptoms:																			
Conjunctivitis	0	0	...	0.26	0.31	0.36	0.41	0.46	0.51	0.56	0.56	0.51	0.46	0.41	0.36	0.31	...	0	a, c, f, k
Skin haemorrhage	0	0	...	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.55	0.5	0.45	0.4	0.35	0.3	...	0	a , c, e, f, k
Blue ear / tail	0	0	...	0.24	0.29	0.34	0.39	0.44	0.49	0.54	0.54	0.49	0.44	0.39	0.34	0.29	...	0	a , f, k
Hind leg weakness	0	0	...	0.23	0.28	0.33	0.38	0.43	0.48	0.53	0.53	0.48	0.43	0.38	0.33	0.28	...	0	c, d, f, k
Pathological findings			...														...		
In blood:																			
Antigen/virus(infectious)	0	0	...	1	1	1	1	1	1	1	1	1	1	1	1	1	...	0	c, d, g, k
Antibodies	0	0	...	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	...	1	j, k
In organs:																			
Tonsil lesions	0	0	...	0	0	0	0.37	0.42	0.47	0.52	0.52	0.47	0.42	0.37	0.32	0.27	...	0	k
Spleen infarction	0	0	...	0	0	0	0.34	0.39	0.44	0.49	0.49	0.44	0.39	0.34	0.29	0.24	...	0	k
Enlargement of lymph node	0	0	...	0	0	0	0.31	0.36	0.41	0.46	0.46	0.41	0.36	0.31	0.26	0.21	...	0	k
Internal bleeding	0	0	...	0	0	0	0.28	0.33	0.38	0.43	0.43	0.38	0.33	0.28	0.23	0.18	...	0	k

[a]Ribbens (2009)
[b]Weesendorp et al. (2009a)
[c]Dewulf et al. (2001a)
[d]Laevens et al. (1999)
[e]Uttenthal et al. (2003)
[f]Klinkerberg et al. (2005)
[g]Dewulf et al. (2001b)
[h]Weesendorp et al. (2009b)
[j]Colijn et al. (1997)
[k]expert opinion

The first column of Table 4.3 is a generic list of possible symptoms. The symptoms are categorized into clinical symptoms and pathological findings. The clinical symptoms are further classified as non-specific clinical symptoms and suspicious clinical symptoms; the pathological findings are either in blood or in organs. The numbers are the time-dependent probabilities for individual animals to show CSF-related symptoms after a certain day post infection. For example, an individual piglet has a probability of 0.5 to have fever nine days after infection has occurred. To save computational space, we assume clinical symptoms and pathologies in organs occur hierarchically.

The infected animals on the index farm are the first to develop these symptoms. After a period of four to six days, the infected animals develop viraemia and become infectious to other

animals (Leavens et al., 1998; Laevens et al., 1999; Dewulf et al., 2001ab; Klinkenberg et al., 2002), which is the start of disease transmission within the farm. A classical Susceptible-Infected-Recovered (SIR) model was applied to simulate this within-farm transmission:

$$C(t+1) = S(t)\frac{\beta_w I(t)}{N} \quad (1)$$

where,

$C(t+1)$ is the number of newly infected animals at day t+1,

$S(t)$ is the number of susceptible animals at day t,

$I(t)$ is the number of infectious animals at day t,

N is the number of animals on farm,

β_w is the within-farm transmission parameter with a value of 0.21 day^{-1} (Klinkenberg et al., 2005).

Accumulation of infectious animals results in between-farm disease spread in many cases. A variant of the SIR model (see for example, Thrusfield et al., 2013 and Klinkenberg et al., 2003) was used to explicitly link the infectivity of an infected farm to the number of infectious animals on that farm, to enable more realistic modelling of between-farm CSF transmission. In the modified SIR model, an infected farm infects a susceptible farm through a Poisson process with rate, $\beta_b I(t)$. Parameter β_b is the between-farm transmission parameter (per infectious animal per day). $I(t)$ is the number of infectious animals on the source infected farm at day t. Through this method, it is explicitly modelled that the between-farm transmission rate, $\beta_b I(t)$, for a source infected farm is proportional to the number of infectious animals on it.

This between–farm transmission process distinguishes between transmission caused by transport contacts and transmission from indirect contacts. Transport contacts are associated with piglet transportation, and this type of transmission can therefore only occur from farrowing farms to finishing farms, whereas the indirect contact transmissions exist between all types of farms. The values of the transmission parameters for transport contacts (β_{b1}) and indirect contacts (β_{b2}) were 0.0029 and 0.0024 per infectious animal per day respectively, based on Klinkenberg et al. (2005).

In the surveillance module, each surveillance setup consists of various SSCs which were combined in different surveillance pathways following defined protocols. SSCs were operated

to sample the population matrix on a daily base. An example of a potential surveillance pathway is shown in Figure 4.3. The first SSC could be ‘daily clinical observations by the farmer’. If the farmer suspects a CSF infection, he could trigger the second SSC, ‘veterinarian inspection’, by making a phone call. If the veterinarian also suspects a CSF infection, then the third SSC, ‘confirmatory PCR’, is initiated to conduct confirmatory PCR tests. This surveillance pathway is for demonstration purposes. In the actual model, multiple surveillance pathways with different SSCs exist simultaneously in a specific surveillance setup.

Each simulated CSF epidemic is stopped at the day of CSF notification. The time it takes to apply each SSC is recorded and the final day of the hazard simulation is consistent with the day of CSF notification (indicated by the dotted line in Figure 4.3). The model also stores the surveillance costs incurred by each SSC. Table 4.4 presents a comprehensive list of SSCs that are used in the Dutch CSF surveillance system or which could be implemented in the future.

Table 4.4
Inventory of SSCs that could be used to detect CSF in the Netherlands

SSCs	Sensitivities	Application frequency/threshold	Time	Sampling size	Cost
1) Daily clinical observation by the farmer[a]	To call a veterinarian: 20% to 100%[b,c] To submit an animal to AHS[d]: 20% to 100%[b,c]	Once every day[b,c]	On the same day of observation[b,c] 1 day after observation[b,c]	All animals[b,c]	no
2) Veterinarian inspection after a call[a]	32%[b,c] (3.2% in CSF-free period[j])	After a call from the farmer[b,c]	1 day after the phone call[b,c]	All animals[b,c]	70€ /time[b]
3) Routine veterinarian inspection[a]	32%[b,c] (3.2% in CSF-free period[j])	Once per four weeks[b,c]		All animals[b,c]	1175€ /herd/year[b]
4) Pathology in AHS[a,d]	50%[b,c]	After the submission of a severely diseased animal[b,c]	The same day of submission[b,c]	1 severely diseased animal[b,c]	400€ /animal[b]
5) PCR on tonsil in AHS[a,d]	98%[c]	In case of a CSF suspicion[c,e]	Result available in the same day of pathology[c,e]	1 tonsil sample[c,e]	42€ /test[e]
		no CSF suspicion[c,e]	Result available 2 days after pathology[c,e]	1 tonsil sample[c,e]	42€ /test[e]
6) PCR on grouped animals in CVI[a,f]	98%[c] (PCR) 77%[g] (veterinarian)	In case more than 40 animals show non-specific clinical symptoms[c]	2 days[c]	6 animals with non-specific clinical symtoms[e]	188.56€ /submission[b,e]
7) Confirmatory PCR by NVWA[a,b]	98%[c] (PCR) 77%[g] (veterinarian)	In case of a CSF suspicion[e]	1 day[c]	5 blood samples[c]	1574€ /case[b,e]
8) Routine serology in slaughterhouses[i]	94%[e]	One batch every 10 days[e]	12 days[e]	5 samples per batch[j]	11.30€ /sample[e]
9) PCR on rendered animals[i]	98%[c]	For farrowing and farrow-to-finish farms: 6 dead animals[j] For finishing farms: 3 dead animals[j]	2 days[c]	All dead animals[c]	32€ /test[e] 10€ /submission[e] 7.26€ /animal[b]
10) Routine serology on sow farms[i]	94%[e]	4 weeks[e]	12 days[e]	12 samples[e]	18,56€ /sample[e]

[a]SSCs in the current Dutch CSF surveillance system (default)
[b]Klinkenberg et al. (2005)
[c]Backer et al. (2011)
[d]Animal Health Service
[e]Expert opinion
[f]The Central Veterinarian Institute
[g]Bouma et al. (2001)
[h]Dutch Food Safety Authority
[i]SSCs not currently used in the Netherlands. These are alternative SSCs that could be implemented in the future.
[j]Assumption

4.2.3. The selection of surveillance setup

The surveillance setups that were investigated in the model are shown in Table 4.5.

Table 4.5
The surveillance-setup scenarios that are compared in the analysis

SSCs	D[1]	D+S_{12}[2]	D+$R_{6,3}$[3]	D+SL_5[4]	D+S_{24}[5]	D+$R_{6,3}$+S_{12}[6]	D+SL_5+S_{12}[7]	D+SL_5+$R_{6,3}$[8]	D+SL_{10}[9]	D+S_{36}[10]	D+SL_5+$R_{6,3}$+S_{12}[11]	D+SL_{15}[12]	D+$R_{6,1}$[13]	D+$R_{1,1}$[14]
Daily clinical observation by the farmer	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Veterinarian inspection after a call	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Routine veterinarian inspection	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pathology in AHS	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PCR on tonsil in AHS	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PCR on grouped animals in CVI	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Confirmatory PCR by NVWA	X	X	X	X		X	X	X			X			
Routine serology in slaughterhouses				X			X	X	X		X	X		
PCR on rendered animals			X			X		X			X		X	X
Routine serology on sow farms		X			X	X	X			X	X			

D: defaut surveillance-setup scenario; S: routine serology on sow farms; SL: routine serology in slaughterhouses; R: PCR on rendered animals

The first one was the default Dutch CSF surveillance setup (denoted as D) which includes the SSCs, "daily clinical observation by the farmer", "veterinarian inspection after a call", "routine veterinarian inspection", "pathology in AHS", "PCR on tonsil in AHS", "PCR on grouped animals in CVI", and "confirmatory PCR by NVWA". The default surveillance setup provided a baseline for further comparison. Other setups were created by adding one or more of three alternative SSCs, which were not part of the current Dutch surveillance system. These three SSCs were "routine serology in slaughterhouses" (SL), "routine serology on sow farms" (S) and "PCR on rendered animals" (R). The sampling intensity for 'routine serology in slaughterhouse' (SL_5) was five animals per batch per ten days. For 'routine serology on sow farms' (S_{12}), the intensity was 12 blood samples per farm per four weeks. For 'PCR on rendered animals' ($R_{6,3}$) the intensity was a submission threshold of six dead animals in a day for farrowing and farrow-to-finish farms, and three dead animals for finishing farms. Lastly, six setups were created by increasing the sampling intensity for the alternative SSCs. For "routine serology in slaughterhouses" the sample size was increased to ten (SL_{10}) or 15 (SL_{15}) animals per batch per ten days. For 'routine serology on sow farms' the sample size was increased to 24 (S_{24}) or 36 (S_{36}) blood samples per farm per four weeks. For PCR on rendered animals, the submission threshold was lowered to one dead animal per day for finishing farms ($R_{6,1}$), or to one dead animal per day for all types of farms ($R_{1,1}$).

In total, there were 14 surveillance setups to be analysed. For each surveillance setup, a simulation was run with 1,000 iterations. The outputs of interest were the annual surveillance costs and the two technical performance parameters, duration of the HRP and number of farms infected at the end of the HRP. An efficient set of surveillance setups was then derived using these outputs.

4.2.4. The low virulent strain case

CSF strains can differ in virulence. In this paper, the default CSF strain is assumed to be moderately virulent. To explore the effect of differences in virulence on the efficient set of surveillance setups, a low virulent strain was also investigated. The probabilities in the symptom matrices (see Table A3 and A4 in the Supporting Information) and the parameters for within-farm and between-farm transmission were adapted for the low virulent strain. The probabilities were changed so that the symptoms occurred later and with lower probability,

relative to the moderately virulent strain. The within-farm and between-farm transmission parameters (β_w and β_b) were changed to half of their values, relative to the moderately virulent strain because literature shows that the spread of low virulent CSF is relatively slow compared to the moderately virulent CSF (Terpstra,1987; Weesendorp et al., 2009b) .

4.2.5. Economic analysis

The efficient set of surveillance setups was derived using Pareto efficiency analysis (see for example, Ben-Israel et al., 1977; Yoo and Harman, 2007; Ho et al., 2010). Surveillance setups included in the efficient set should fulfil the following mathematical conditions:

s^* is an efficient surveillance setup, if there is no other setup s, among the setups evaluated, such that

$C(s) \leqslant C(s^*)$ (the annual surveillance costs)
and
$P(s) \leqslant P(s^*)$ (duration of HRP or the number of infected farms at the end of HRP)
with at least one strict inequality (Ben-Israel et al., 1977),

Häsler (2011) suggested that, when possible, cost-benefit analysis is preferred because cost-effectiveness analysis does not quantify the benefits of the surveillance setups. Therefore, a cost-benefit analysis was conducted for the efficient set of surveillance setups. The results of CSF impact simulation model for the Netherlands, described by Hop et al. (2014), was used to estimate the direct costs (DC) and direct consequential costs (DCC) of a CSF epidemic, using the number of infected farms at the end of the HRP as the input. The DC include those related to organising the disease, clinical examination and serological screening, depopulation and feed destruction; the DCC include those due to welfare problems, empty stables (idle production factors), and movement restrictions (Hop et al., 2014). Previous studies (Berentsen, et al., 1992; Saatkamp et al, 2000; Mahul and Durand, 2000; Asseldonk et al., 2005; Longworth et al., 2012ab) have shown that for countries exporting more than 50 percent of their domestic production (i.e. the production within a country), the indirect consequential costs (ICC) due to the losses of exports can be larger than the DC and DCC. Hereby, the ICC are assumed three times the DC and DCC using Danish situation as a reference (Boklund et al.

2009). This assumption actually overestimates the ICC in Dutch situation, because Denmark exports a larger proportion of pigs than the Netherlands. However, as we will see later, this overestimation will not affect the conclusion drawn from this work. Since the CSF impact simulation model only considers a moderately virulent strain, it was only possible to do a cost-benefit analysis for the efficient surveillance setups for the moderately virulent strain. The number of infected farms at the end of the HRP for the 10th, 50th, and 90th percentiles (as shown in Figure 4.4) for each efficient surveillance setup was used as input for the CSF impact simulation model (Hop et al., 2014). The impact simulation model was run using this input to obtain a distribution of the estimated costs (10th, 50th, and 90th percentiles) associated with an epidemic characterized by that number of farms at the end of the HRP. Then, the reduced costs, compared to the default surveillance setup (baseline), for implementing the alternative efficient surveillance setups can be obtained. These reduced costs are the benefits derived from more intensive surveillance and earlier detection of CSF. The annual benefits from intensified surveillance were obtained by multiplying the benefits by the default annual CSF introduction probability of 0.06 (De Vos et al., 2004).

4.2.6. Sensitivity analysis

Sensitivity analysis was conducted for the CSF surveillance simulation model, for both the moderately virulent and low virulent CSF strains. The sensitivity analysis focused on the factors that were expected to have a large impact on the results. These factors were: the values of the within-farm and between-farm transmission parameters, the speed and severity of symptom developments in the diseased animals (by modifying the CSF symptom matrices), and the sensitivities of the ELISA and PCR tests.

The sensitivity of the benefits to the annual introduction probability was also investigated. Four alternative annual introduction probabilities of 0.01, 0.03, 0.1 and 0.2 were assumed,

4.3 Results

4.3.1. Moderately virulent strain

For each surveillance setup, the 10th, 50th, and 90th percentiles for the duration of the HRP (Figure 4.4a), and the number of infected farms at the end of the HRP (Figure 4.4b), are

presented with their corresponding annual surveillance cost. A square is used to denote the median for the efficient surveillance setups; otherwise the median is denoted with a triangle.

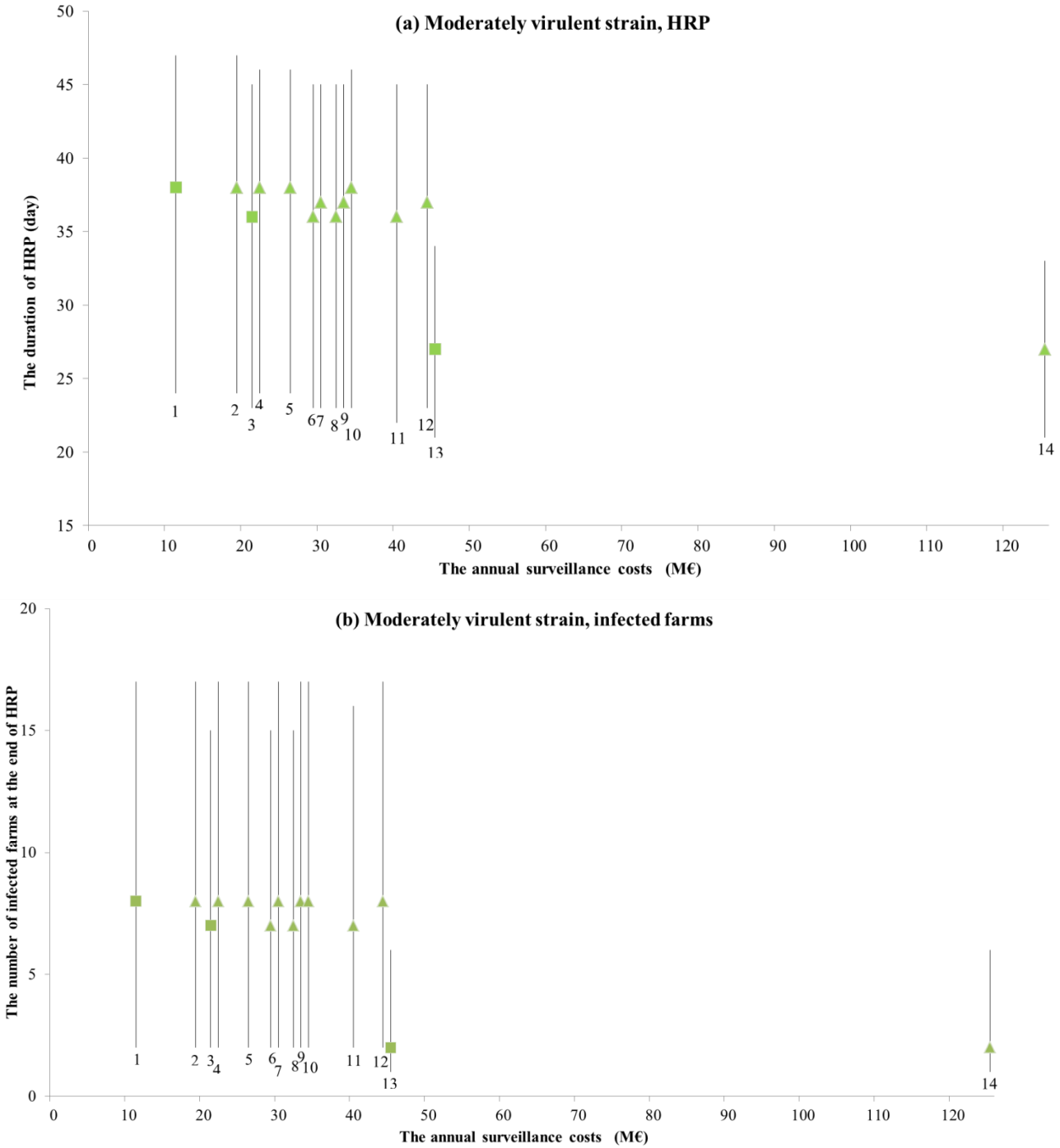

Fig. 4.4 The 10th, 50th and 90th percentiles of the duration of the HRP (Figure 4.4a) and the number of the infected farms at the end of the HRP (Figure 4.4b) for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

The median of the duration of the HRP under the default surveillance setup, D, was 38 days (with eight infected farms), and the 10th and 90th percentiles values were 24 days (with two

infected farms) and 47 days (with 17 infected farms) respectively (see surveillance setup 1 in Figure 4.4). Adding the SSC 'routine serology on sow farms' to the default surveillance setup, $D+S_{12}$, did not have an impact on the duration of the HRP but resulted in an extra €7.5 million annual surveillance costs (see surveillance setup 2 in Figure 4.4). Even after intensifying the routine serology on sow farms, setups $D+S_{24}$ and $D+S_{36}$, the median duration of the HRP was not affected (see surveillance setup 5 and 10 in Figure 4.4). Similarly, adding the SSC 'routine serology in slaughterhouses', $D+SL_5$, had little effect on the median duration of the HRP even when the sampling was intensified (see surveillance setup 4, 9 and 12 in Figure 4.4). Adding the SSC, 'PCR on rendered animals', to the default surveillance setup, $D+R_{6,3}$, reduced the median duration of the HRP by two days (36 days with seven infected farms) and increased the annual surveillance costs by €10.5 million (see surveillance setup 3 in Figure 4.4). Intensifying the SSC "PCR on rendered animals" to $D+R_{6,1}$, shortens the median duration of the HRP to 27 days with two infected farms (see surveillance setup 13 in Figure 4.4).

In this way, for each surveillance setup, the HRP and the annual surveillance costs are plotted. Based on the median of the duration of the HRP and the annual surveillance costs, a set of efficient surveillance setup for the moderately virulent strain were obtained: D, $D+R_{6,3}$, and $D+R_{6,1}$ (see surveillance setup 1, 3 and 13 in Figure 4.4a). The two alternative efficient surveillance setups both contained the SSC "PCR on rendered animals", but no other additional SSCs.

4.3.2. Low virulent strain

A similar procedure was followed for the low virulent strain; the results are presented in Figure 4.5.

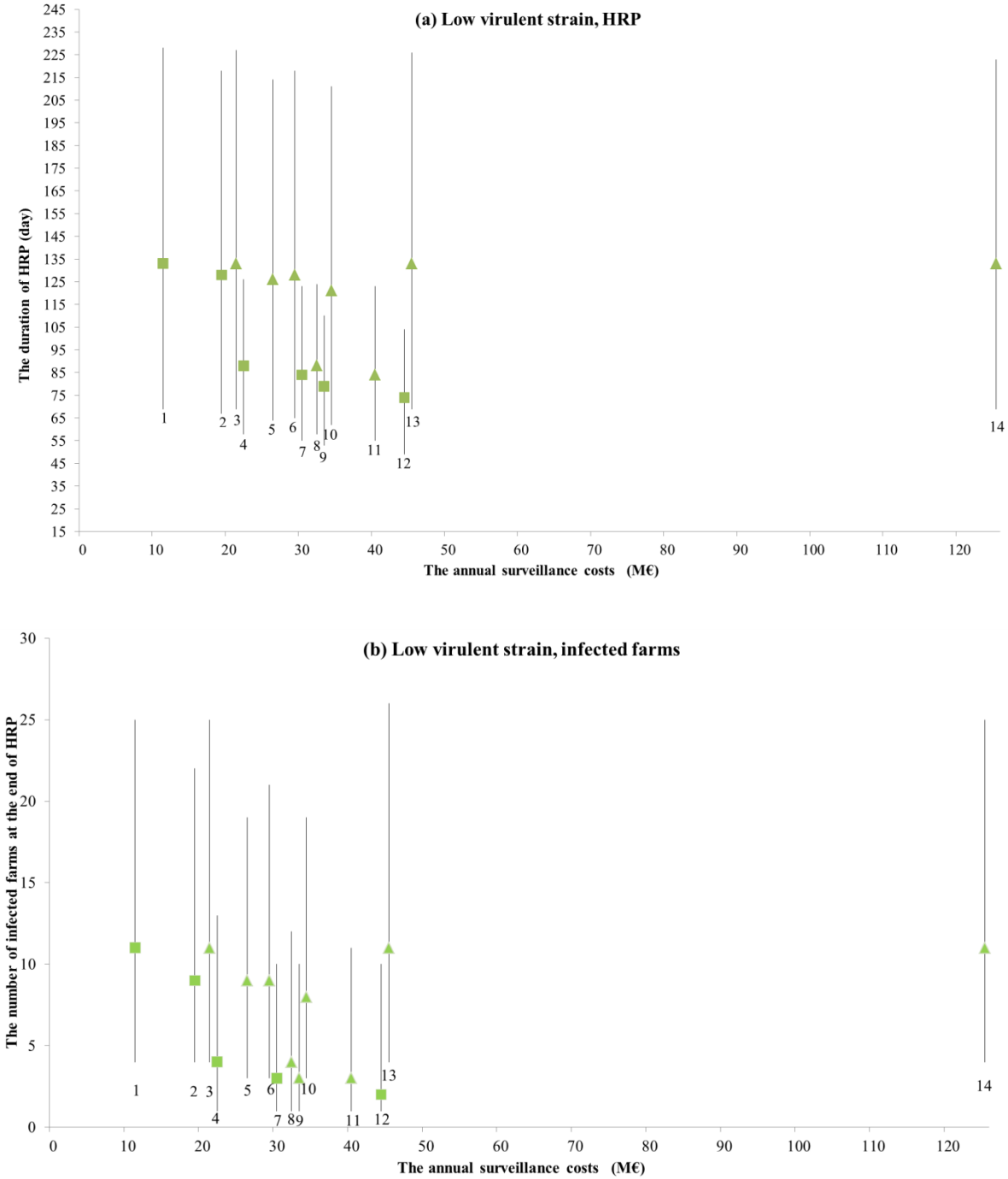

Fig. 4.5. The 10th, 50th and 90th percentiles of the duration of the HRP (Figure 4.5a) and the number of the infected farms at the end of the HRP (Figure 4.5b) for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setup with square-shaped medians are the most efficient among the surveillance setups evaluated.

The median duration of the HRP under the default surveillance setup, D, was 133 days (with 11 infected farms), and the 10th and 90th percentiles were 69 days (with four infected farms) and 228 days (with 25 infected farms) respectively (see surveillance setups 1 in Figure 4.5).

The efficient set of surveillance setups for the low virulent CSF strain changed to: D, D+S_{12}, D+SL_5, D+SL_5+S_{12}, D+SL_{10}, D+SL_{15} (see surveillance setups 1, 2, 4, 7, 9, 12 in Figure 4.5a). All of the five alternative efficient surveillance setups contained serological SSCs.

4.3.3. Cost-benefit analysis for the moderately virulent strain

Table 4.6 shows the detailed comparisons between the additional annual surveillance costs and the annual benefits for each alternative efficient surveillance setup, for the five annual CSF introduction probabilities.

Table 4.6
Cost-benefit analysis for the efficient surveillance-setup scenarios with the moderately virulent strain

Alternative efficient surveillance-setup scenarios	Additional annual surveillance costs(M€)	Annual benefits (M€) on the *10th* perencile of the number of infected farms at the end of HRP under the surveillance-setup scenario			Annual benefits (M€) on the *50th* perencile of the number of infected farms at the end of HRP under the surveillance-setup scenario			Annual benefits (M€) on the *90th* perencile of the number of infected farms at the end of HRP under the surveillance setup scenario		
		10%	50%	90%	10%	50%	90%	10%	50%	90%
Annual introduction probability: 0.01										
D+R6,3	11	0	0	0	0.04	0.04	0.08	0.09	0.20	0.16
D+R6,1	34	0	0.12	0.24	0.20	0.32	0.68	0.56	0.88	0.96
Annual introduction probability: 0.03										
D+R6,3	11	0	0	0	0.12	0.12	0.24	0.27	0.60	0.48
D+R6,1	34	0	0.36	0.72	0.60	0.96	2.04	1.68	2.64	2.88
Annual introduction probability: 0.06 (default)										
D+R6,3	11	0	0	0	0.24	0.24	0.48	0.54	1.20	0.96
D+R6,1	34	0	0.72	1.44	1.20	1.92	4.08	3.36	5.28	5.76
Annual introduction probability: 0.1										
D+R6,3	11	0	0	0	0.40	0.40	0.80	0.90	2.00	1.60
D+R6,1	34	0	1.20	2.40	2.00	3.20	6.80	5.60	8.80	9.60
Annual introduction probability: 0.2										
D+R6,3	11	0	0	0	0.80	0.80	1.60	1.80	4.00	3.20
D+R6,1	34	0	2.40	4.80	4.00	6.40	13.60	11.20	17.60	19.20

The additional annual surveillance costs were €11 million and €34 million respectively for setups D+$R_{6,3}$ and D+$R_{6,1}$ (see surveillance setups 3 and 13 in Figure 4.4a). The 10th, 50th, and 90th percentiles of annual benefits from the intensified surveillance setups are presented for each of the 10th, 50th, and 90th percentiles of the number of infected farms at the end of the HRP (see Table 4.7).

Table 4.7
The number of infected farms at the end of the HRP for each efficient surveillance-setup scenario with the moderately virulent strain

Efficient surveillance-setup scenarios	Annual surveillance costs (M€)	Percentiles of the number of infected farms at the end of the HRP		
		10%	50%	90%
D	11	2	8	17
D+R6,3	22	2	7	15
D+R6,1	45	1	2	6

It is shown that the additional annual surveillance costs for both setups were much larger than the annual benefits from intensified surveillance. This result was valid for all five scenarios of surveillance setups regarding the probability of CSF introduction.

4.3.4. Sensitivity analysis

For the CSF surveillance simulation model, the parametric changes either shortened or lengthened the durations of the HRP and the number of infected farms at the end of the HRP for all surveillance setups following the same pattern. The efficient set of surveillance setups remained the same across all parameter changes (to save space, those results are presented as the *Supporting Information*). For the cost-benefit analysis, the higher annual CSF introduction probabilities (than 0.06) did not reverse the relationship between the benefits and additional surveillance costs (see Table 4.6).

4.4 Discussion

4.4.1. Content of this study

This study extends the current body of Dutch CSF surveillance literature (Crauwels et al., 1999; Elbers et al., 2002; Klinkenberg et al., 2005; Backer et al., 2011), in three specific areas: it includes most of the potential SSCs, it considers different virulent strains, and the study includes an in-depth cost-effectiveness analysis and cost benefit analysis where possible.

For the moderately virulent strain, the surveillance setups including the SSCs 'routine serology in slaughterhouses' and 'routine serology on sow farms' had minimal impact on the duration of the HRP and the number of infected farms at the end of the HRP. This finding can be explained by the fact that clinical symptoms occur much earlier than antibodies in the blood. The finding is consistent with the claim of Crauwels et al. (1999) that routine serological screening would not have shortened the duration of the HRP during the 1997-1998 CSF epidemic. The SSC 'PCR on rendered animals' had impact on the reduction of the duration of the HRP and the number of infected farms at the end of the HRP. CSF greatly increases the mortality of infected animals, and conducting PCR tests on dead animals can therefore substantially increase the probability of detecting CSF. Both of the alternative efficient surveillance setups ($D+R_{6,3}$ and $D+R_{6,1}$) contained the SSC 'PCR on rendered animals'. This finding is consistent with the result in Backer et al. (2011) that 'PCR on rendered animals' can reduce the duration of HRP.

The analysis of the efficient set of surveillance setups for the moderately virulent CSF was extended by including a cost-benefit analysis. For the two alternative efficient surveillance-setups, the results of CSF impact simulation model of Hop et al. (2014) was used to calculate the DC and DCC of a CSF epidemic, and an overestimated ICC, based on Danish situation, was assumed. The results show that the costs of intensified surveillance were much larger than the benefits for both these surveillance setups even with the overestimated ICC caused by a CSF outbreak. One point should be addressed here is that in this study, only the financial impact of CSF surveillance is considered. CSF also causes other impacts (e.g. socio-ethical impacts) which could be reduced by intensifying the CSF surveillance system. These aspects are not considered in this study. From an economic perspective, intensifying the Dutch CSF surveillance system for detecting the moderately virulent CSF is not preferable.

In contrast to the findings for the moderately virulent strain, the surveillance setups containing routine serology SSCs were highly effective for the low virulent CSF strain. Animals infected with low virulent CSF are slow to develop clinical symptoms and these symptoms are often more obscure, which makes clinical inspection ineffective. Since routine serological tests do not rely on clinical inspections, they have a positive effect on the early detection of low virulent CSF. Incorporating the SSC 'PCR on rendered animals' had a negligible impact on the duration of the HRP and the number of infected farms at the end of HRP. This is expected,

since infection with low virulent CSF does not increase the mortality of animals. Hence, conducting PCR on rendered animals does not enhance the probability of CSF detection, compared with PCR testing on randomly sampled animals. All of the alternative efficient surveillance setups contained routine serology SSCs.

A cost-benefit analysis for the low virulent CSF scenario was not conducted for two reasons. Firstly, re-parameterizing the CSF simulation model (Hop et al., 2014) for low virulent CSF requires data for the low virulent strain which are not available in the literature. Secondly, the risk of low virulent CSF introduction is extremely low for the Netherlands in current situation, because the low virulent CSF reserved in wild boars in Germany-Netherlands border areas has been eradicated (2012/250/EU: Commission Implementing Decision of 8 May 2012). The low introduction probability will make the annual benefits very small compared to the additional surveillance costs. Hence, it is very likely that applying intensified surveillance-setups for a low virulent CSF strain will not be beneficial.

4.4.2. Modelling approach

The current research uses two simulation models: the CSF surveillance simulation model and the CSF impact simulation model (Hop et al., 2014). The CSF surveillance simulation model was developed based on the conceptual framework for economic analysis of single hazard surveillance systems (Guo et al., 2014). The CSF impact simulation model described by Hop et al. (2014) was developed based on a generic model, InterSpread Plus, and its credibility was verified by Sanson et al. (1999), Stevenson et al. (2013), and Dube et al. (2007). Hence, the modelling approach is suitable for this research.

Two types of data are used in this research: 1) the data to parameterize the CSF surveillance simulation model, and 2) the data on the economic impact of a CSF epidemic to quantify the benefits of CSF surveillance. The data required by the surveillance simulation model include the values of transmission parameters, the background and CSF-related symptom probabilities for individual animals, and the data for the surveillance system components (SSCs). Where possible, parameterization was based on data from literature (transmission parameters, background mortalities), followed by expert opinion in situations where no literature was available (background probabilities for clinical symptoms). In some cases, a combination of both sources was used (CSF-related symptom probabilities and data for SSCs). The data on

the economic impact of a CSF epidemic were derived from Hop et al. (2014). The models were parameterized with appropriate inputs based on the best available data.

The sensitivity analysis for the CSF surveillance simulation model showed that the sets of efficient surveillance setups for both low and moderately virulent strains were robust (i.e. changes in the parameter values did not change the efficient surveillance setups). The results of the cost-benefit analysis (Table 4.6) were also robust, because the additional annual surveillance costs are much higher than the annual benefits in all cases. Even though the input data was uncertain, this uncertainty is not likely to change the findings regarding the efficient surveillance setups. The model results are also consistent with the actual 1997-1998 CSF epidemic in the Netherlands and with existing literature on CSF surveillance. The estimated median duration of the HRP with the moderately virulent CSF was 38 days, which is close to the actual HRP for the 1997-1998 Dutch CSF epidemic of approximately six weeks (Jalvingh et al. 1999). It is also similar to the durations of 35 days, 37 days and 38 days in Klinkenberg et al. (2005), Raulo and Lyytikainen (2007) and Backer et al. (2011), respectively.

4.4.3. Implications for other countries

The results of this study are also relevant for other countries, especially the Western European countries such as Germany, Belgium, Denmark and France, where the pig industry structures have quite some similarity to that of the Netherlands. For those countries, since prevention methods are applied, the probability of CSF introduction has been reduced to a relatively low level (the Western Europe has been free of CSF in commercial pigs for 16 years). The low introduction probability makes the expected surveillance benefits become much smaller than the surveillance costs to maintain intensified surveillance setups. Therefore, the conclusion that intensified surveillance setups are economically unbeneficial could also apply to the aforementioned Western European countries. Moreover, for some areas of those Western European countries (e.g. Part of Northern Vosges, France (Laddomada, 2000)), there are wild boars that can contain low virulent CSFVs; therefore, in those areas, the probability of low virulent CSF introduction to the commercial pigs is high. Our finding that serology surveillance is cost-effective for detecting low virulent CSF implies that adding additional serology surveillance in such areas can be justified.

4.4.4. Conclusions and limitations

From the current study, several conclusions can be drawn. Firstly, the default Dutch CSF surveillance setup (including "Daily clinical observation by the farmer", "Veterinarian inspection after a call", "Routine veterinarian inspection", "Pathology in AHS", "PCR on tonsil in AHS", "PCR on grouped animals in CVI", and "Confirmatory PCR by NVWA") is included in the efficient set of surveillance setups for both the moderately virulent and low virulent CSF strains. This indicates that the default surveillance setup is a reasonable choice. Secondly, with the exception of the default surveillance setup, the efficient sets of surveillances for the moderately and low virulent CSF strains are different. For the moderately virulent strain, all of the alterative efficient surveillance-setups contained the SSC 'PCR on rendered animals'. For the low virulent strain, the alterative efficient surveillance setups all contained the routine serology SSCs. Finally, from an economic perspective, the current Dutch CSF surveillance system is considered adequate for the moderately virulent CSF strain; there is little to be gained by intensifying surveillance.

The limitations of this study include the lack of cost-benefit analysis for the low virulent strain and the neglect of the non-economic benefits in the evaluation. Moreover, although the number of the specific breeding farms is small, excluding such farms may have impact on the model's outcome because the infected breeding farms can have a big capacity to spread the virus. Future research should focus on dealing with such limitations.

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Appendix

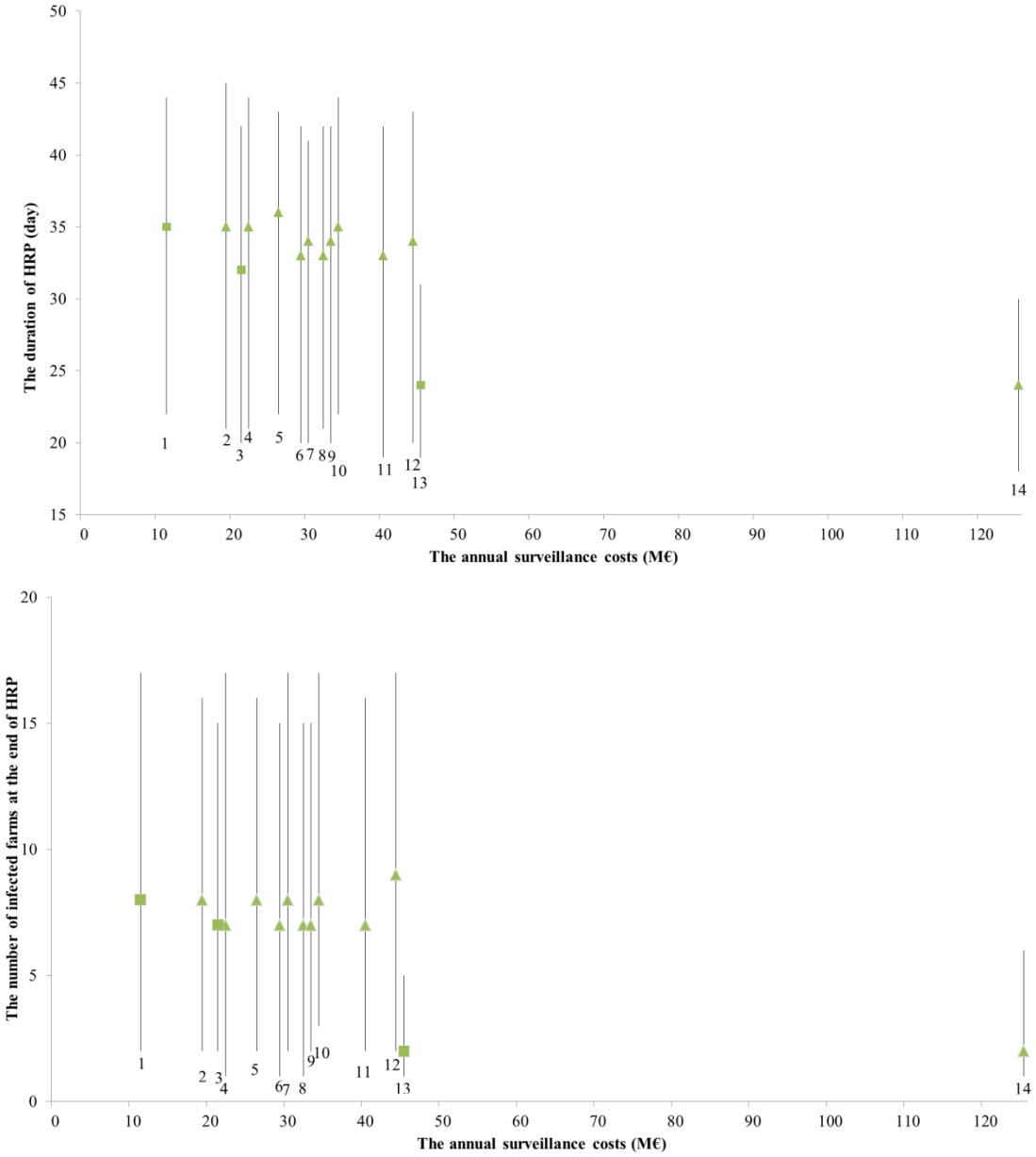

Fig. A1. Sensitivity analysis: increasing the with-farm transmission parameter by 50% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setup with square-shaped medians are the most efficient among the surveillance setups evaluated.

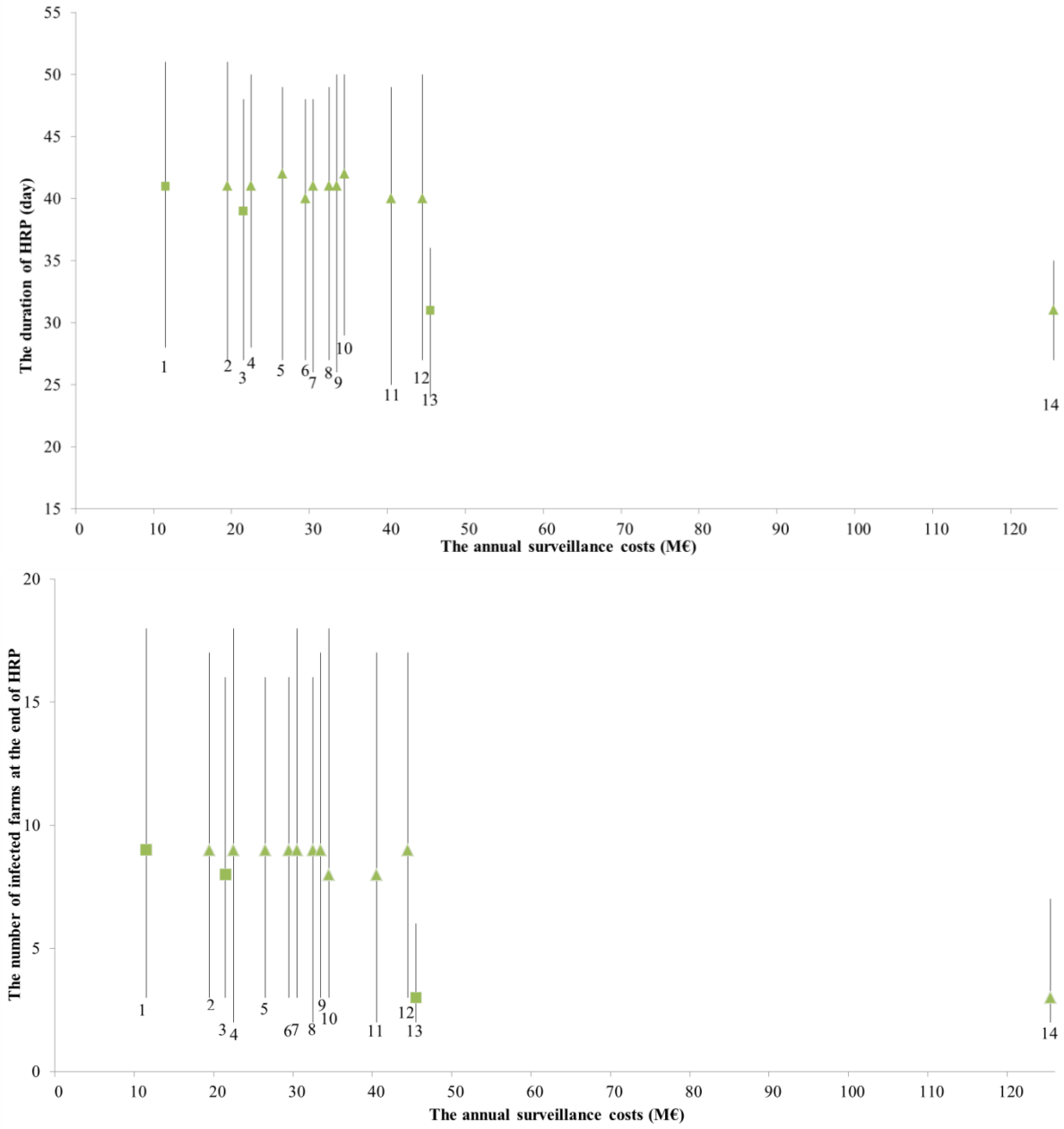

Fig. A2. Sensitivity analysis: decreasing the with-farm transmission parameter by 50% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setup with square-shaped medians are the most efficient among the surveillance setups evaluated.

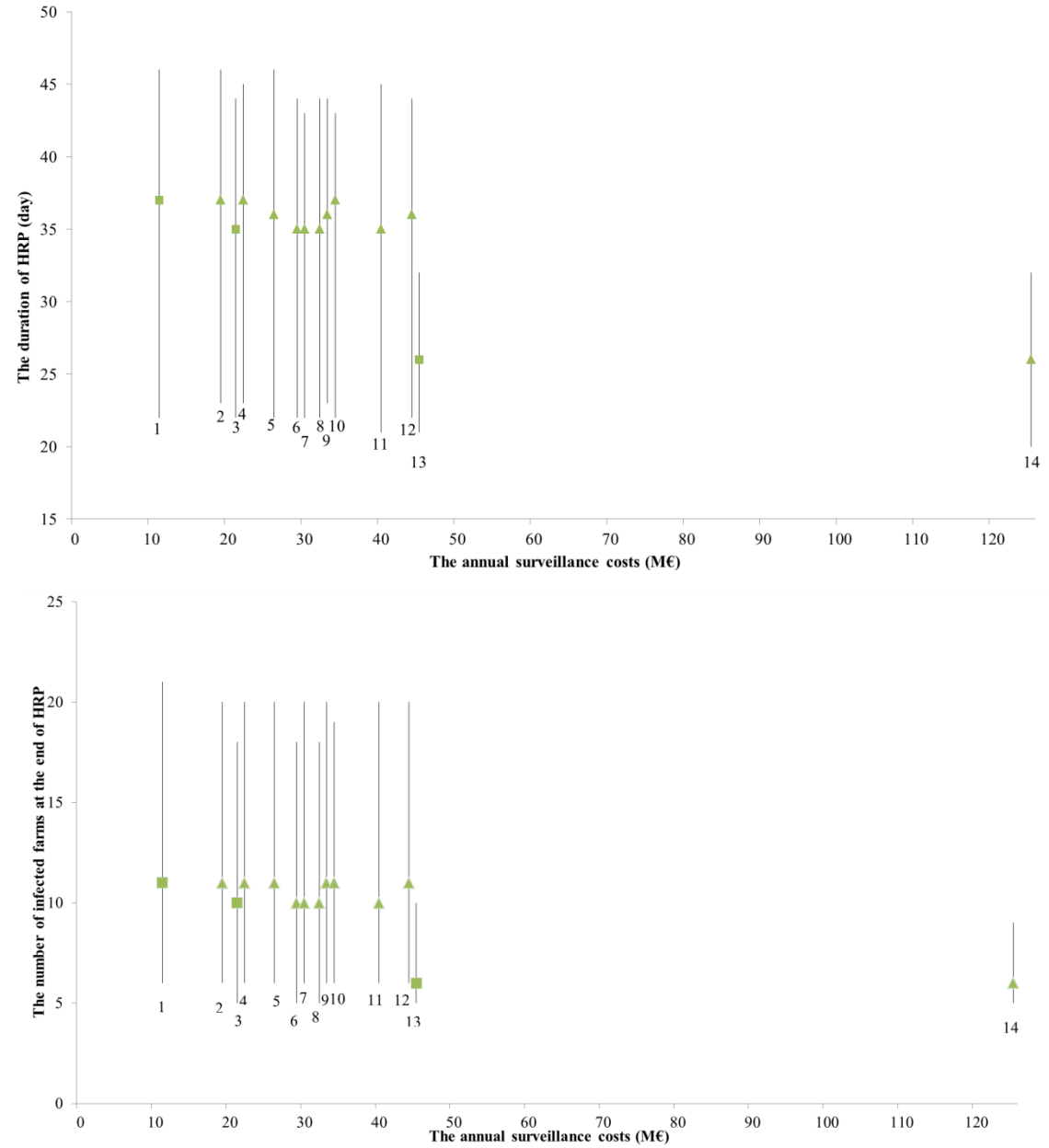

Fig. A3. Sensitivity analysis: increasing the between-farm transmission parameter by 50% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

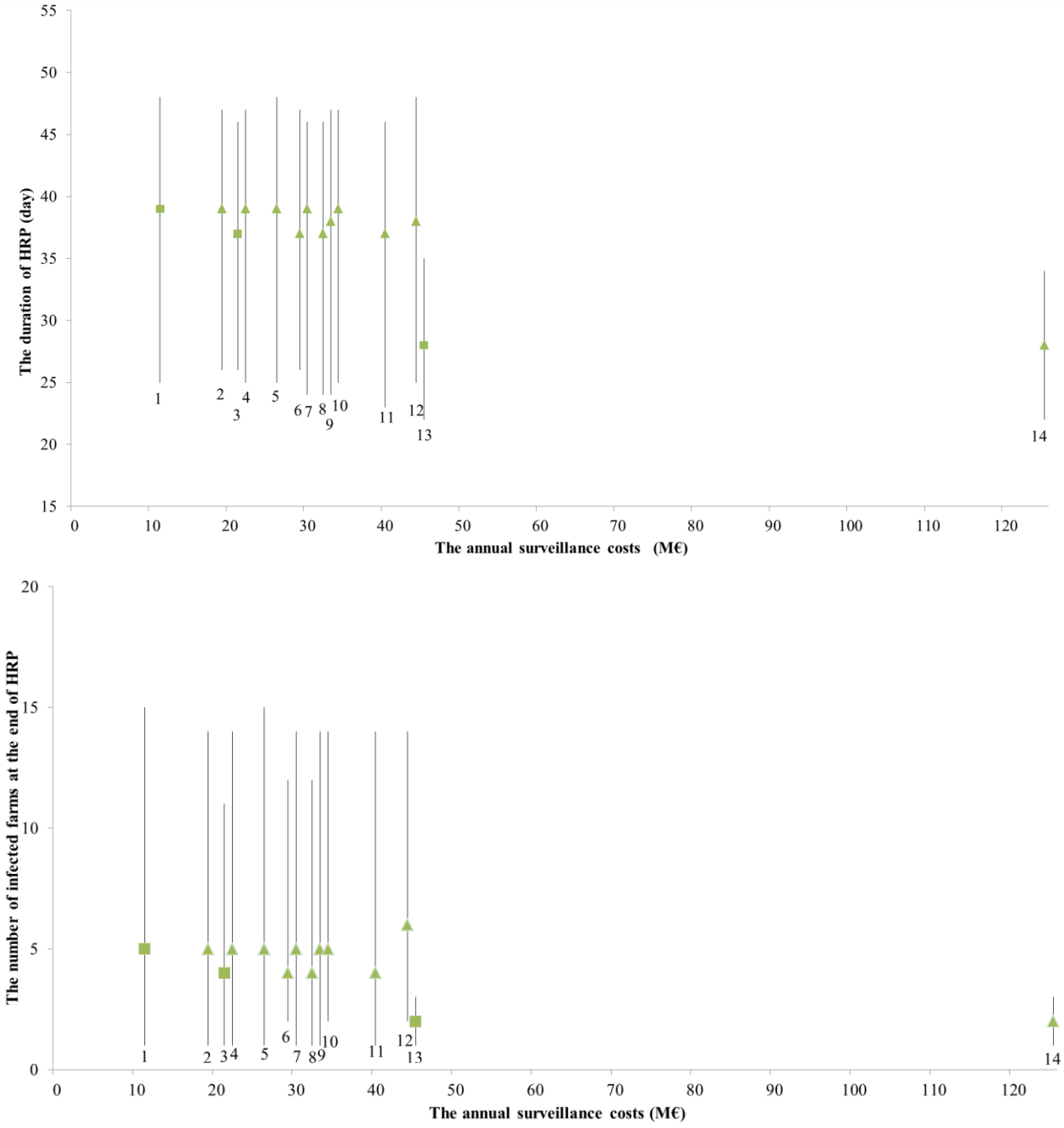

Fig. A4. Sensitivity analysis: decreasing the between-farm transmission parameter by 50% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

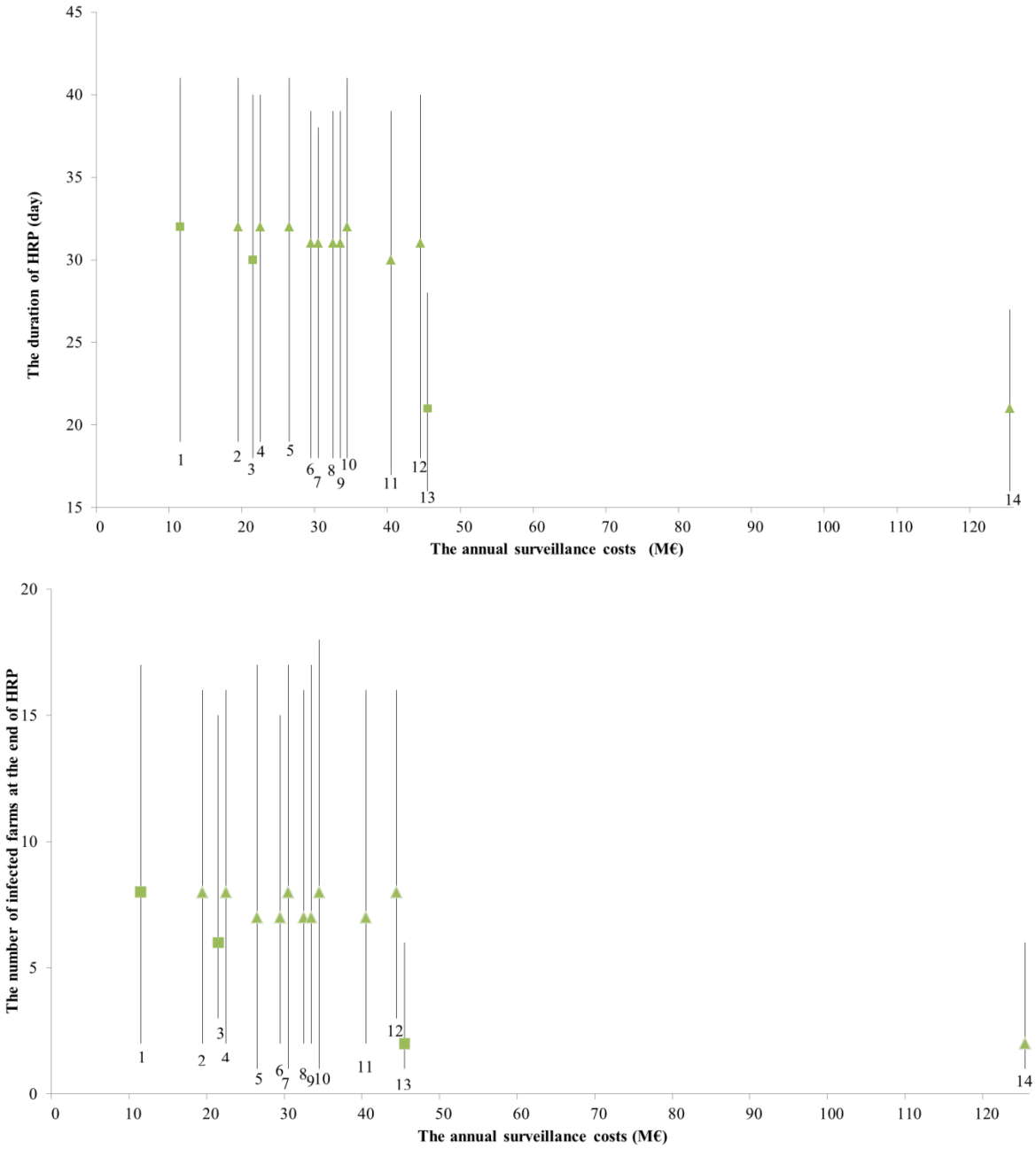

Fig. A5. Sensitivity analysis: making the CSF-related symptoms of the infected individuals occur two days earlier for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP for 14 surveillance setups are presented with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

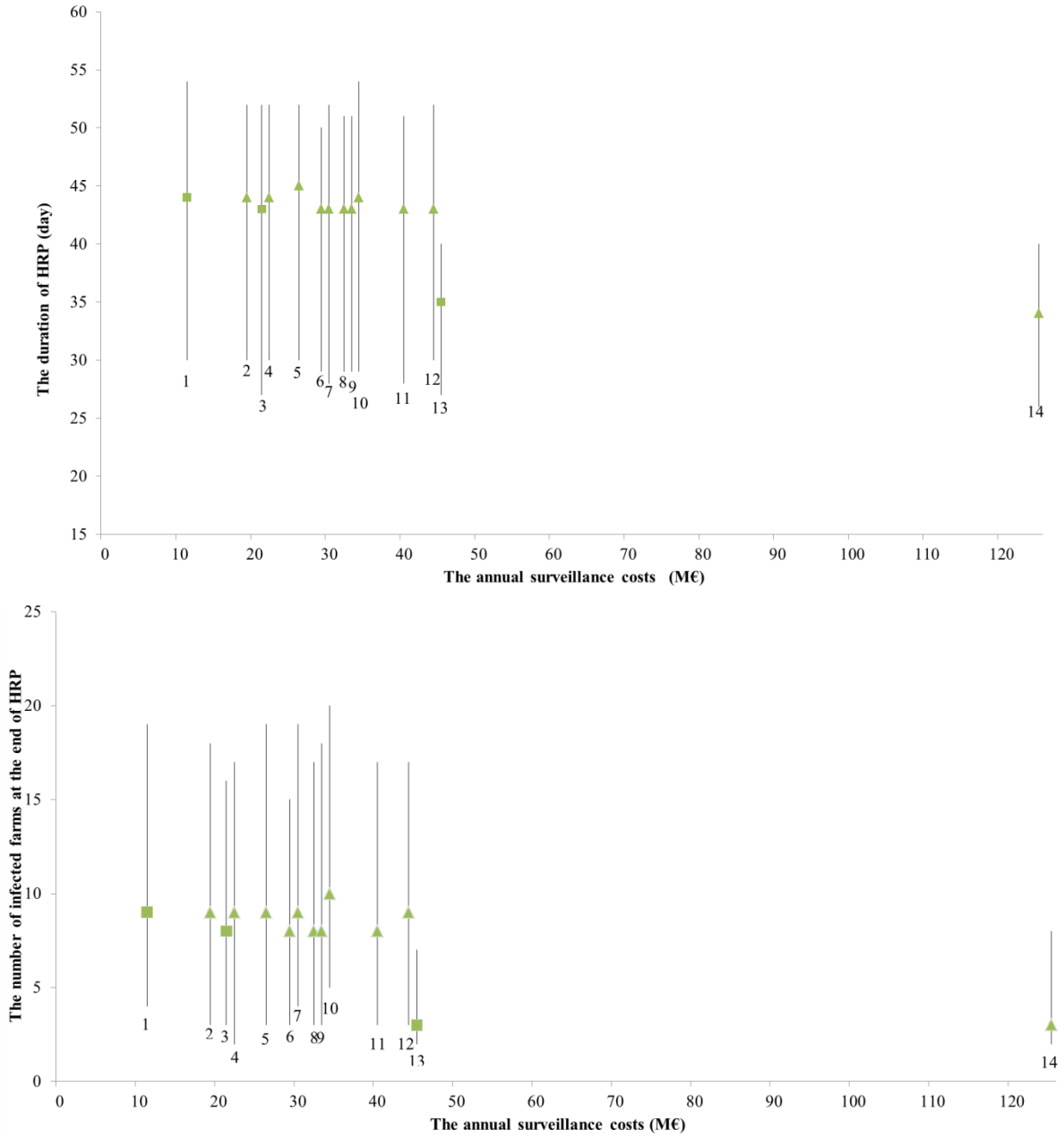

Fig. A6. Sensitivity analysis: making the CSF-related symptoms of the infected individuals occur two days later for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

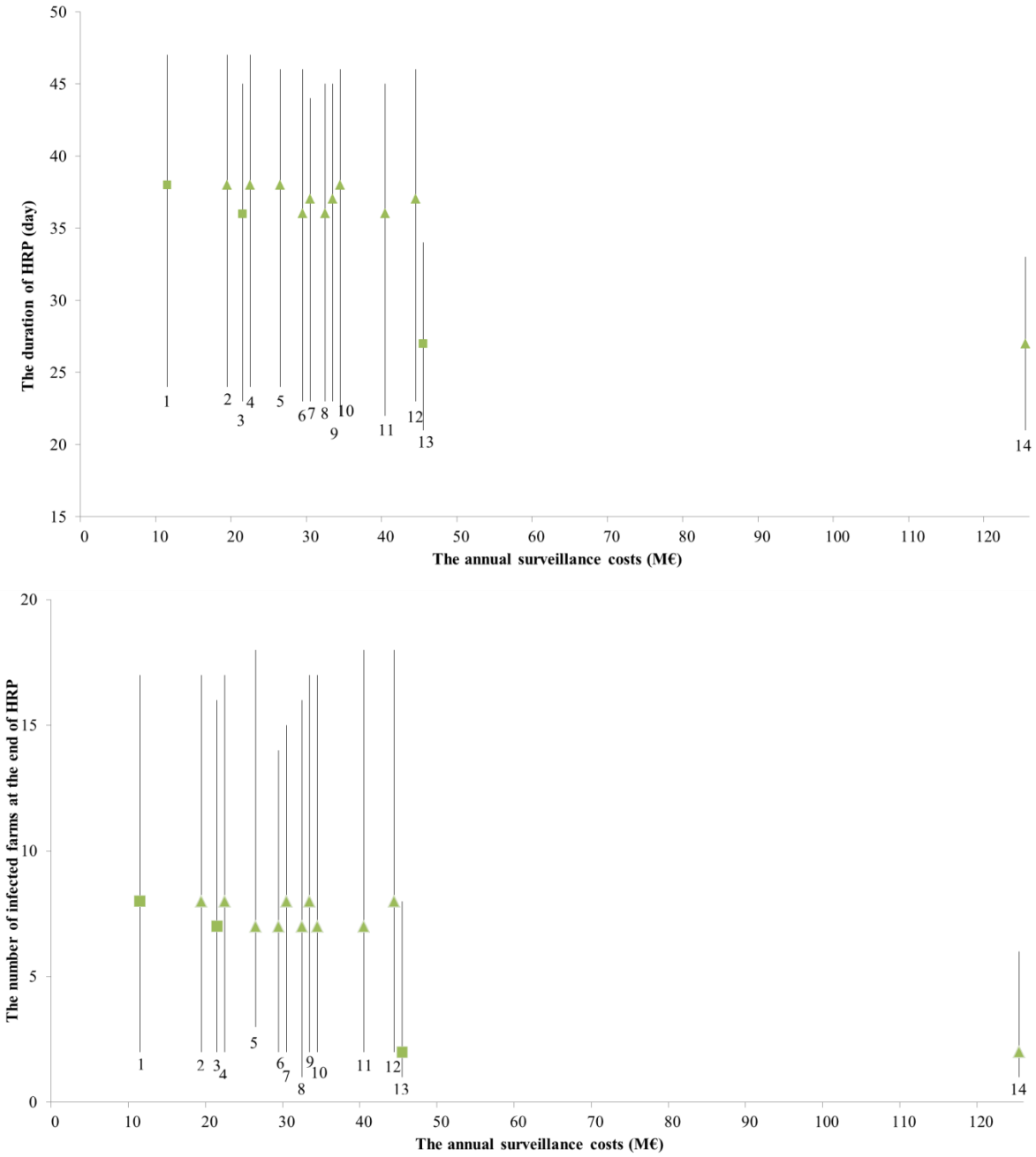

Fig. A7. Sensitivity analysis: reducing the sensitivity of the ELISA test to 90% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

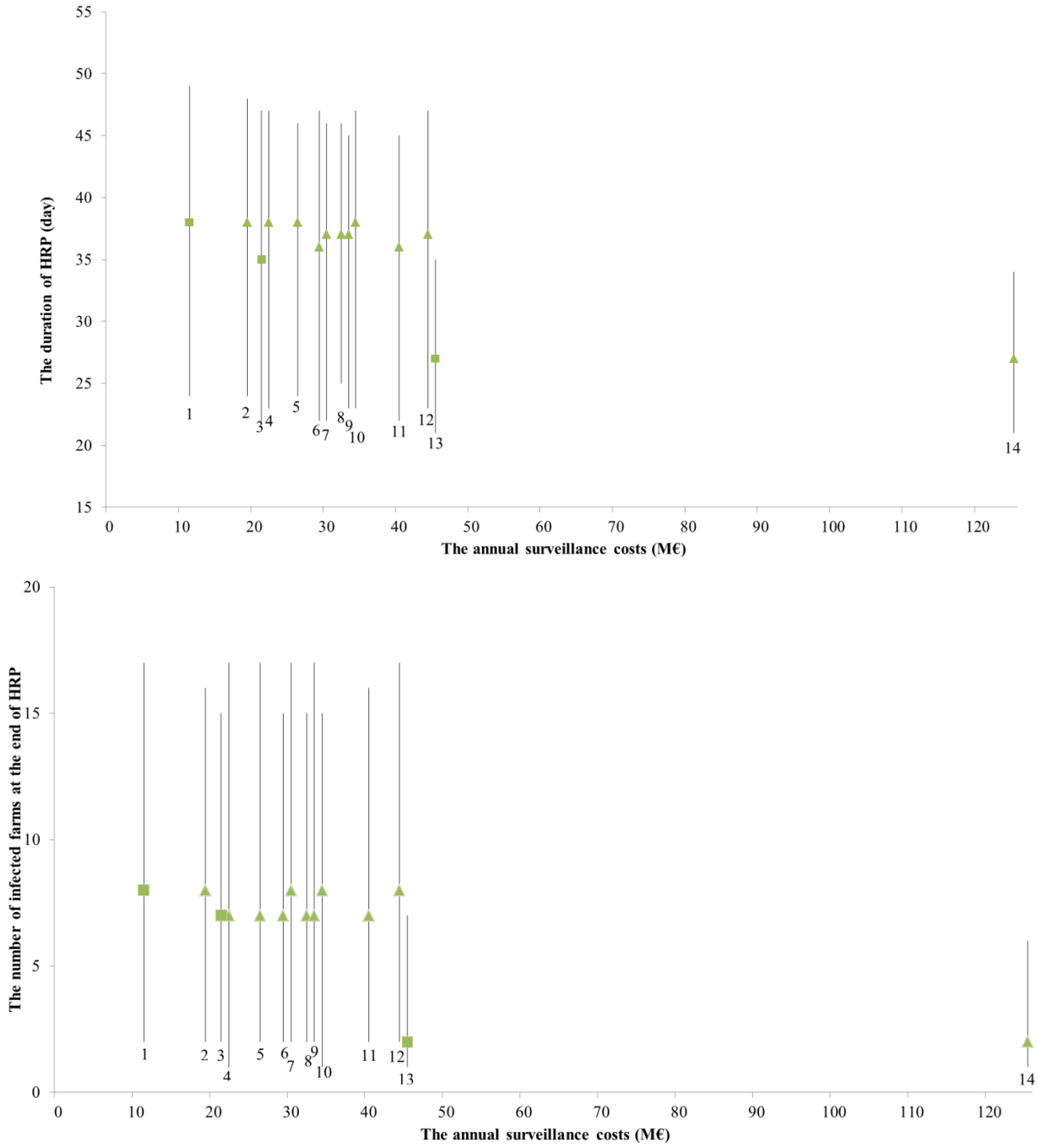

Fig. A8. Sensitivity analysis: reducing the sensitivity of the PCR test to 90% for moderately virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the moderately virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setup with square-shaped medians are the most efficient among the surveillance setups evaluated.

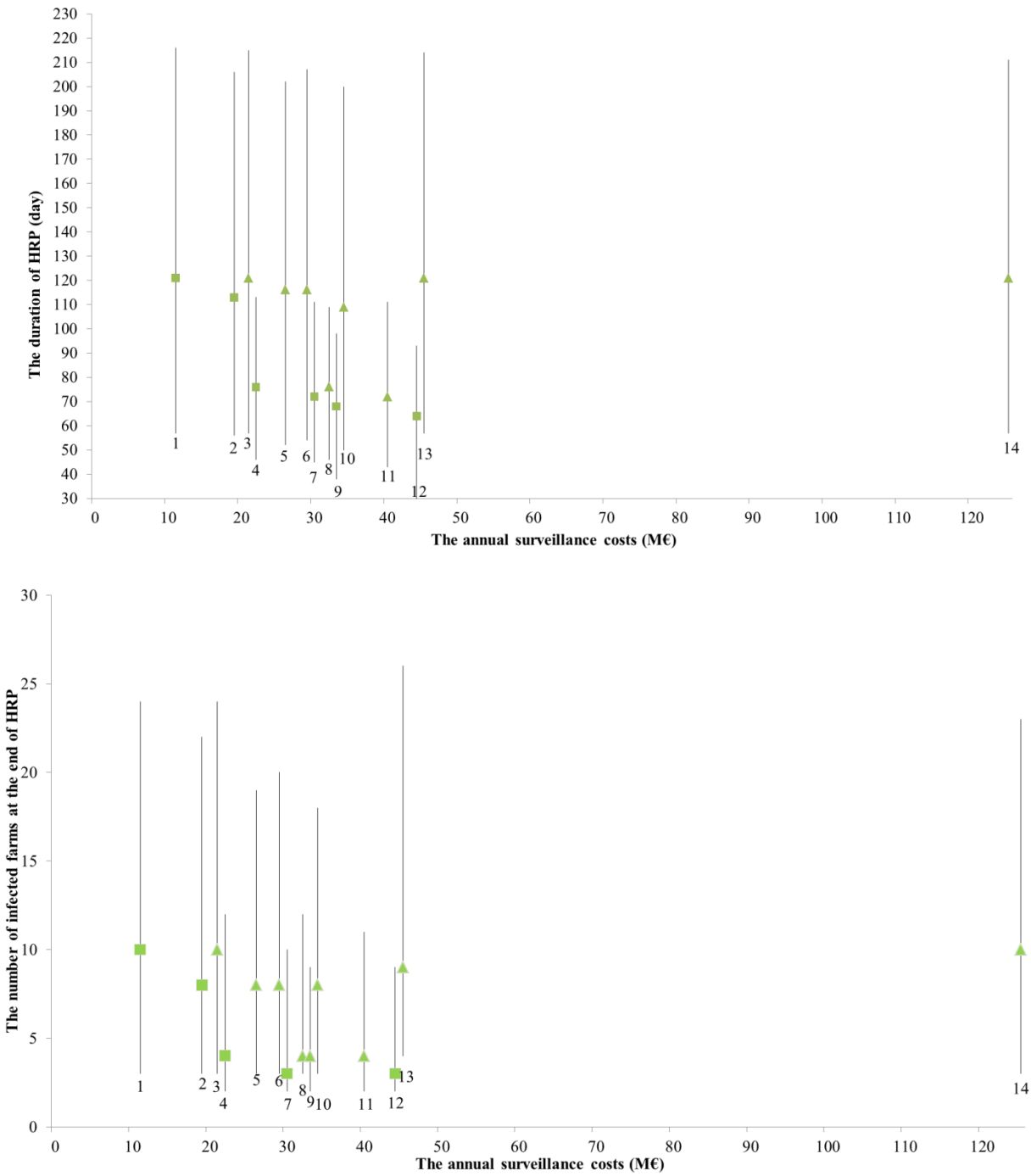

Fig. A9. Sensitivity analysis: increasing the with-farm transmission parameter by 50% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

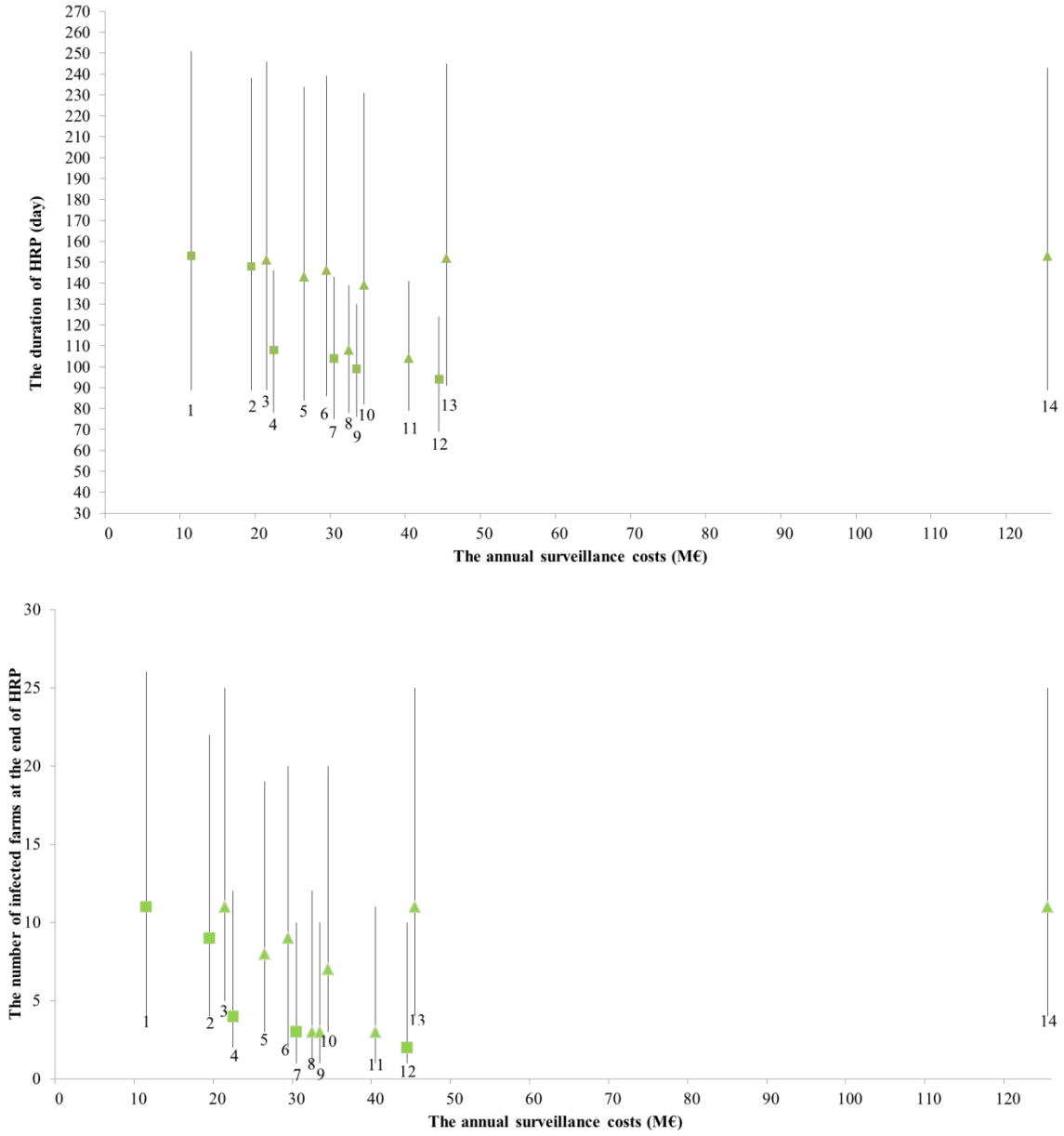

Fig. A10. Sensitivity analysis: decreasing the with-farm transmission parameter by 50% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

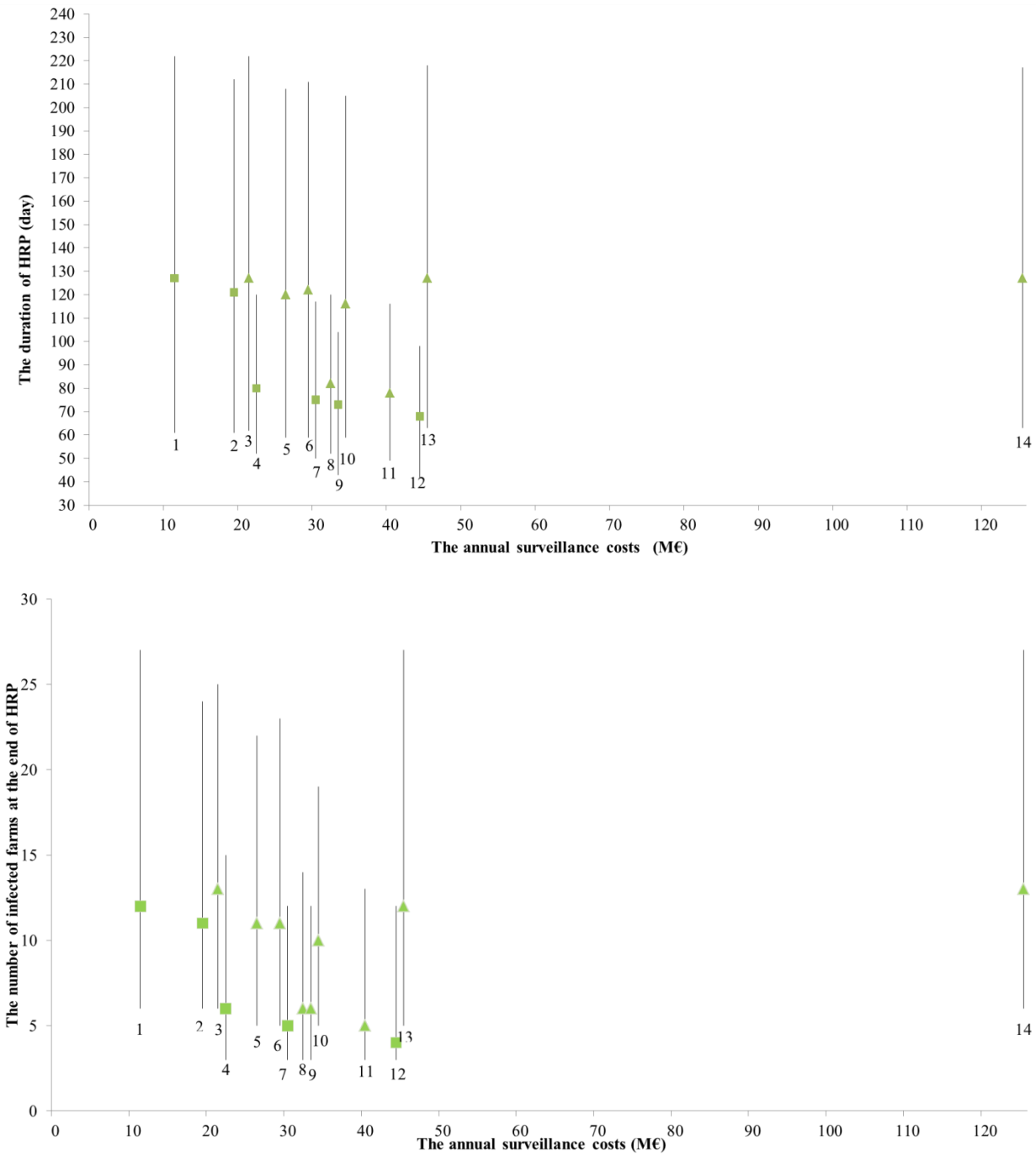

Fig. A11. Sensitivity analysis: increasing the between-farm transmission parameter by 50% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

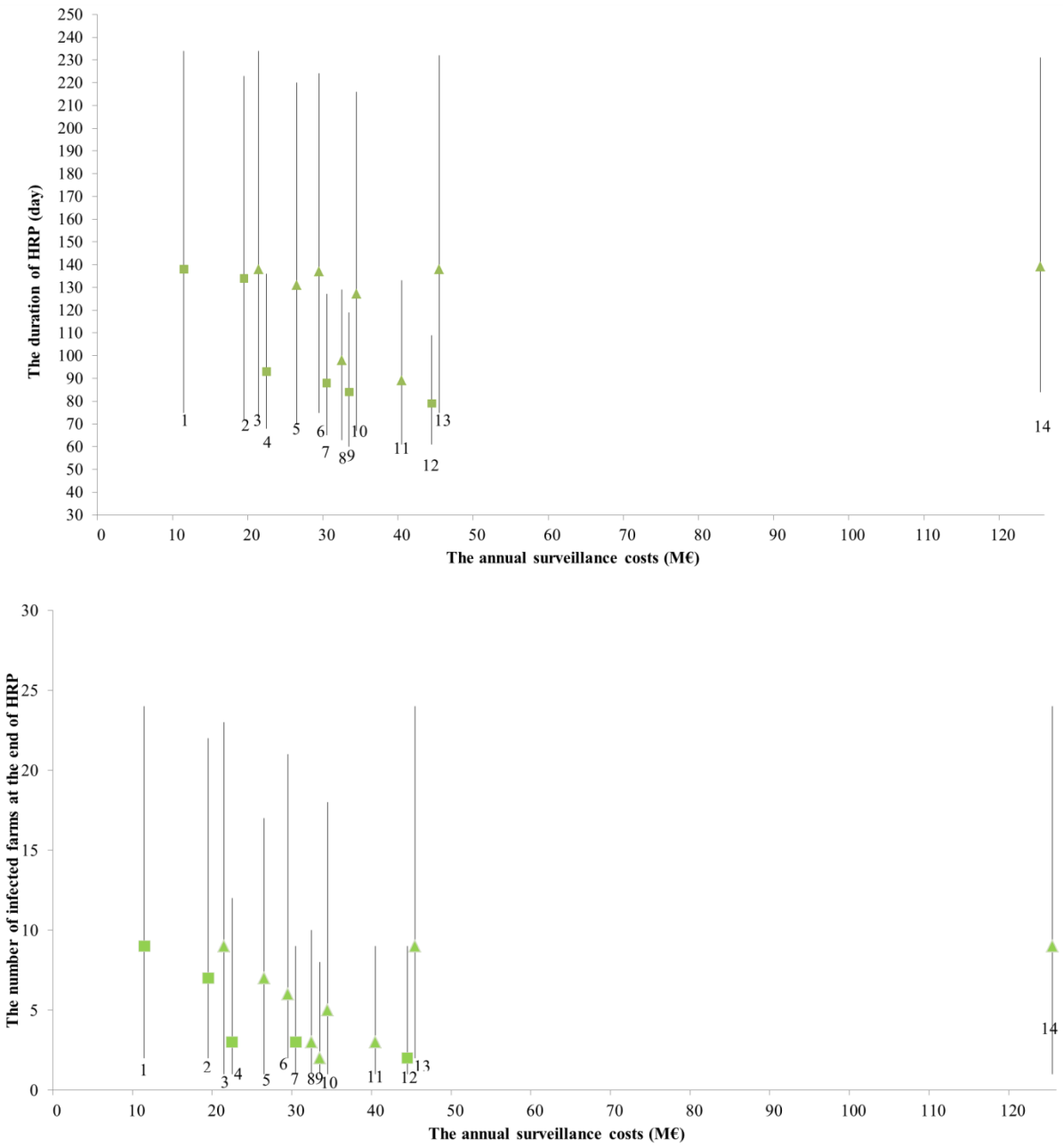

Fig. A12. Sensitivity analysis: decreasing the between-farm transmission parameter by 50% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

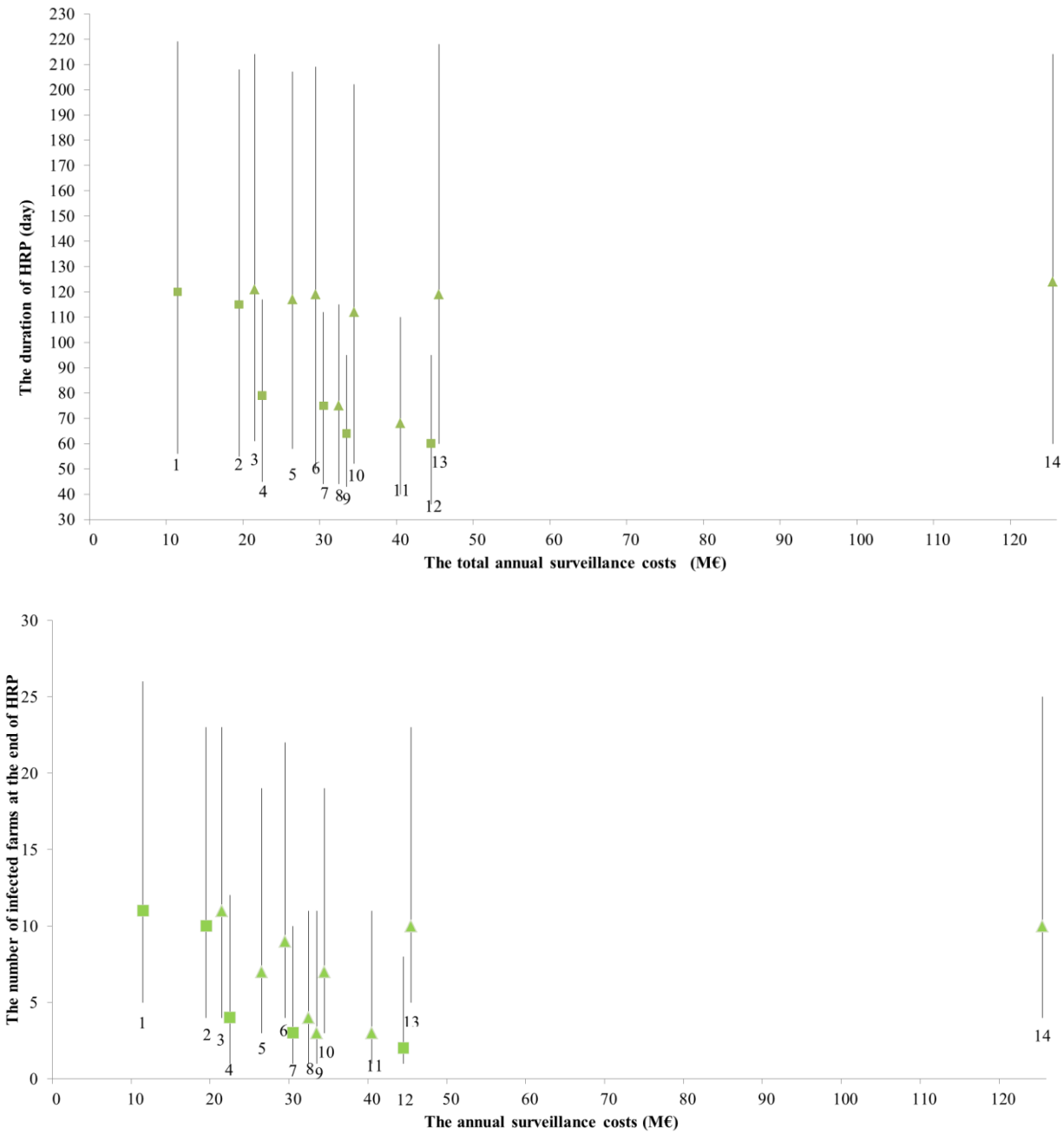

Fig. A13. Sensitivity analysis: making the CSF-related symptoms of the infected individuals occur two days earlier for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

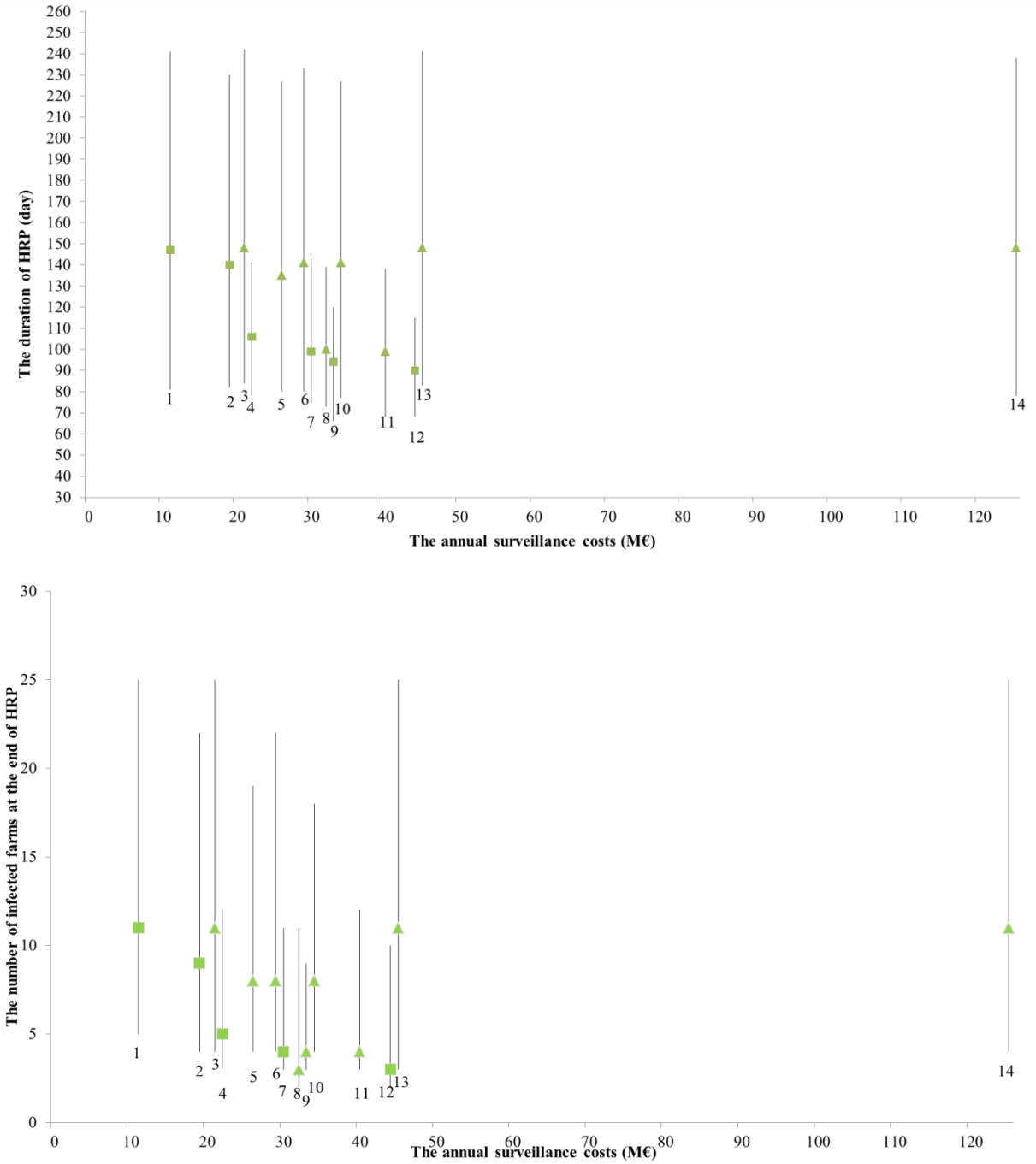

Fig. A14. Sensitivity analysis: making the CSF-related symptoms of the infected individuals occur two days later for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

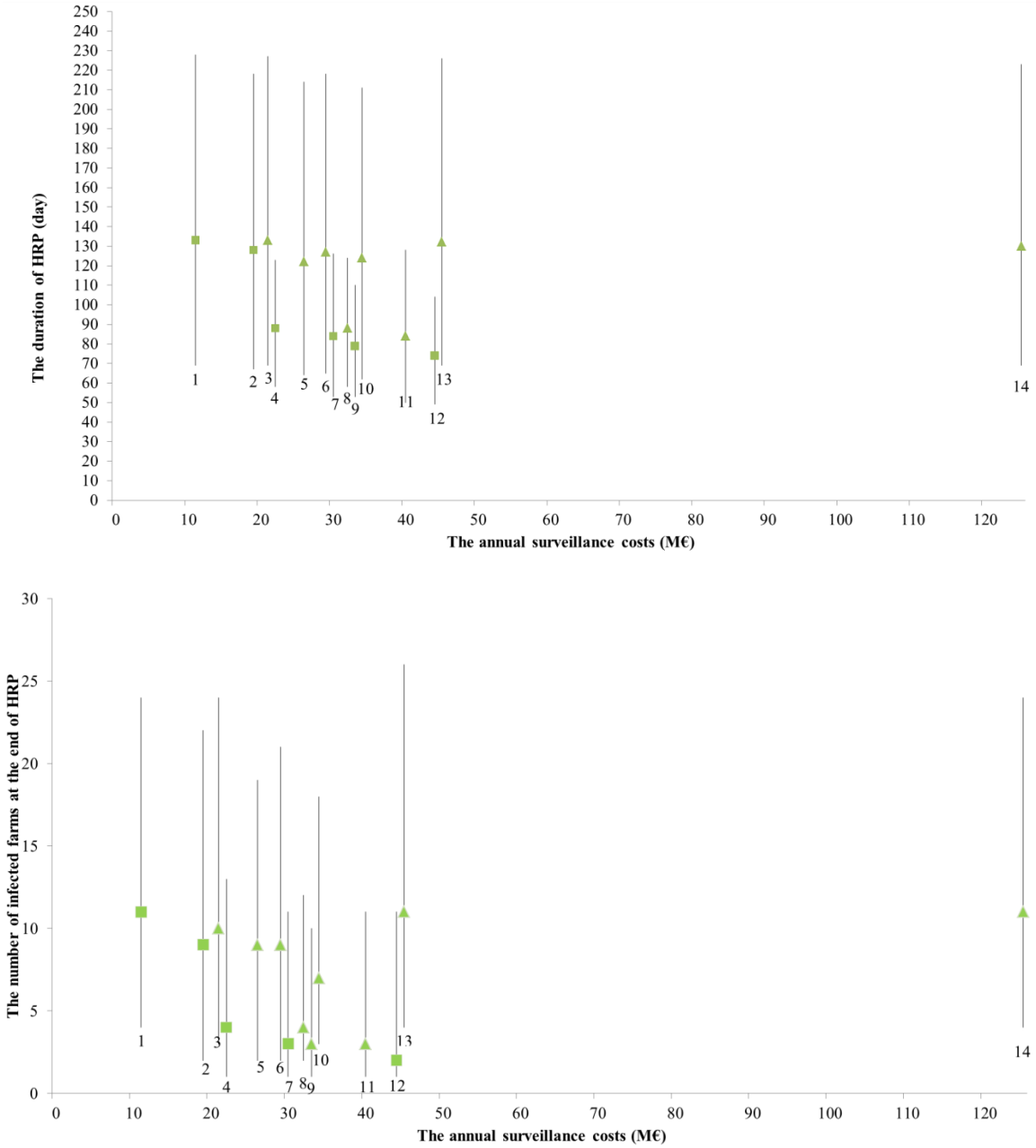

Fig. A15. Sensitivity analysis: reducing the sensitivity of the ELISA test to 90% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setups with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

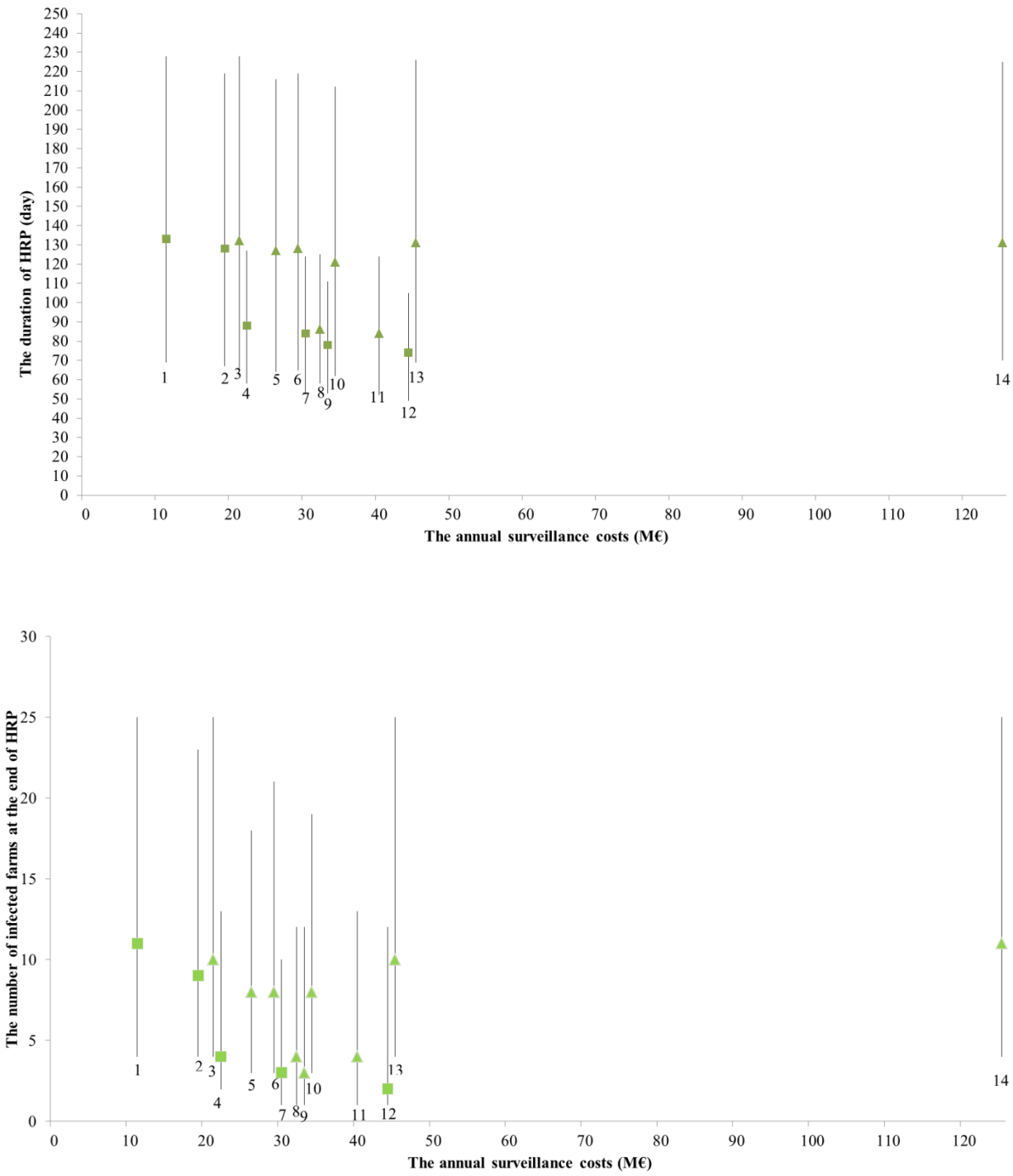

Fig. A16. Sensitivity analysis: reducing the sensitivity of the PCR test to 90% for low virulent CSF

The 10th, 50th and 90th percentiles of the duration of the HRP and the number of the infected farms at the end of the HRP are presented for 14 surveillance setup scenarios with the low virulent strain.

1: D, 2: D+S_{12}, 3: D+$R_{6,3}$, 4: D+SL_5, 5: D+S_{24}, 6: D+$R_{6,3}$+S_{12}, 7: D+SL_5+S_{12}, 8: D+SL_5+$R_{6,3}$, 9: D+SL_{10}, 10: D+S_{36}, 11: D+SL_5+$R_{6,3}$+S_{12}, 12: D+SL_{15}, 13: D+$R_{6,1}$, 14: D+$R_{1,1}$.

The surveillance setups with square-shaped medians are the most efficient among the surveillance setups evaluated.

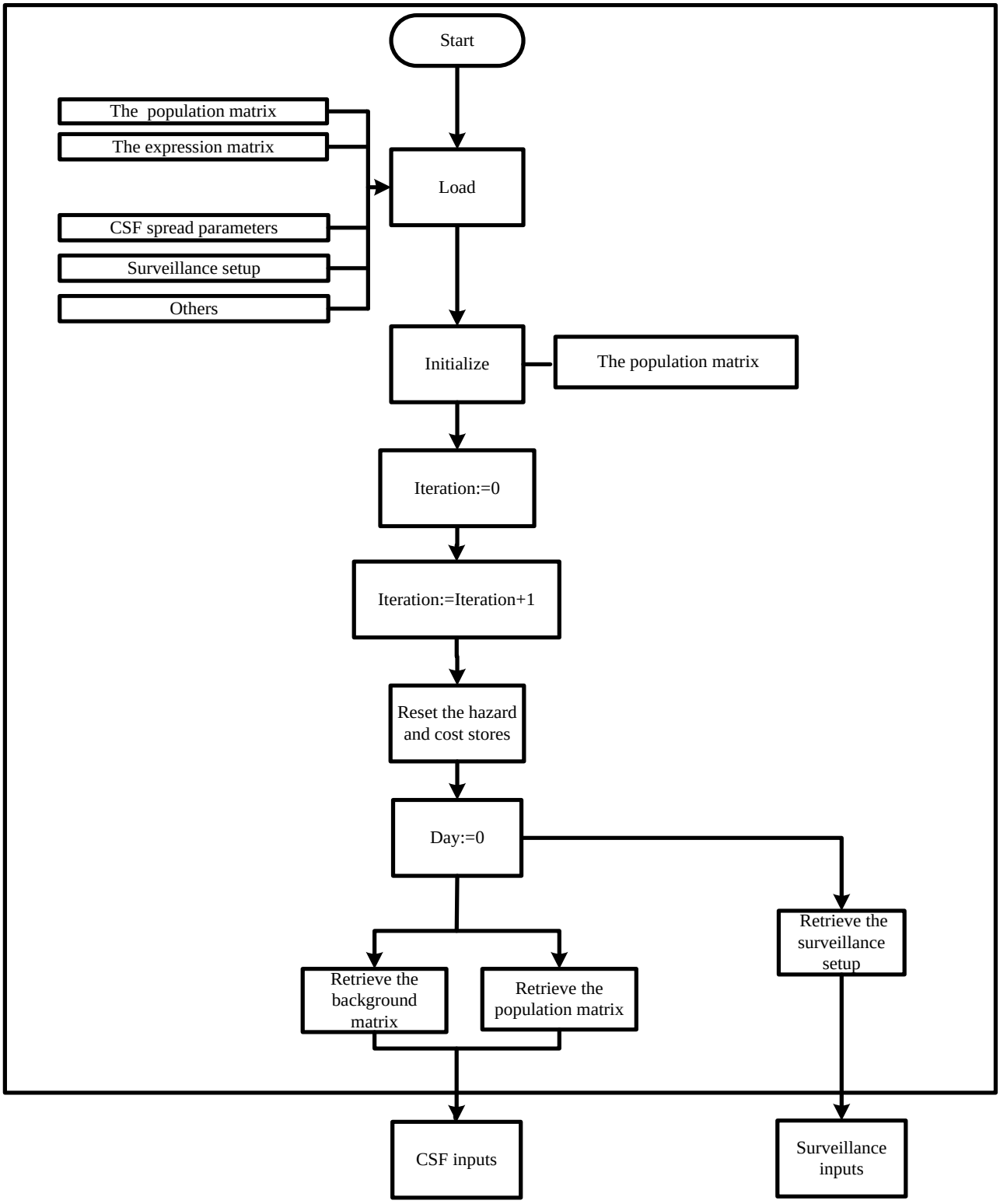

Fig. A17. The module of initialization

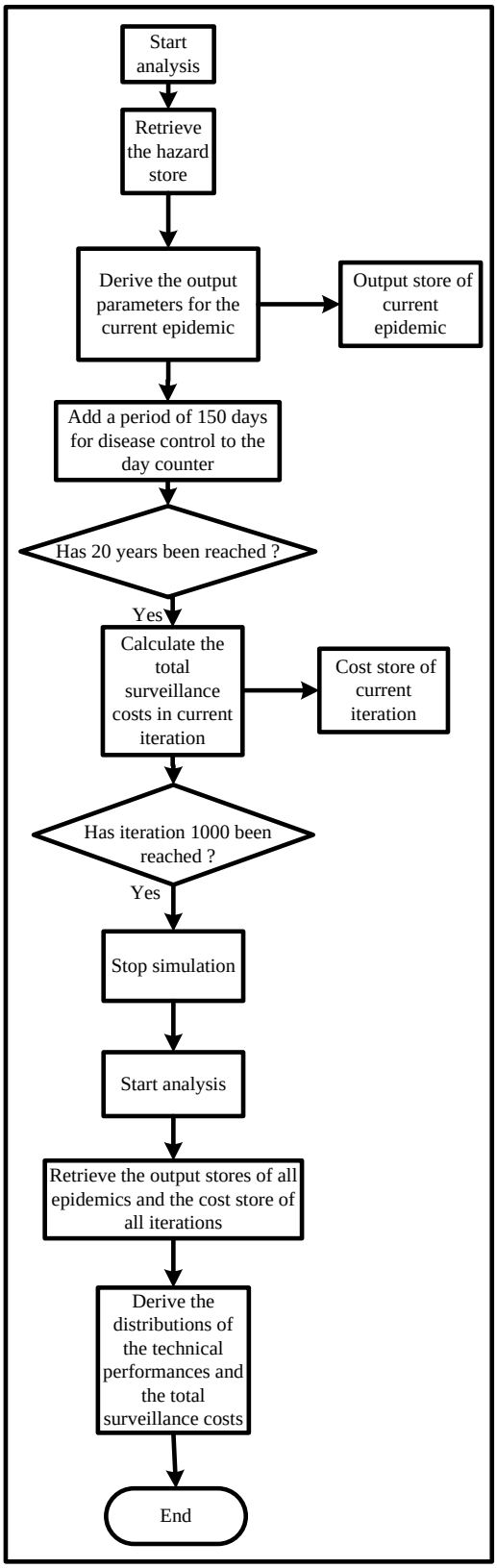

Fig. A18. The module of data analysis

Table A1

Daily probability of showing CSF-related symptoms for individual piglets infected by moderately virulent CSF

symptoms	Days post infection																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	References
	Daily probability of showing CSF-related symptoms for infected individuals																													
Clinical symptoms																														
Non-specific symptoms:																														
Fever	0	0	0	0	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	a, h , c, d, k
Apathy	0	0	0	0	0	0.09	0.19	0.24	0.29	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.64	0.59	0.54	0.49	0.44	0.39	0.34	0.29	0.24	0.19	0.14	0.09	0	c, d, k
Loss of appetite	0	0	0	0	0	0.08	0.18	0.23	0.28	0.33	0.38	0.43	0.48	0.53	0.58	0.63	0.63	0.58	0.53	0.48	0.43	0.38	0.33	0.28	0.23	0.18	0.13	0.08	0	c, d, k
Respiratory disease	0	0	0	0	0	0.07	0.17	0.22	0.27	0.32	0.37	0.42	0.47	0.52	0.57	0.62	0.62	0.57	0.52	0.47	0.42	0.37	0.32	0.27	0.22	0.17	0.12	0.07	0	k
Constipation	0	0	0	0	0	0	0.02	0.07	0.12	0.31	0.36	0.41	0.46	0.51	0.56	0.61	0.61	0.56	0.51	0.46	0.41	0.36	0.31	0.26	0.21	0.16	0	0	0	c, d, k
Diarrhoea	0	0	0	0	0	0	0	0.05	0.1	0.29	0.34	0.39	0.44	0.49	0.54	0.59	0.59	0.54	0.49	0.44	0.39	0.34	0.29	0.24	0.19	0.14	0	0	0	a, c, k
Death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.1	0.3	0.5	0.3	0.1	0.05	0	c, d, e, b, k
Suspicious symptoms:																														
Conjunctivitis	0	0	0	0	0	0	0	0	0	0.26	0.31	0.36	0.41	0.46	0.51	0.56	0.56	0.51	0.46	0.41	0.36	0.31	0.26	0.21	0.16	0.11	0	0	0	a, c, f, k
Skin haemorrhage	0	0	0	0	0	0	0	0	0	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0	0	0	a , c, e, f, k
Blue ear / tail	0	0	0	0	0	0	0	0	0	0.24	0.29	0.34	0.39	0.44	0.49	0.54	0.54	0.49	0.44	0.39	0.34	0.29	0.24	0.19	0.14	0.09	0	0	0	a , f, k
Hind leg weakness	0	0	0	0	0	0	0	0	0	0.23	0.28	0.33	0.38	0.43	0.48	0.53	0.53	0.48	0.43	0.38	0.33	0.28	0.23	0.18	0.13	0.07	0	0	0	c, d, f, k
Pathological findings																														
In blood:																														
Antigen/virus(infectious)	0	0	0	0	0.5	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9	0.5	0	c, d, g, k
Antibodies	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	0.84	0.89	0.93	0.95	0.97	0.98	1	j, k
In organs:																														
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0	0	0.37	0.42	0.47	0.52	0.52	0.47	0.42	0.37	0.32	0.27	0.22	0.17	0.12	0.05	0	0	0	k
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0.34	0.39	0.44	0.49	0.49	0.44	0.39	0.34	0.29	0.24	0.2	0.15	0.1	0.03	0	0	0	k
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0.36	0.41	0.46	0.46	0.41	0.36	0.31	0.26	0.21	0.18	0.13	0.08	0.01	0	0	0	k
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0.28	0.33	0.38	0.43	0.43	0.38	0.33	0.28	0.23	0.18	0.16	0.11	0.06	0	0	0	0	k

[a]Ribbens (2009)

[b]Weesendorp et al. (2009a)

[c]Dewulf et al. (2001a)

[d]Laevens et al. (1999)

[e]Uttenthal et al. (2003)

[f]Klinkerberg et al. (2005)

[g]Dewulf et al. (2001b)

[h]Weesendorp et al. (2009b)

[j]Colijn et al. (1997)

[k]expert opinion

Table A2

Daily probability of showing CSF-related symptoms for sows and slaughter pigs infected by moderately virulent CSF

symptoms	Days post infection																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Reference
	Daily probability of showing CSF-related symptoms for infected individuals																													
Clinical symptoms																														
Non-specific symptoms:																														
Fever	0	0	0	0	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0	a, h, c, d, k
Apathy	0	0	0	0	0	0	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.3	0.33	0.36	0.39	0.39	0.36	0.33	0.3	0.27	0.24	0.21	0.18	0.15	0.12	0.09	0	c, d, k
Loss of appetite	0	0	0	0	0	0	0.08	0.11	0.14	0.17	0.2	0.23	0.26	0.29	0.32	0.35	0.38	0.38	0.35	0.32	0.29	0.26	0.23	0.2	0.17	0.14	0.11	0.08	0	c, d, k
Respiratory disease	0	0	0	0	0	0	0.07	0.1	0.13	0.16	0.19	0.22	0.25	0.28	0.31	0.34	0.37	0.37	0.34	0.31	0.28	0.25	0.22	0.19	0.16	0.13	0.1	0.07	0	k
Constipation	0	0	0	0	0	0	0.02	0.05	0.08	0.11	0.14	0.17	0.2	0.23	0.26	0.29	0.32	0.32	0.29	0.26	0.23	0.2	0.17	0.14	0.11	0.08	0.05	0.02	0	c, d, k
Diarrhoea	0	0	0	0	0	0	0.01	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.3	0.3	0.27	0.24	0.21	0.18	0.15	0.12	0.09	0.06	0.03	0.01	0	a, c, k
Death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.05	0.15	0.3	0.15	0.05	0.03	0	c, d, e, b, k
Suspicious symptoms:																														
Conjunctivitis	0	0	0	0	0	0	0	0	0	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.16	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.03	0.01	0	a, c, f, k
Skin haemorrhage	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.15	0.15	0.14	0.12	0.1	0.08	0.06	0.04	0.02	0	0	a , c, e, f, k
Blue ear / tail	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.14	0.14	0.13	0.11	0.09	0.07	0.05	0.03	0	0	0	a , f, k
Hind leg weakness	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0.06	0.08	0.1	0.12	0.13	0.13	0.12	0.1	0.08	0.06	0.04	0	0	0	0	c, d, f, k
Pathological findings																														
In blood:																														
Antigen/virus(infectious)	0	0	0	0	0	0	0.5	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9	0.5	0	c, d, g, k
Antibodies	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	0.84	0.89	0.93	0.95	0.97	0.98	1.00	j, k
In organs:																														
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0.05	0.07	0.09	0.11	0.12	0.12	0.11	0.09	0.07	0.05	0	0	0	0	0	k
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0.06	0.08	0.1	0.11	0.11	0.1	0.08	0.06	0.04	0	0	0	0	0	k
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0.05	0.07	0.09	0.1	0.1	0.09	0.07	0.05	0.03	0	0	0	0	0	k
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0.06	0.08	0.09	0.09	0.08	0.06	0.04	0.02	0	0	0	0	0	k

[a]Ribbens (2009)

[b]Weesendorp et al. (2009a)

[c]Dewulf et al. (2001a)

[d]Laevens et al. (1999)

[e]Uttenthal et al. (2003)

[f]Klinkerberg et al. (2005)

[g]Dewulf et al. (2001b)

[h]Weesendorp et al. (2009b)

[j]Colijn et al. (1997)

[k]expert opinion

Table A3

Daily probability of showing CSF-related symptoms for individual piglets infected by low virulent CSF

symptoms	Days post infection																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Reference
	Daily probability of showing CSF-related symptoms for infected individuals																													
Clinical symptoms																														
Non-specific symptoms:																														
Fever	0	0	0	0	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.2	0.2	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0	0	0	a, b, c, g, k
Apathy	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0	0	0	a, b, c, g, k
Loss of appetite	0	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0	0	0	a, b, c, g, k
Respiratory disease	0	0	0	0	0	0	0	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0	0	0	a, b, c, g, k
Constipation	0	0	0	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0	0	0	a, b, c, g, k
Diarrhoea	0	0	0	0	0	0	0	0	0	0.09	0.1	0.11	0.12	0.13	0.14	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0	0	0	a, b, c, g, k
Death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	d, e, k
Suspicious symptoms:																														
Conjunctivitis	0	0	0	0	0	0	0	0	0	0.06	0.07	0.08	0.09	0.1	0.11	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0	0	0	a, b, c, g, k
Skin haemorrhage	0	0	0	0		0	0	0	0	0.05	0.06	0.07	0.08	0.09	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	a, b, c, g, k
Blue ear / tail	0	0	0	0	0	0	0	0	0	0.04	0.05	0.06	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	a, b, c, g, k
Hind leg weakness	0	0	0	0	0	0	0	0	0	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	0	a, b, c, g, k
Pathological findings																														
In blood:																														
Antigen/virus(infectious)	0	0	0	0	0.2	0.22	0.24	0.26	0.28	0.3	0.32	0.34	0.36	0.38	0.4	0.4	0.38	0.36	0.34	0.32	0.3	0.28	0.26	0.24	0.22	0.2	0	0	0	a, b, k
Antibodies	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	0.84	0.89	0.93	0.95	0.97	0.98	1.00	f, k
In organs:																														
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0.07	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	0	0	k
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.03	0.04	0.04	0.03	0.02	0.01	0	0	0	0	0	0	0	0	0	0	k
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	k
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	k

[a]Weesendorp et al. (2009a)

[b]Weesendorp et al. (2009b)

[c]Floegel-Niesmann et al. (2003)

[d]Terpstra (1991)

[e]Liess (1988)

[f]Colijn et al. (1997)

[g]Mittelholzer et al. (2000)

[k]expert opinion

Table A4

Daily probability of showing CSF-related symptoms for sows and slaughter pigs infected by low virulent CSF

symptoms	Days post infection																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	29	Reference
	Daily probability of showing CSF-related symptoms for infected individuals																													
Clinical symptoms																														
Non-specific symptoms:																														
Fever	0	0	0	0	0	0	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.2	0.2	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0	a, b, c, g, k
Apathy	0	0	0	0	0	0	0.09	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0	a, b, c, g, k
Loss of appetite	0	0	0	0	0	0	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0	a, b, c, g, k
Respiratory disease	0	0	0	0	0	0	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0	a, b, c, g, k
Constipation	0	0	0	0	0	0	0	0	0	0	0	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0	a, b, c, g, k
Diarrhoea	0	0	0	0	0	0	0	0	0	0	0	0.09	0.1	0.11	0.12	0.13	0.14	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0	a, b, c, g, k
Death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	d, e, k
Suspicious symptoms:																														
Conjunctivitis	0	0	0	0	0	0	0	0	0	0	0	0.06	0.07	0.08	0.09	0.1	0.11	0.11	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0	a, b, c, g, k
Skin haemorrhage	0	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0.07	0.08	0.09	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	a, b, c, g, k
Blue ear / tail	0	0	0	0	0	0	0	0	0	0	0	0.04	0.05	0.06	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	a, b, c, g, k
Hind leg weakness	0	0	0	0	0	0	0	0	0	0	0	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	a, b, c, g, k
Pathological findings																														
In blood:																														
Antigen/virus(infectious)	0	0	0	0	0	0	0.2	0.22	0.24	0.26	0.28	0.3	0.32	0.34	0.36	0.38	0.4	0.4	0.38	0.36	0.34	0.32	0.3	0.28	0.26	0.24	0.22	0.2	0	a, b, k
Antibodies	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.16	0.23	0.33	0.44	0.56	0.67	0.77	0.84	0.89	0.93	0.95	0.97	0.98	1.00	f, k
In organs:																														
Tonsil lesions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0.07	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	k
Spleen infarction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.03	0.04	0.04	0.03	0.02	0.01	0	0	0	0	0	0	0	0	k
Enlargement of lymph node	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	k
Internal bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	k

[a]Weesendorp et al. (2009a)

[b]Weesendorp et al. (2009b)

[c]Floegel-Niesmann et al. (2003)

[d]Terpstra (1991)

[e]Liess (1988)

[f]Colijn et al. (1997)

[g]Mittelholzer et al. (2000)

[k]expert opinion

Chapter 5

Economic optimization of the pig-hazard surveillance portfolio in a Dutch food company

Xuezhen Guo, G.D.H. Claassen, H.J. Wisselink, A.G.J.M. Oude Lansink, H.W. Saatkamp

Abstract

Traditional research treats livestock hazard surveillance as a single-hazard surveillance optimization problem. The single-hazard perspective fails to find the optimal surveillance resource allocation within a surveillance organization. To solve this problem, we have developed a novel conceptual framework that uses a surveillance portfolio perspective to guide surveillance resource allocation. This paper aims to apply that framework to a case study where a Dutch food company tries to optimize its pig-hazard surveillance portfolio in the slaughterhouses. This study, on the one hand, vividly shows that livestock hazard surveillance should be conducted from a portfolio point of view because it can increase the efficiency of the surveillance activities in a surveillance organization. On the other hand, it also demonstrates the difficulty in applying the surveillance-portfolio conceptual framework due to the limitation of the data.

Keywords: Livestock hazard surveillance; surveillance portfolio; surveillance resource allocation

5.1 Introduction

Resources available to conduct livestock hazard surveillance in general are becoming more and more limited (Stärk et al., 2006). As a result, increasing demands are posed on surveillance organizations to improve the cost-effectiveness of their surveillance activities. In practice, surveillance organizations often have multiple hazards to survey which compete for the same limited surveillance resources; hence, the resource allocation problem should be tackled from a surveillance portfolio (SP) point of view instead of single hazard surveillance system (SHSS) (Prattley et al., 2007; Prattley et al., 2009; Guo et al., 2014c). In additions, since the decision maker may have different preferences on various types of impacts mitigated by hazard surveillance (e.g. reduced economic losses, reduced human health influence, etc.), stakeholder's valuation of such impacts must be incorporated into the analysis.

A Dutch food company provides services in pig slaughtering and pork processing. To ensure food safety, currently the company conducts surveillance activities on a portfolio of pig hazards, including Swine Vesicular Disease (SVD), Aujeszky's Disease (AD), Salmonella, Toxoplasma and Mycobacterium avium (MA). Routine serological surveillance is conducted in the slaughterhouses of that company with various sampling surveillance setups, subject to a

certain level of annual surveillance budget. However, due to the lack of quantitative decision support tool, the previously applied serological sampling scheme was arbitrarily determined, which is not scientifically sound.

Towards an improved serological surveillance performance in the aforementioned Dutch food company, this paper conduct a model-based analysis of the company's pig-hazard SP, based on the conceptual framework described by Guo et al. (2014c), aiming at optimizing the surveillance resource allocation among competing hazards to maximize the total performance of the pig-hazard SP.

5.2 Material and Method

5.2.1. The surveillance portfolio optimization model

The original SP optimization model has been developed in Guo et al. (2014c) to solve the multi-stakeholder, multi-criteria SP optimization problem. Since the pig-hazard case only has one stakeholder (i.e. the Dutch food company), the original model can be deduced to a single-stakeholder model as follows:

$$Max\ PV\ = (w_1 \quad \cdots \quad w_I) \times \begin{pmatrix} v_1(X) \\ \vdots \\ v_I(X) \end{pmatrix} \tag{1}$$

s.t. various constraints, such as

$\sum_{s=1}^{S_h} x_{h,s} \leq 1$ for all h, (2)

$\sum_{h=1}^{H} \sum_{s=1}^{S_h} c_{h,s} x_{h,s} \leq B$, (3)

$x_{h,s} \in (0, 1)$ for all h, s (4)

where

PV is the surveillance portfolio performance;

$(w_1 \quad \cdots \quad w_I)$ are the weights on HIIs 1 to I;

$\begin{pmatrix} v_1(X) \\ \vdots \\ v_I(X) \end{pmatrix}$ is the vector of the standardized portfolio performances (SPP) on all HIIs;

$v_i(X)$ is the standardized portfolio performance on indicator i, given X.

X is the decision variable matrix of $x_{h,s}$.

$x_{h,s}$ denotes the binary *decision variable* to judge whether, for hazard h, surveillance setup s is selected to compose the SP.

S_h denotes the number of the alternative surveillance setups for hazard h.

B denotes the total annual budget available to carry out the surveillance activities.

$c_{h,s}$ is the annual surveillance costs for hazard h, when surveillance setup s is implemented.

The set of constraints (2) ensure that a maximum of one surveillance setup for each hazard will be included in the SP; constraints (3) ensure that the total annual surveillance costs for stakeholder group g cannot exceed the annual available surveillance budget; and definitions (4) defines $x_{h,s}$ as binary variables. Additional constraints are considered in this paper including the minimum required surveillance performance constraint and legal obligation constraints.

5.2.2. Farms and animals

In this study, three types of pig farms are considered, which are the farrowing farms, the finishing farms and farrow-to-finish farms. The detailed distributions of the farms and animals on them are estimated based on a database of Dutch pig farms in 2010 (provided by Dutch Animal Health Service), combined with expert options (see Table 5.1).

Table 5.1
The distribution of farms and animals (averages) estimated from the Dutch pig farm database 2010 provided by the Animal Health Service

Farm type	Number of farms	Number of animals		
		Piglet	Sow	Hog
Farrowing	2300	2000	400	0
Finishing	5000	0	0	830
Farrow-to-finish	360	1090	220	800

It is also estimated from the same database that there are about half of the finishing and farrow-to-finish farms that submit pigs to the slaughterhouses of the Dutch food company. Therefore, approximately 2500 finishing farms and 180 farrow-to-finish farms submit pigs to the company's slaughterhouses. In practice, the farrowing farms can also send old sows for slaughtering. However, compared to the submission frequency of the slaughter pigs, the frequency for the farrowing farms to submit the old sows to slaughterhouses is relatively low and will have a minimal impact on the performances of surveillance systems. Hence, the submissions of old sows from the farrowing farms to the slaughterhouses of the Dutch food company are disregarded in the model.

5.2.3. The single hazard analysis model

SVD and AD are the zero-prevalence diseases: the diseases that do not exist in the Netherlands at the moment. Guo et al. (2014b) adapted the SHSS analysis framework described by Guo et al. (2014a) to develop the surveillance simulation model for classical swine fever (CSF) which is another typical zero-prevalence disease for the Netherlands. In this work, the same surveillance simulation model is re-parameterized to analyse the SVD and AD surveillance. The technical surveillance performances for SVD and AD are (1) the duration of high risk period (HRP) and (2) the number of infected farms at the end of HRP. For SVD, the within- and between-farm transmission parameters are β_w =0.52 per infectious animal per day and β_b=0.0017 per infectious animal per day respectively (Eisinger, 2012). For AD, they are β_w =0.1 per infectious animal per day (De Jong and Kimman, 1994) and β_{b1}=0.0012[7] (Local spread) and β_{b1}=0.0015 (transport spread) per infectious animal per day. The SVD and AD expression matrices for disease symptom modelling in individual animals are presented in Appendix (Table 1A, Table 2A, Table 3A and Table 4A). These matrices were constructed by combining literature studies with expert opinions.

Salmonella, Toxoplasma and MA are the diseases that currently exist in the Netherlands. The technical surveillance performance for them is measured by the "herd-level sensitivity" for detecting the positive farms. Van der Wolf et al. (2001) shows that the distribution of herd prevalence of salmonella for Dutch pig farms is close to exponential distribution with the mean 15.4% (Van der Wolf et al., 2001). Therefore, the exponential distribution is used to generate the starting situation of salmonella for the Netherlands. The transmission parameter for salmonella refers to Correia-Gomes et al. (2014), which equals to 0.22 per animal per week (i.e. 0.44 per animal per two weeks). The expression matrices for salmonella are constructed based on Nielsen et al. (1995) and Calveyra et al. (2011), combined with expert opinions, and are presented in Appendix (Table 5A). The prevalence of Toxoplasma and MA in slaughter pigs are 3% (Meerburg et al., 2006) and 1% (Hiller et al. 2013) respectively. Exponential distributions with the means 3% and 1% are also used to generate the starting situations of Toxoplasma and MA. The used within-farm transmission parameter for Toxoplasma is 0.02 per infectious animal per week (Aranda et al., 2008). The within-farm

[7]The transmission parameters for AD should be smaller than that for CSF (Personal contact with a CSF expert). The within farm transmission parameter for AD (β_w =0.1) is about half of the size for CSF (β_w =0.21 in Klinkenberg et al. (2005)). Hence, the between farm transmission parameter is also assumed half of the size for CSF. Since Klinkenberg, et al. (2005) estimate that β_{b1} and β_{b2} are 0.0024 and 0.0029 per infectious animal per day, the between farm transmission parameters is assumed 0.0012 (local spread) and 0.0015 (transport spread) per infectious animal per day.

transmission parameter for MA is assumed following uniform distribution [0, 0.67] per infectious animal per week. The expression matrices for MA and Toxoplasma are constructed by combining literature data with expert opinions (Table 6A and Table 7A).

5.2.4. Investigated surveillance setups

The investigated surveillance setups for each hazard are presented in Table 5.2.

Table 5.2
The investigated surveillance setups

SVD (blood samples per herd per trimester)	AD (blood samples per herd per trimester)	Salmonella (blood samples per herd per year)	MA (blood samples per herd per year)	Toxoplasma (blood samples per herd per year)
0	0	0	0	0
3	**3**	12	10	10
		24	20	20
		36	30	30
		72	**45**	**45**
		108	60	60
			75	75

The surveillance setups in bold are currently applied by the company

The surveillance setups currently applied by the company are marked in bold. Each surveillance setup for each hazard is investigated by the single hazard analysis model which delivers the technical surveillance performance and annual surveillance costs. Based on the derived technical surveillance performances and annual surveillance costs for each surveillance setup, an efficient set of surveillance setups can be obtained for each hazard (See Guo et al., 2014a).

5.2.5. Input derivation for the surveillance portfolio optimization model

Regardless of the types of technical surveillance performances, each hazard causes impacts (e.g. economic impacts, food safety impacts, etc.), and the implementation of a SP can mitigate these impacts which are the benefits delivered by that SP. Therefore, estimating and valuating the impacts under each potential SP based on the corresponding technical surveillance performances is the prerequisite for SP optimization (i.e. providing the inputs for the SP optimization model). Below are the two steps we follow for impact estimation and valuation:

Step 1: By consulting surveillance managers in the Dutch food company, four hazard impact indicators (HII) are identified to measure the impacts of the hazards, including "Economics", "Animal Health and Welfare", "Food Safety" and "Consumer and Customer Trust". The surveillance managers also give the weights to each HII to reflect their relative importance, and the summation of the weights of all indicators is equal to 1 (See: Table 5.3).

Step 2: To estimate the impact parameters on each of the four HIIs under each surveillance setup for each hazard, theoretically, hazard impact simulation models such as the model of Hop et al. (2014) should be used. However, there are no such models for the five hazards considered in this work, and developing those models is extremely laborious. Considering the time and resource limitations, we decided to use a shortcut way described in (Guo et al., 2014c) to estimate the impact parameters, namely, asking three relevant disease experts to estimate the impact parameters based on the obtained technical performances from the single hazard surveillance analysis. Since it is very difficult for the experts to come up with absolute numbers on HIIs, the experts are asked to give category-based impact parameters from 0 to 100, where 0 indicates the worst performance on a HII and 100 indicates the best performance (See: Table 5.3).

5.2.6. Sensitivity analysis

As is shown in previous sections, there are quite some uncertainties associated with the surveillance portfolio optimization model's inputs such as the impact parameters and weights to HIIs. Hence, sensitivity analysis is conducted on those parameters to check how robust the results of the model are. The investigated model parameters are suggested by the experts and stakeholders including (1) the legal constraints for SVD and AD (i.e. each farm is obligatory to have 3 blood samples tested per trimester by law), (2) the stakeholder's weights[8] to each HII and (3) the uncertain impact parameters on HIIs according to the experts.

5.3 Results

5.3.1. Results under the default setting

The results from the first-stage analysis under the default setting are presented in Table 5.3 which provides the inputs for the surveillance portfolio optimization model. The currently implemented surveillance setups and alternative surveillance setups are listed. The currently implemented surveillance setups are marked in bold. For each surveillance setup of each hazard, items are listed including the annual surveillance costs, technical surveillance performances, hazard impact parameters estimated by three disease experts, and the weights to each HII assigned by the stakeholder (i.e. the food company).

[8] The investigated parameter space is suggested by the stakeholder.

Table 5.3
The first-stage results for each surveillance setup of each hazard under the default setting

Potential surveillance setups for each hazard	Annual surveillance costs (K€)	Technical surveillance performances (medians)	Hazard Impact Parameters (0 - 100)			
			Economics (50%)	Animal health and welfare (20%)	Food safety (25%)	Consumer and customer trust (5%)
SVD						
(1) 0 blood sample per herd per trimester	0	HRP: 36 days, infected farms: 6	50	50	0	55
(2) 3 blood samples per herd per trimester	147	HRP: 36 days, infected farms: 6	50	50	0	55
AD						
(1) 0 blood sample per herd per trimester	0	HRP: 47 days, infected farms: 4	60	60	0	55
(2) 3 blood samples per herd per trimester	130	HRP: 47 days, infected farms: 4	60	60	0	55
Salmonella						
(1) 0 blood samples per herd per year	0	Herd-level Sensitivity 0	0	0	0	0
(2) 12 blood samples per herd per year	170	Herd-level Sensitivity 0.59	80	75	5	85
(3) 24 blood samples per herd per year	341	Herd-level Sensitivity 0.71	90	86	10	93
(4) 36 blood samples per herd per year	511	Herd-level Sensitivity 0.76	94	95	20	96
(5) 72 blood samples per herd per year	1023	Herd-level Sensitivity 0.77	95	96	35	97
(6) 108 blood samples per herd per year	1534	Herd-level Sensitivity 0.82	97	98	60	98
MA						
(1) 0 blood samples per herd per year	0	Herd-level Sensitivity 0	0	0	0	0
(2) 10 blood samples per herd per year	214	Herd-level Sensitivity 0.17	0	0	2	60
(3) 20 blood samples per herd per year	429	Herd-level Sensitivity 0.31	50	0	5	76
(4) 30 blood samples per herd per year	643	Herd-level Sensitivity 0.41	58	0	8	86
(5) 45 blood samples per herd per year	965	Herd-level Sensitivity 0.52	64	0	12	93
(6) 60 blood samples per herd per year	1286	Herd-level Sensitivity 0.61	71	0	15	96
(7) 75 blood samples per herd per year	1608	Herd-level Sensitivity 0.67	76	0	25	98
Toxoplasma						
(1) 0 blood samples per herd per year	0	Herd-level Sensitivity 0	0	0	0	0
(2) 10 blood samples per herd per year	67	Herd-level Sensitivity 0.32	55	0	5	65
(3) 20 blood samples per herd per year	134	Herd-level Sensitivity 0.50	67	0	10	85
(4) 30 blood samples per herd per year	201	Herd-level Sensitivity 0.60	73	0	15	90
(5) 45 blood samples per herd per year	302	Herd-level Sensitivity 0.71	81	0	23	94
(6) 60 blood samples per herd per year	402	Herd-level Sensitivity 0.75	83	0	30	95
(7) 75 blood samples per herd per year	503	Herd-level Sensitivity 0.80	87	0	40	97

The results from the second-stage analysis with the surveillance portfolio optimization model are presented in Figure 5.1.

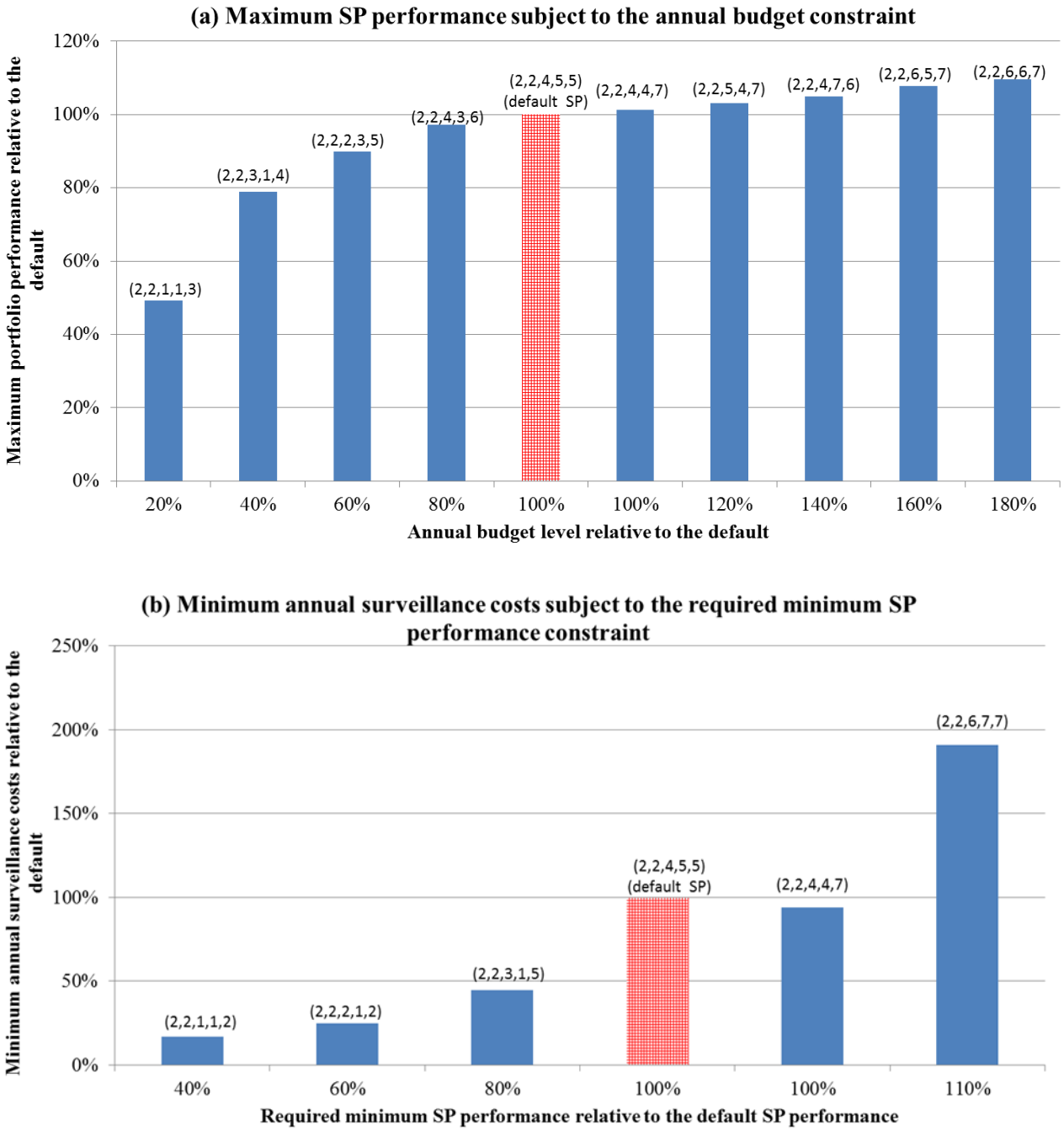

Fig. 5.1. The analytical results under the default setting.

Graph (a) of Figure 5.1 presents SPs that ensure the maximum portfolio performance (relative to the performance delivered by the default SP) subject to various annual budget levels (relative to the default annual budget level). Graph (b) just shows the opposite, namely, the

SPs that ensures the minimum annual surveillance costs (relative to the default annual budget level) subject to various minimum required SP performances (relative to the performance delivered by the default SP).

Graph (a) of Figure 5.1 shows that the alternative SP (2,2,4,3,6) can almost ensure the same SP performance as the default SP (2,2,4,5,5) but only require 80% of the annual default budget. The difference is caused by reducing the surveillance intensity for MA (from surveillance setup 5 to 3) and using the saved money to intensify the surveillance for Toxoplasma (from surveillance setup 5 to 6). It is also shown that even though reducing the budget to 20% of the default, it can still maintain around 50% of the default SP performance (see SP(2,2,1,1,3)). Moreover, even if increasing the budget to 180% of the default, the corresponding maximum SP performance is just 110% of the default SP performance (see SP (2,2,6,6,7)). In general, Graph (a) of Figure 5.1 demonstrates diminishing returns of the SP performance to every additional level of budget.

Graph (b) of Figure 5.1 shows that maintaining the default SP performance actually only requires about 95% of the default annual budget (see SP (2,2,4,4,7)). If increasing the required minimum SP performance to 110% of the default, then it requires about 190% of the default annual budget (see SP (2,2,6,7,7)). If reducing the minimum SP performance to 40% of the default, the required annual budget only equals 17% of the default. In general, Graph (b) of Figure 5.1 exhibits an increasing annual-budget requirement for every additional level of required minimum SP performance.

5.3.2. Results of the sensitivity analysis

The results of the sensitivity analysis are presented in Figure 5.2, 5.3, 5.4, 5.5, 5.6, 5.7.

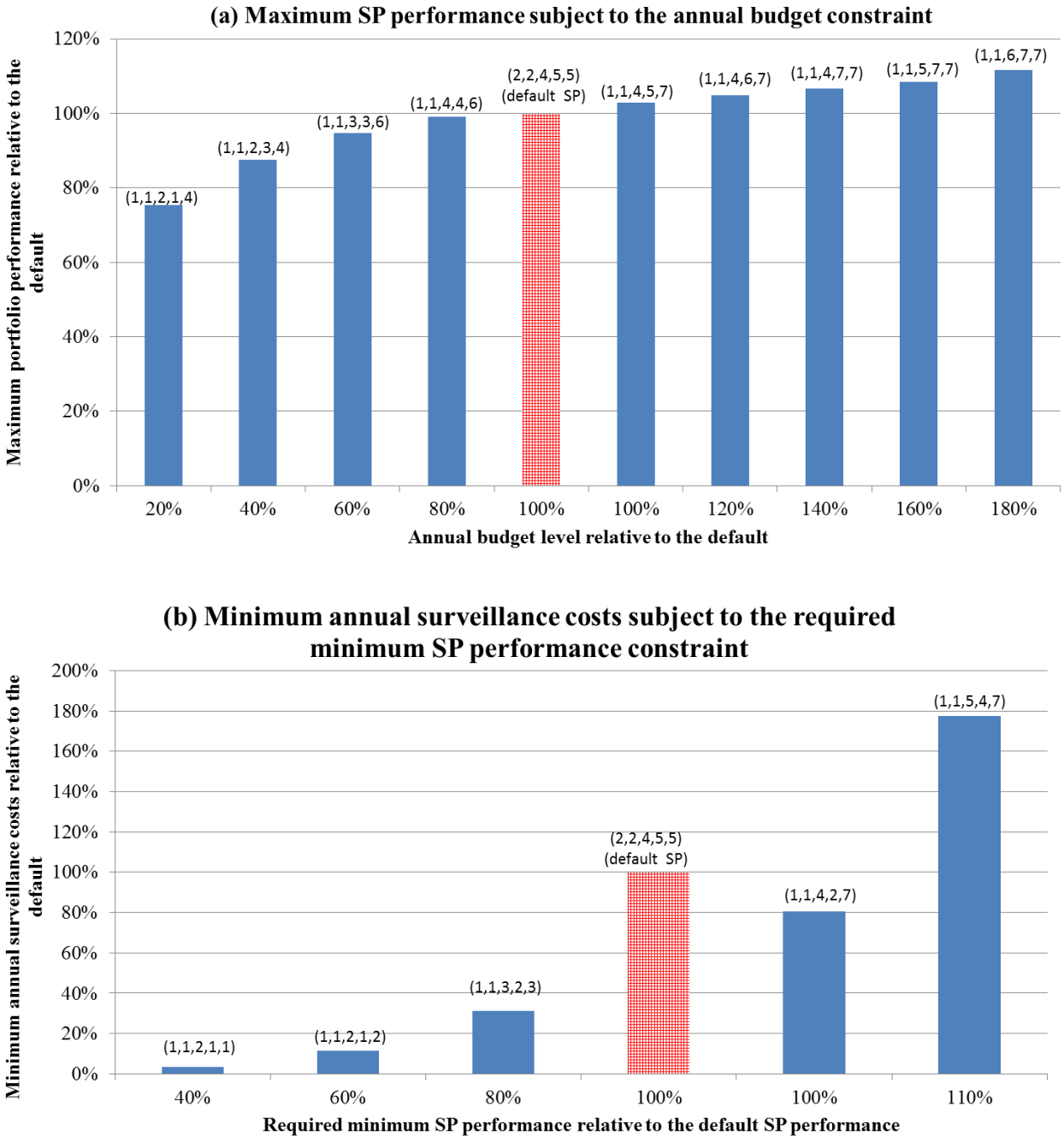

Fig.5.2. The sensitivity analysis results when the legal constraints for SVD and AD are relaxed.

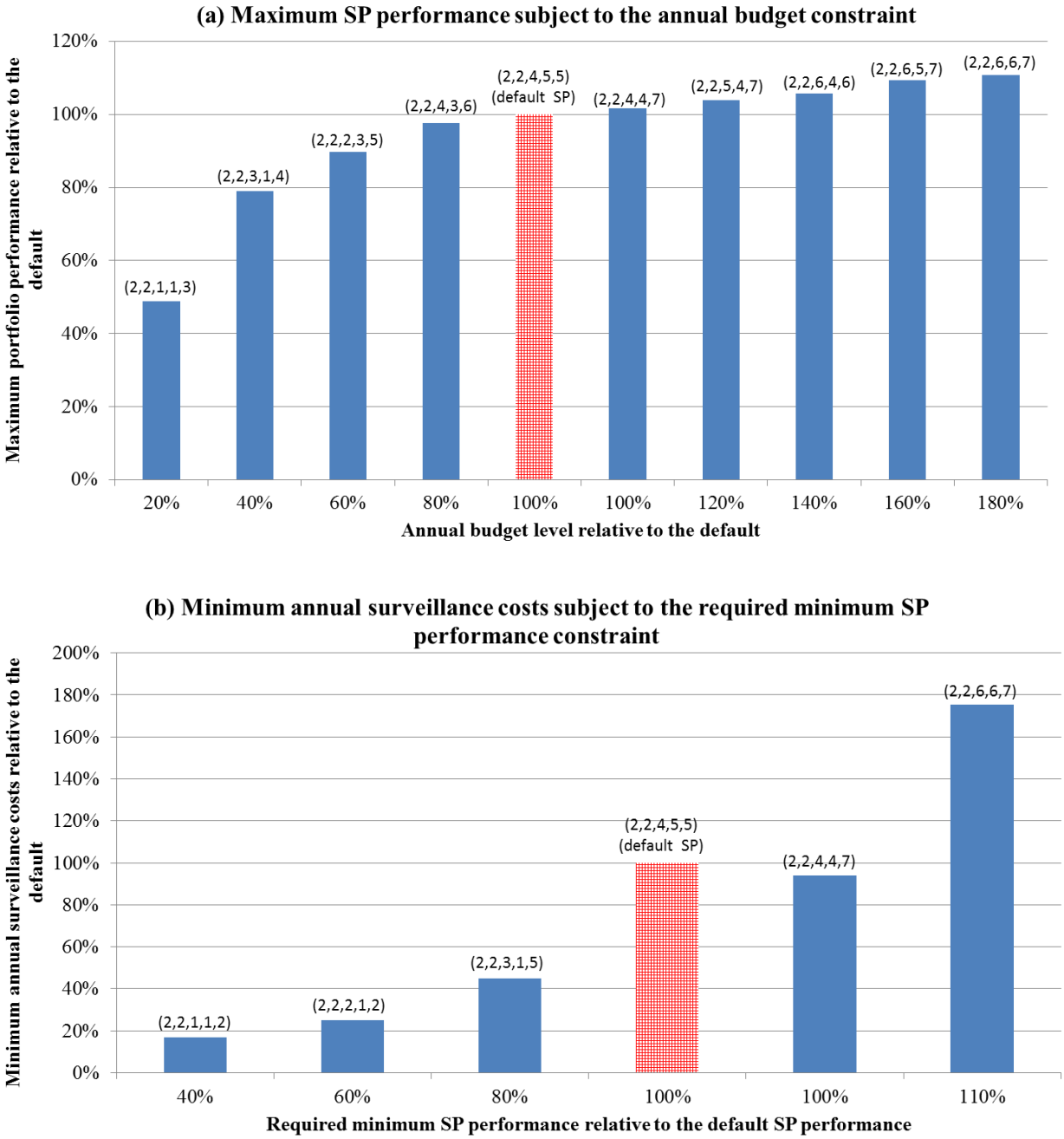

Fig. 5.3. The sensitivity analysis results when the stakeholder's weights on HIIs are changed to: Economics (0.3), Animal health and welfare (0.25), Food safety (0.3) and Consumer and customer trust (0.15).

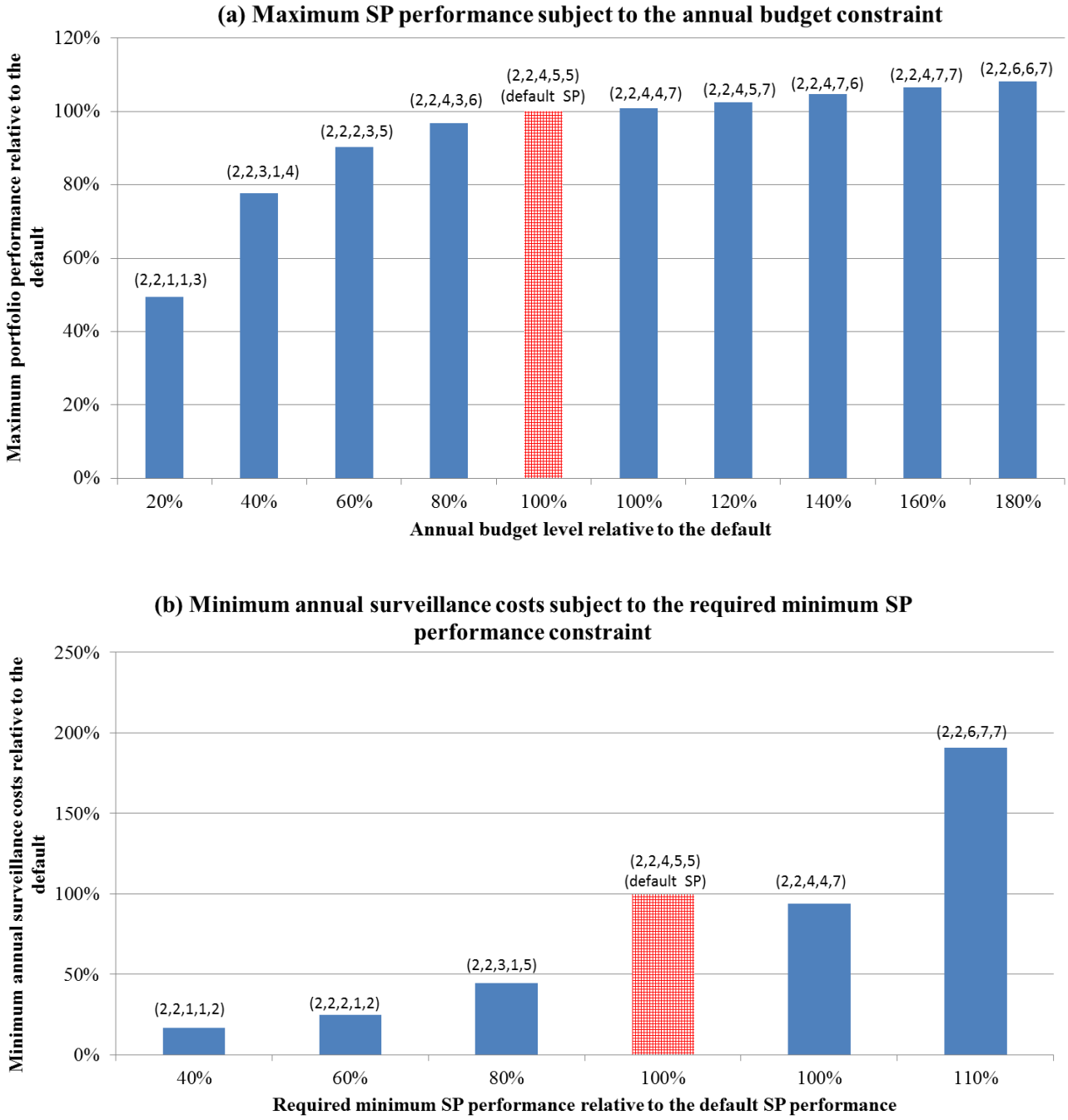

Fig. 5.4. The sensitivity analysis results when the stakeholder's weights on HIIs are changed to: Economics (0.7), Animal health and welfare (0.08), Food safety (0.2) and Consumer and customer trust (0.02).

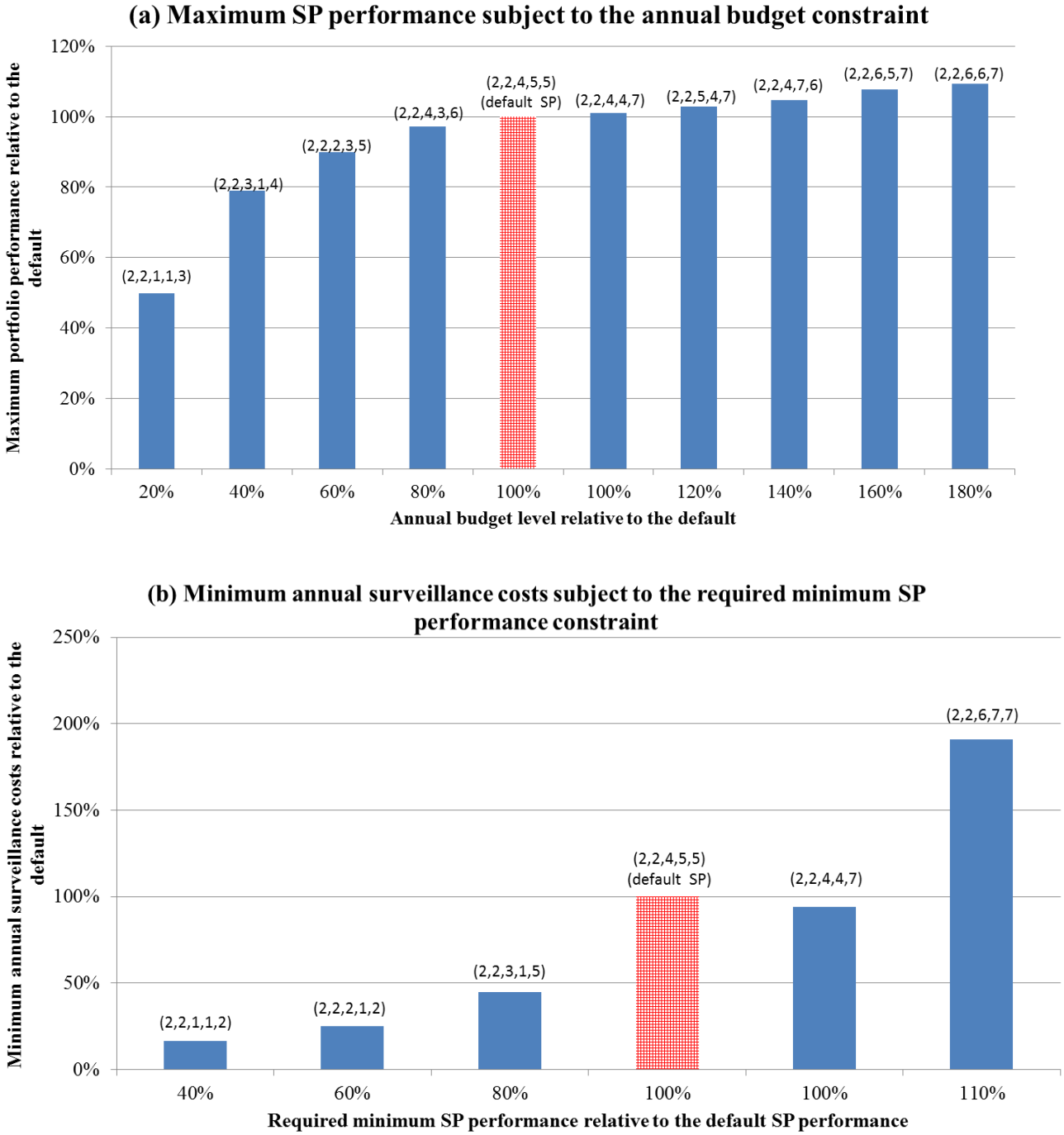

Fig. 5.5. The sensitivity analysis results when the impact parameters on the HII "Consumer and customer trust" for SVD changed to: surveillance setup 1 (80), surveillance setup 2 (80); for AD, they are changed to: surveillance setup 1 (85), surveillance setup 2 (85).

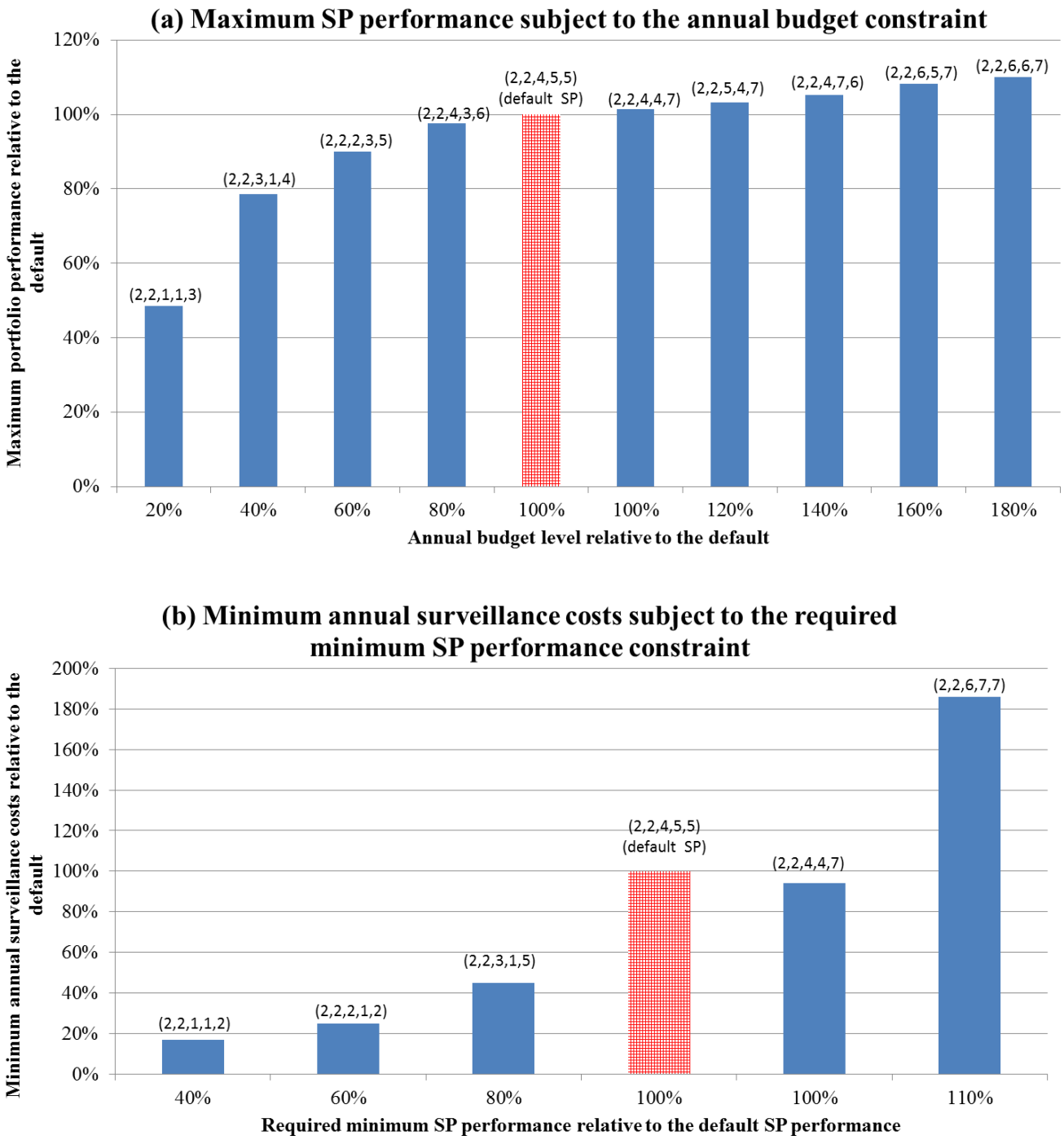

Fig. 5.6. The sensitivity analysis results when the impact parameters on the HII "Consumer and customer trust" for SVD changed to: surveillance setup 1 (5), surveillance setup 2 (5); for AD, they are changed to: surveillance setup 1 (15), surveillance setup 2 (15).

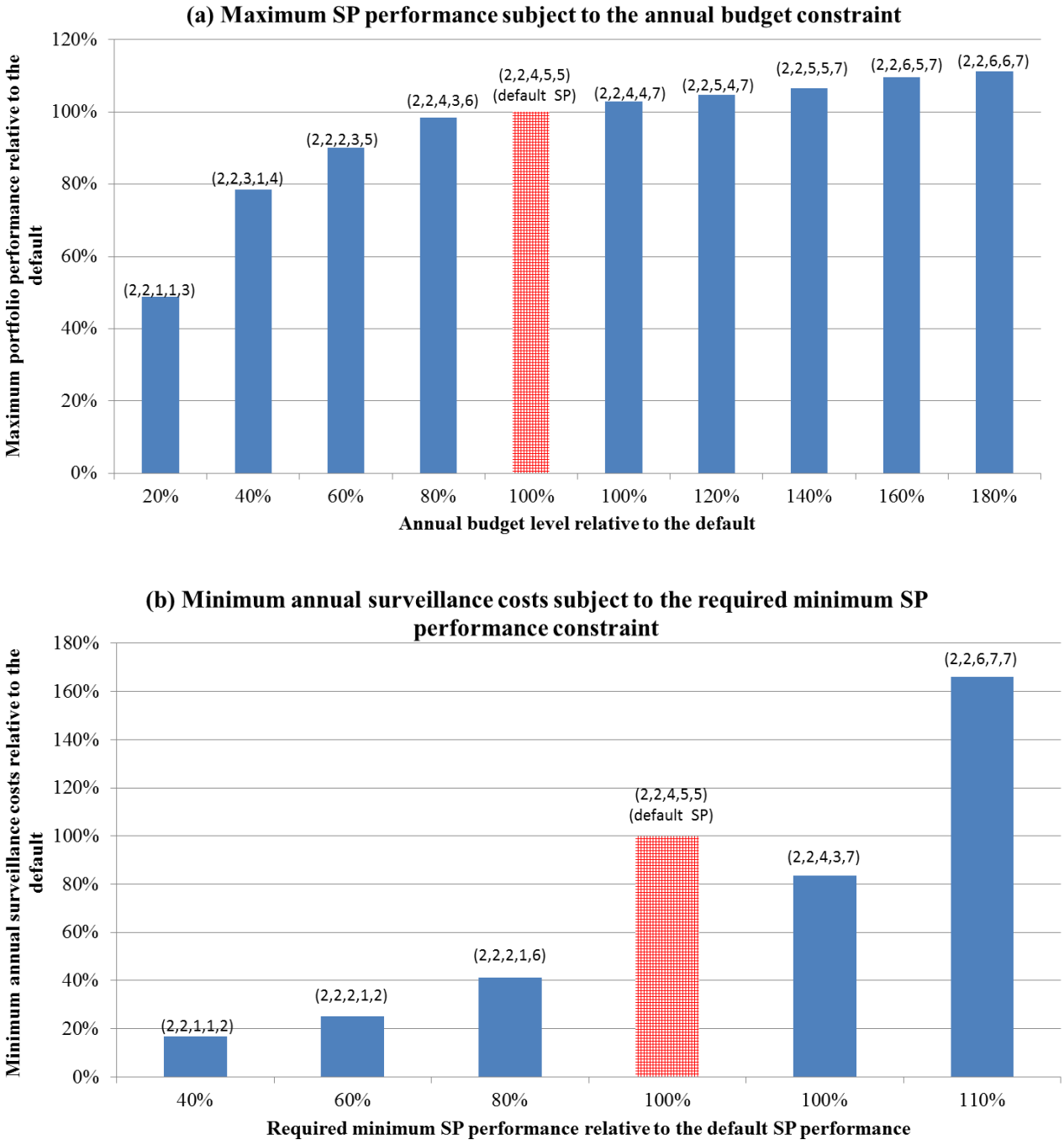

Fig. 5.7. The sensitivity analysis results when the impact parameters on the HII "food safety" for Toxoplasma changed to: surveillance setup 1 (0), surveillance setup 2 (5), surveillance setup 3 (10), surveillance setup 4 (20), surveillance setup 5 (35), surveillance setup 6 (53), surveillance setup 7 (70).

The results in Figure 5.2 show that the elimination of legal constraints for SVD and AD will result in the switches to the SPs all containing the first surveillance setups for SVD and AD (i.e. do not conduct serological surveillance for SVD and AD). The maximum SP performances for certain levels of budget become larger than that under the default setting (i.e. with the legal constraints for SVD and AD). Correspondingly, the minimum annual surveillance costs to maintain certain levels of required minimum SP performance become smaller than that under the default setting. Changing stakeholder' weights to HIIs does not have obvious impacts on the results compared to those in the default setting (see Figure 5.3 and 5.4). This is because in this specific case, the estimated impact parameters on HIIs are highly correlated between indicators. The changes of the uncertain impact parameters also do not have big impacts on the outlook of the graphs (see Figure 5.5, 5.6 and 5.7), which demonstrates the robustness of the modelling results.

5.4 Discussion and conclusion

5.4.1 Content of this study

This study extends the current body of SP optimization literature (Prattley et al., 2007; Prattley et al., 2009) by considering the stakeholder's valuation of surveillance outcomes according to various hazard impact indicators (HIIs). The SP conceptual framework in Guo et al (2014c) is adapted to conduct the optimization analysis of a pig-hazard SP operated by a Dutch food company.

The modelling results clearly demonstrate the non-optimum situation of the current pig-hazard SP in the Dutch food company due to the fact that the food company can improve the SP performance without increasing the annual surveillance budget or decrease the annual surveillance costs without scarifying the SP performance. This demonstrates the usefulness of applying the SP optimization framework for surveillance resource allocations. Moreover, the investigated pig-hazard SP exhibits diminishing returns of surveillance performance to every additional level of annual budget (i.e. surveillance performance is easier to improve when its value is low but harder to improve when its value is high). Consistently, it also exhibits increasing annual-budget requirement for every additional level of required minimum SP performance.

5.4.2 Modelling approach

The general modelling approach used in this work is the SP optimization model developed based on the SP optimization framework proposed by Guo et al. (2014c). Before running the SP optimization model, its inputs should be derived using the single hazard surveillance simulation models adapted from the single hazard analysis framework developed by Guo et al. (2014a). The theoretical appropriateness of both the single hazard and the SP frameworks has been extensively discussed in Guo et al. (2014a,c). The single hazard analysis framework has been adapted to analyze the CSF surveillance in the Netherlands (Guo et al. 2014b), which demonstrates the practical appropriateness of the single hazard analysis framework.

5.4.3 Limitations

There are several limitations associated with this research. The biggest limitation is caused by the lack of data for parameterizing the single hazard surveillance simulation model as well as the SP optimization model. Since the epidemiological data, such as disease transmission parameters and the data to construct the hazard expression matrices, are not rich in the literature, we need to make approximations and rely on relevant experts' opinions. An even bigger problem is to estimate the impact parameters on HIIs based on the derived technical surveillance performance for each surveillance setup. For the hazards investigated in the pig-hazard portfolio, it has been already very hard to find adequate experts to make the estimations, not even to mean to construct expert panel for more sophisticated analysis (e.g. Delphi analysis). Moreover, due to the time and resource limitations, the single hazard simulation models were constructed in a simplified way because adapting and parameterizing five single hazard surveillance models in such a way has been already extremely laborious. The highly simplifications of the modelling process inevitably brings in some bias to the model's results.

5.4.4 Conclusions

Although this is a more theoretical-oriented work, we can still draw useful conclusions from it. The first conclusion we can draw is that surveillance organizations should really use a portfolio perspective to guide their surveillance resource allocation because the case clearly shows that arbitrarily allocating surveillance costs can cause efficiency losses (either in terms of higher surveillance costs or low SP performance). Furthermore, eliminating legal constraints for some hazards in a SP may result in higher SP performance. Finally, the

robustness of the results (with regard to the stakeholder's weights to HIIs) given the high correlations of impact parameters between HIIs implies that under such a situation, it will not be necessary to have a very robust elicitation of the stakeholder's preferences to HIIs.

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Appendix

Table 1A
The expression matrix for piglets infected by swine vescular disease

Expressions	Probabilities of expression occurrences in each day post infection																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Reference
Clinical symptoms																							
Non-specific symptoms:																							
Fever	0	0	0	0	0.3	0.6	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, b, d, e
Anorexia	0	0	0	0	0.2	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, d
Lamness	0	0	0	0	0.1	0.4	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, d
Vesicles	0	0	0	0	0	0.05	0.1	0.15	0.2	0.25	0.2	0.15	0.1	0.05	0	0	0	0	0	0	0	0	a, d, g, h, j
horn saparation	0	0	0	0	0	0	0	0	0	0	0.05	0.1	0.15	0.2	0.15	0.1	0.05	0	0	0	0	0	a, c, f
Pathological findings																							
In blood:																							
Antigen/virus(infectious)	0	0	0	0	0.5	1	1	1	1	1	0.5	0	0	0	0	0	0	0	0	0	0	0	b, d, e
Antibodies	0	0	0	0	0	0	0.25	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	d

[a]Loxan and Hedger (1983)

[b]EFSA (2012)

[c]Hakhverdyan et al.(2006)

[d]Dekker et al. (1995)

[e]Eisinger (2012)

[f]OIE

[g]Burrows et al. (1974)

[h]Lai et al. (1979)

[j]Mann and Hutchings (1980)

Table 2A
The expression matrix for hogs and sows infected by swine vescular disease

Expressions	Probabilities of expression occurrences in each day post infection																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Reference
Clinical symptoms																							
Non-specific symptoms:																							
Fever	0	0	0	0	0	0.15	0.3	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, b, d, e
Anorexia	0	0	0	0	0	0.1	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, d
Lamness	0	0	0	0	0	0.05	0.1	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a, d
Vesicles	0	0	0	0	0	0	0	0.05	0.1	0.15	0.15	0.15	0.1	0.05	0	0	0	0	0	0	0	0	a, d, g, h, j
horn saparation	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.07	0.09	0.11	0.13	0.11	0.09	0.07	0.05	0	a, c, f
Pathological findings																							
In blood:																							
Antigen/virus(infectious)	0	0	0	0	0	0.25	0.5	0.75	1	0.75	0.5	0.25	0	0	0	0	0	0	0	0	0	0	b, d, e
Antibodies	0	0	0	0	0	0	0	0.25	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	d

[a]Loxan and Hedger (1983)

[b]EFSA (2012)

[c]Hakhverdyan et al.(2006)

[d]Dekker et al. (1995)

[e]Eisinger (2012)

[f]OIE

[g]Burrows et al. (1974)

[h]Lai et al. (1979)

[j]Mann and Hutchings (1980)

Table 3A
The day-dependent, post-infection probabilities of symptoms occurences for individual piglets infected by Aujesky's Disease

Expressions	The probabilities of symptoms occurrences in each day post infection																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Reference
Clinical symptoms																							
Fever	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0	0	a, b, c
Neurological symptoms	0	0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0	0	0	0	b, c, d, e
Anorexia	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0	0	0	0	b, c, d, e
Lossing Weights	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0	0	0	0	0	a
Respiratory symptoms	0	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.25	0.2	0.15	0.1	0.05	0	0	0	0	0	0	0	b, c, d, e
Death	0	0	0	0	0	0.1	0.2	0.3	0.4	0.5	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0	0	b, c
Pathological findings																							
Antigen/virus (infectious)	0	0.5	0.8	1	1	1	1	0.8	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	a, c
Antibodies	0	0	0	0	0	0	0	0.2	0.4	0.6	0.8	1	1	1	1	1	1	1	1	1	1	1	f

[a]Vilnis et al. (1998)

[b]Gerdts et al. (1997)

[c]Gerdts et al. (1999)

[d]Mikulska-Skupien et al. (2004)

[e]Kritas et al. (1997)

[f]Todd et al. (1987)

Table 4A

The day-dependent, post-infection probabilities of symptoms occurences for adult animals infected by Aujesky's Disease

Expressions	The probabilities of symptoms occurrences in each day post infection																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Reference
Clinical symptoms																							
Fever	0	0.1	0.2	0.3	0.4	0.5	0.5	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	a, b, c, d, e
Respiratory symptoms	0	0	0.2	0.3	0.4	0.5	0.5	0.4	0.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0	c, d
Anorexia	0	0	0.1	0.2	0.3	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	c, d
Lossing Weights	0	0	0.1	0.2	0.3	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a
Neurological symptoms	0	0	0	0.1	0.2	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	c, d
Death	0	0	0	0.05	0.08	0.1	0.08	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	d
Pathological findings																							
Antigen/virus (infectious)	0	0.15	0.25	0.35	0.45	0.55	0.55	0.45	0.35	0.25	0.15	0	0	0	0	0	0	0	0	0	0	0	a, c, e
Antibodies	0	0	0	0	0	0	0	0.2	0.4	0.6	0.8	1	1	1	1	1	1	1	1	1	1	1	c

[a]Rakel et al. (2007)

[b]Kimman et al. (1992)

[c]Wittmann et al. (1980)

[d]Nauwynck and Pensaert (1995)

[e]Miry et al. (1987)

Table 5A

The expression matrix for adult animals infected by salmonella

Expressions	Probabilities of expression occurrences each week post infection														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Reference
Antigen/bacteria(infectious)	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0	0	0	0	0	a, b
Antibodies	0	0.3	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	a

[a]Nielsen et al. (1995)

[b]Calveyra et al. (2012)

Table 6A

The weekly probability of symptom occuring for pigs infected by Mycobacterium avium

Symptoms	Week post infection															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Reference
	Probabilities of symptom occurrences for individuals															
Mycobacterium avium excretion	0	0	0	0	0	0.1	0.4	0.5	0.4	0.1	0	0	0	0	0	b, c
Antibodies	0	0	0	0	0	0.1	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	a, d

[a]Wisselink et al. (2010)

[b]Garrido et al. (2010)

[c]Angelika et al. (2012)

[d]Hiller et al. (2013)

Table 7A

The weekly probability of symptom occuring for pigs infected by Toxoplasma gondii

Symptoms	Week post infection															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Reference
	Probabilities of symptom occurrences for individuals															
Toxoplasma gondii isolation	0	0	0	0	0	0	0.3	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	e
Antibodies	0	0	0.5	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	a, b, c, d

[a]Lind et al. (1997)

[b]Basso et al. (2013)

[c]Garcia et al. (2006)

[d]Forbes et al. (2012)

[e]Dubey et al. (1996)

Chapter 6

General Discussion

6.1 **Introduction**

This PhD dissertation aims to address the economic optimization problem for livestock hazard surveillance, namely, improving the surveillance resource allocation to achieve surveillance performance maximization or surveillance costs minimization. Although several studies have been conducted to improve surveillance in livestock production chains, they have limitations in terms of their coverage of economic aspects and the level of modelling in the interaction between hazard dynamics and surveillance activities. Hence, the dissertation is motivated to (1) improve the understanding of hazard surveillance in livestock production chains from an economic perspective, and (2) to apply the obtained knowledge for better model-based in-depth analysis of livestock hazard surveillance. To realize this overall objective, four research chapters (Chapter 2, 3, 4 and 5) were developed. Chapter 2 presented a conceptual framework for single hazard surveillance analysis including a stochastic simulation model and a multi-criteria decision making model to evaluate the impacts of the hazard surveillance. Chapter 3 proposed a conceptual framework for surveillance portfolio optimization when multiple hazard surveillance systems are operated by a surveillance organization such as the Food Safety Authority. Chapter 4 and 5 apply the developed frameworks to two case studies for single hazard surveillance analysis and surveillance portfolio optimization respectively.

6.2 **Synthesis**

Surveillance in livestock production chains is an important managerial issue from both scientific and practical perspectives. However, a conceptual framework that can be applied by decision makers and stakeholders to guide their surveillance activities is still to some extent lacking. To fill in this knowledge gap, this dissertation developed two interlinked conceptual frameworks (Chapter 2 and 3) to address livestock hazard surveillance from different angles, i.e. single hazard and surveillance portfolio. Traditional research on single-hazard surveillance analysis tends to focus on the technical aspects of surveillance (i.e. the technical surveillance performances) but neglects the economic aspects of surveillance (e.g., Ward et al., 1996; Bouma, et al., 2001; Paisley et al., 2011; Willeberg et al., 2011; Bruhn et al., 2014; Stevens and Pfeiffer, 2014). The conceptual framework developed in Chapter 2 for single-hazard surveillance analysis incorporates economic aspects to address livestock hazard surveillance in a standard way, considering the principles described by Häsler et al. (2011). The single-hazard surveillance analysis framework also incorporates stakeholders' preferences into the evaluation process. The surveillance-portfolio analysis framework uses the single-hazard

surveillance analysis framework as the basis. It extends the problem scope from single hazard to multiple hazards. Livestock surveillance analyses have been extensively conducted for single hazard (e.g., Feld et al., 2000; Raulo and Lyytikainen, 2007; Martinez et al., 2011; Todd and Notermans, 2011; Chan et al., 2013; Dürr et al., 2013. To the opposite, research addressing livestock hazard surveillance from a portfolio perspective has been rarely seen in the literature, except for Prattley et al. (2007) and Prattley (2009). Whereas Prattley et al., (2007) and Prattley (2009) only address the epidemic disease surveillance, the developed surveillance-portfolio analysis framework in Chapter 3 is applicable to different types of hazards (e.g. epidemic diseases, endemic diseases). Moreover, Prattley et al., (2007) and Prattley (2009) do not consider stakeholders' preferences while the developed surveillance-portfolio analysis framework does. Compared to the single-hazard surveillance analysis framework, modelling the surveillance-portfolio analysis framework is more complex because it requires combining the outputs of the single-hazard surveillance analysis into the surveillance-portfolio optimization model. This complexity has been vividly demonstrated by the numerical example in Chapter 3 and also by the application in Chapter 5.

Although with increased modelling complexity, the surveillance-portfolio analysis framework has its importance in finding the optimal resource allocation among a number of resource-competing hazard surveillance systems. Specifically, the surveillance-portfolio analysis framework enables the overall optimal resource allocation (a unique solution) among different hazards taking into account the budget constraint faced by a surveillance organization. By contrast, the single-hazard analysis framework finds the most preferred surveillance setup by the stakeholders among an efficient set of non-dominated solutions (i.e. surveillance setups) based on two criteria, i.e., the technical surveillance performance and surveillance costs. The surveillance-portfolio analysis framework also includes the step to obtain an efficient set of non-dominated solutions for each hazard using the single-hazard surveillance analysis framework. That is why the single-hazard analysis framework is considered the basis of the surveillance-portfolio analysis framework. Moreover, since a surveillance portfolio usually contains hazards of various types (e.g. epidemic disease, endemic disease, etc.), it is necessary to differentiate surveillance objectives for different types of hazards. Chapter 3 distinguishes five categories of livestock hazards that can make up a surveillance portfolio into, i.e. zero-prevalence biological hazards, close-to-zero biological hazards, higher prevalence biological hazards, zero-threshold chemical hazards and low-threshold chemical hazards. These hazards

are considered to be the most relevant ones in the context of hazard surveillance in livestock production chains. For each category, the surveillance objectives, ranging from early detection to trend monitoring, are identified. Given the different surveillance objectives, the framework for different types of single hazard analysis should be modified to adapt to specific hazard features. For example, the first model developed in Chapter 4 is for the epidemic disease, classical swine fever (CSF). Since there is no CSF in the country at the beginning of the simulation, the framework contains a module that models pathogen introduction. However, for the endemic disease e.g., salmonella, the pathogen already exists in the country, and hence, the pathogen-introduction module is eliminated from the model. Moreover, since the technical surveillance performance indicators for CSF and Salmonella are different (because of different surveillance objectives), the modules that compute the technical surveillance performances for the two hazards are also different. Hence, the framework is not fully generic to allow a homogeneous modelling process. However, although part of the framework should be modified to adapt to the specific features of different types of single hazards, the framework is generic in the sense that the major modules that mimic the hazard dynamics (the three-dimensional population matrix) and surveillance setups (the sampling on the three-dimensional population matrix) are the same for all hazards.

Compared to the single-hazard analysis framework, the surveillance-portfolio analysis framework makes an important theoretical contribution because existing research rarely uses the portfolio's perspective to address the livestock-hazard surveillance problem. Both frameworks require intensive data input to setup the single-hazard surveillance simulation and surveillance-portfolio analysis models. The required data includes the epidemiological data to model the hazard dynamics in the animal population (e.g., the within and between farm transmission parameters), the economic and other impact data, and the stakeholder preference data. Compared to the single-hazard analysis framework that only targets at a single hazard, the surveillance-portfolio analysis framework is more difficult to apply and require more data because it deals with multiple hazards. Therefore, one important dimension of the application of the surveillance-portfolio analysis framework is to use it as a guideline for surveillance decision makers to conduct the surveillance activities. For the single-hazard surveillance analysis framework, in case the required data are available (e.g., the classical swine fever case study in Chapter 4), detailed quantitative modelling is possible to facilitate the analysis.

For the single-hazard surveillance analysis, the framework (Chapter 2) proposes to conduct both cost-effectiveness and cost-benefit analysis (including stakeholders' valuation of various types of benefits). This is because cost-effectiveness analysis can not quantify the benefits of surveillance activities (Häsler, et al., 2011). Following this principle, the application in Chapter 4 conducts both a cost-effectiveness analysis and a simplified version of cost-benefit analysis without incorporating stakeholders' preferences. This is because time limitations did not allow incorporating more types of benefits and stakeholders' valuation. Through both types of analyses, the efficient set of surveillance setups was identified and a robust conclusion was drawn that the current surveillance setup is adequate for classical swine fever surveillance (i.e. no more benefits to be gained from an intensified surveillance setup). This experience shows that even with the simplified version of cost-benefit analysis, we can still draw valuable insights on the single hazard surveillance evaluation. This implies that when time and resource are limited, conducting the simplified version of cost-benefit analysis can be a good alternative.

The single-hazard surveillance analysis framework (Chapter 2) models the "hazard dynamic" and "surveillance activities" into two separate modules. The hazard dynamic module captures "what is happening in the animal population", while the surveillance activities module captures "what is the surveillance practitioners looking at". Using the surveillance activities module to sample the animal population in the hazard dynamic module will deliver the technical surveillance performances (e.g. duration of the HRP, the herd-level sensitivity, etc.) of the surveillance system (i.e. the collection of the surveillance activities). The detailed capture of the interactions between the two modules is a distinct feature of the single-hazard surveillance analysis framework. Separately modelling the hazard dynamic and surveillance activities into two modules is convenient from a modelling point of view. Experience from the application study for Dutch CSF surveillance (Chapter 4) shows that with such modelling scheme, different surveillance activities (also called surveillance system components) can be easily added and abolished from the surveillance system.

Despite the separately modelling scheme, there will still be a big burden for the cost-benefit analysis after obtaining the technical surveillance performances and surveillance costs for each potential surveillance setup. This holds in particular when the number of potential surveillance setups is relatively large. To mitigate the burden of the cost-benefit analysis, the

single-hazard surveillance analysis framework (Chapter 2) proposes to use the efficient-set based approach to reduce the number of surveillance setups for the followed-up cost-benefit analysis. This approach maps all potential surveillance setups in a two dimensional space (i.e. the "technical surveillance performance" and "surveillance cost" space), and finds out the efficient surveillance setups (i.e. the surveillance setups that are not dominated by others) automatically based on the efficiency-set theory. The experience from the application in Chapter 4 shows that the majority of the potential surveillance setups are the dominated ones and therefore can be excluded from the efficient set, which saves substantial efforts for the subsequent cost-benefit analysis.

Another special feature of the proposed single-hazard surveillance analysis framework is the use of the "expression-probability matrix" to model the hazard-related expressions in the infected animals (Chapter 2). Compared to existing literature (Crauwels et al., 1999; Klinkenberg et al.,2005; Backer et al., 2011), the use of the "expression-probability matrix" enables a more realistic modelling of the hazard development in the animal population. The applications in Chapter 4 and Chapter 5 show that the "expression-probability matrix" allows a detailed mimic of the hazard dynamics in the animal population. The model can point out the number of animals on a farm showing a particular kind of hazard-related expressions in a specific day. This provides the basis for the surveillance activities module to sample the very specific features of the animal population, and therefore makes the sampling procedure more realistic. However, the use of the "expression-probability matrix" requires a substantial effort in deriving appropriate data. The work includes an extensive literature study to derive the raw data (e.g., the data from the experimental infection research) as well as translation of the raw data into the format needed to parameterize the model. This data translation usually requires the consultation of experts in relevant fields. The applications in Chapter 4 and Chapter 5 show that the expert consultation could be quite laborious, especially for the surveillance portfolio analysis where multiple experts had to be consulted.

The surveillance-portfolio analysis framework (Chapter 3) intends to solve the overall resource allocation problem for the surveillance organizations such as Food Safety Authorities. However, the applications show that due to the time and resource limitation, it is very hard to consider all hazards surveyed by a surveillance organization at once, and the surveillance portfolio should be narrowed down to include a relative small number of hazards

that fall in a smaller category. For example, the application in Chapter 5 only takes the serological surveillance in a Dutch food company's slaughterhouses into account (instead of all surveillance activities that are conducted by the Dutch food company), which reduces the number hazards in the surveillance portfolio problem to five. The surveillance-portfolio analysis framework also proposes to first conduct thorough analyses of all single hazards to provide basis (inputs) for surveillance portfolio analysis. However, the experience in Chapter 5 shows that even with a relatively small size, some extent of simplification has to be made due to time and data limitations.

In most cases, decisions on hazard surveillance do not only affect the interests of the surveillance organization (e.g., the Food Safety Authority) itself, but also the interests of other parties (e.g., farmers, citizens). Therefore, the surveillance-portfolio analysis framework (Chapter 3) suggests that the analysis should include multiple stakeholders and aim at achieving the overall maximum well-being for all stakeholders. However, the complexity of the surveillance-portfolio application sometimes requires reducing the multi-stakeholder decision problem to a single-stakeholder decision-making problem. The application in Chapter 5 showed that the single-stakeholder analysis for hazard surveillance could also be appropriate (in terms of providing valuable insights) especially when the surveillance organization is private and have a relatively unique interest (e.g., the specific food company's serological surveillance-portfolio case).

Incorporating the stakeholders' preference to the analysis is a key contribution of the proposed frameworks to the literature. The numerical example in Chapter 3 showed that preferences can have a big impact on the optimal surveillance portfolio selection. However, Chapter 5 demonstrated that when the hazard impact parameters are highly correlated among different HIIs, the results become very robust.

6.3 **Policy Implications**

The policy implications of this PhD dissertation are at two levels, i.e. the conceptual level and the application level. The conceptual level implications are derived from Chapter 2 and 3, which proposed two conceptual frameworks respectively for single-hazard surveillance analysis and surveillance portfolio optimization. These frameworks have generalized the relevant aspects of economic analysis of livestock hazard surveillance for both single hazard

and multiple-hazard portfolio. They provide new insights for surveillance practitioners and decision makers towards livestock hazard surveillance (i.e. look at livestock hazard surveillance in a holistic way). When the surveillance decision makers make decisions on surveillance resource allocation, the frameworks can serve as a conceptual guideline to indicate what relevant issues should be considered and what procedure should be followed. For example, both frameworks emphasize the importance of considering the asymmetric distribution of surveillance costs and benefits among stakeholders. Hence, a thorough stakeholder analysis should be conducted considering all parties' interests, before any decision is made. Moreover, both frameworks are decomposed into several detailed steps which can be easily followed by the decision maker.

At the application level, the single-hazard surveillance analysis framework (Chapter 2) includes a surveillance simulation model successfully capturing the interactions between the detailed hazard dynamics and the surveillance activities. The core of the surveillance simulation model, the hazard expression-probability matrix, enables to model the hazard dynamics in three dimensions. Using the hazard expression-probability matrix allows the model to better mimic the hazard development and capture the real-life situation that provides information with improved quality for decision support. However, to construct the expression-probability matrix, extensive epidemiological data are required, and therefore it requires the surveillance organization (e.g. food safety authorities, food companies) to invest in data collection research (e.g., experimental infection research).

By applying the proposed surveillance analysis frameworks, the research of two application studies has drawn fruitful managerial insights to help the surveillance decision makers improve surveillance performance in the livestock production chains. Several managerial implications for Dutch CSF surveillance were drawn from the analysis of Chapter 4. Firstly, the finding that there is no economic benefit to be gained by intensifying the current surveillance activities provides the justification for Dutch FSA to retain the current CSF surveillance system. Only when there is a significant increase of the risk of CSF introduction (e.g. outbreaks in neighbourhood countries), more intensified surveillance setups should be considered. Secondly, the finding that the efficient sets of surveillance setups are different for the moderately and low virulent CSF implies decision makers should treat the surveillance of the two virulence strains differently. Specifically, for the moderate virulent CSF, when it is

necessary to intensify the surveillance, the decision maker should consider to apply PCR tests on rendered animals. Differently, for the low-virulent CSF, the decision maker should consider to add more serological tests as the risk of low virulent CSF introduction increases. Thirdly, the fact that serological surveillance is effective for early detection of low virulent CSF provides the opportunity for FSAs to consider applying the serology-related surveillance system components in the area where the risk of low virulent CSF introduction is high. Fourthly, the results of the surveillance-portfolio framework application (Chapter 5) show that there is a clear gap between the currently applied surveillance portfolio by the Dutch food company and the optimal surveillance portfolio, which implies a good opportunity for either improved surveillance performance or reduced surveillance costs. This finding suggests that surveillance decision makers should use a surveillance portfolio perspective instead of applying protocols previously based on a single hazard. Finally, the surveillance organizations should make trade-offs between investing more in livestock hazard surveillance research or in intensifying the current livestock hazard surveillance systems.

6.4 **Future Research**

Future research can either focus on improving the developed conceptual frameworks (i.e. make theoretical modifications of the frameworks) or improving the practicability of the proposed frameworks (i.e. make the frameworks easier for practical use). The latter deserves more attention because the basic principles of surveillance have been comparably well addressed in the conceptual frameworks, whereas the application of these frameworks remains a big limitation. Since, the ultimate goal of developing any conceptual approach should be towards real application, research priority needs to be given to solving the data limitation problem, which is the biggest barrier for framework applications.

Data limitations have been extensively discussed for the application of the single hazard analysis framework (Chapter 2) and surveillance-portfolio analysis framework (Chapter 3), and is the prime obstacle to application of the proposed frameworks. For the two applications in Chapter 4 and 5, expert elicitation methods had to be used due to lack of directly usable data. The data required by the proposed frameworks can be classified into two categories, i.e. the hard data and preference data. The hard data include the data for parameterizing the hazard simulation model (such as the disease transmission parameters and the data for constructing the hazard expression-probability matrix) and the hazard impact simulation

model (e.g., Hop et al, 2014). Such data are available for some well-studied hazards, like CSF, avian influenza (AI), and foot and mouth disease (FMD). However, the well-studied hazards only account for a small proportion of total livestock hazards. The preference data refer to the elicited stakeholder preferences to various types of mitigated hazard impacts (or benefits from surveillance). The difficulty in obtaining such data is that the preferences of the stakeholders towards the mitigated hazard impacts could be different when he or she is in different states (e.g., Karni, 1987; Melino and Yang, 2003). This requires setting up a stakeholder panel to regularly recalculate the optimal surveillance portfolio to account for the possible changed stakeholder's preferences. Apparently, this process is laborious and may have limited applicability in practice. Moreover, in some cases, the stakeholders may not want to show their real preferences to others due to strategic reasons. This will bias the multi-criteria decision making model. In other words, both the hard and preference data availability restricts the application of the proposed conceptual frameworks.

Given the data limitation, the single hazard and surveillance portfolio frameworks should be used in a different way. For the single-hazard framework application, especially for the well-studied hazards, it is relatively easy to find the required data. Hence, it can be used in a quantitative way for decision support. For the surveillance-portfolio analysis framework, since it requires a large amount of data, it should be used more carefully as a decision support tool. To improve the data availability, firstly, more bio-epidemiological studies (including experimental and statistical studies) need to be conducted for the little-known livestock hazards to provide the hard data, such as disease transmission parameters and disease symptom occurrence probabilities, for developing the disease simulation model. Secondly, since there are various data sources in literature which often provide inconsistent information, meta-analyses should be carried out to contrast and combine results from different studies. As such, the analysis will then rely less on expert opinions to confirm the values of model parameters, and therefore increase the objectivity of model parameterization.

Another limitation of this research is that to focus on elaborating the main objective of this dissertation, i.e. addressing economics of hazard surveillance in livestock production chains, I took the intervention strategy as given to allow for investigating the effects of surveillance only. This assumption implies that the possible effects of intervention on hazard impact mitigations are neglected when comparing different surveillance scenarios. It is pointed by

Häsler et al., (2011) and Howe et al. (2013) that the mitigated impacts caused by the hazard do not only depend on the quality of surveillance but also the quality of intervention. In other words, surveillance and intervention should be considered simultaneously. However, as shown by the research in this dissertation, only addressing the aspects of surveillance itself (by assuming a fixed default intervention strategy) has already made the study very complicated; investigating the joint effects of surveillance and intervention is an interesting avenue for future research.

The case study in Chapter 5 only considered a single stakeholder surveillance portfolio (i.e. the Dutch food company is the only stakeholder) due to the time limitation. Because livestock hazard surveillance actually has the impacts on multiple parties' interests (e.g., farmers, consumers, citizens, and animal welfare protection groups), future research can optimize surveillance activities applying a multi-stakeholder perspective, aiming to achieve societal welfare maximization. Also because of the time limitation, the case study in Chapter 5 only used four hazard impact indicators (HIIs), which were suggested by the surveillance managers in the Dutch food company, to evaluate the surveillance performance for the pig-hazard surveillance portfolio. In future research, a more extensive list of hazard impact indicators (reflecting different types of benefits) could be used to facilitate a more complete evaluation of livestock hazard surveillance. Furthermore, the surveillance-portfolio optimization model did not take into account the uncertainty of the hazard impact parameters for each investigated surveillance portfolios. Instead, we conduct sensitivity analysis to test the robustness of the results. Future research should focus on finding a way to incorporate the uncertainty of the hazard impact parameters into the model.

In additions, the conceptual frameworks are developed to analyze hazard surveillance for different species of animals. However, due to the time limitation, both application studies are applied to pig hazards. Future research should try to extend the application of the frameworks to hazards of other animal species (e.g., chicken, cows).

Moreover, since this research focuses on addressing the livestock-hazard surveillance problem in the Netherlands, the conceptual frameworks were only adapted to fit the Dutch situation. However, since the frameworks are generic and can also be applied to other countries.

Finally yet importantly, part of the conceptual frameworks may also be applied to evaluate surveillance systems in other fields, e.g., surveillance of the plant diseases, surveillance of cargos and surveillance of crimes.

6.5 **Main conclusions**

The main conclusions derived from the dissertation are:

- The single hazard analysis conceptual framework improves the understanding of livestock hazard surveillance on the single hazard level and it has a relatively good applicability because it requires relatively few data for the application (Chapter 2).
- The surveillance-portfolio analysis conceptual framework improves the understanding of livestock hazard surveillance to a surveillance portfolio level but it requires more data for real application, compared to the single hazard analysis (Chapter 3).
- Adding serological surveillance to the current Dutch CSF surveillance system is ineffective for detecting the moderate virulence CSF but effective for low virulent CSF detection (Chapter 4).
- Adding the PCR testing on rendered animals to the current Dutch CSF surveillance system is effective for moderate virulence CSF detection but ineffective for detecting low virulence CSF (Chapter 4).
- The current Dutch CSF surveillance system is adequate and there is little to be gained economically by implementing more intensified surveillance setups (Chapter 4).
- The Dutch food company can improve the performance of its current surveillance portfolio by better allocating its surveillance resource or can reduce its annual surveillance costs but still maintain the same level of surveillance performance (Chapter 5).
- Surveillance in livestock production chains by the Dutch food company should be addressed from a portfolio perspective, instead of a single hazard, because addressing single hazard surveillance separately could result in sub-optimal surveillance resource allocation. (Chapter 5)
- The results of the pig-hazard surveillance portfolio optimization are robust with respect to the changes of stakeholder's weights to hazard impact indicators (HIIs) due to the high correlations of impact scores among the HIIs (Chapter 5).
- Relaxing legal constraints for livestock hazard surveillance could improve the overall surveillance portfolio performance (Chapter 5).

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Summary

Hazard surveillance in livestock production chains is an essential activity that is usually conducted by surveillance organizations. Its importance has been highlighted by the major crises that occurred in the field of livestock production and food safety during the last decades. Examples include Classical Swine Fever (CSF) during the 1990s in the Netherlands, Belgium and Germany, Bovine Spongiform Encephalopathy (BSE) in the 1990s in the United Kingdom, recent Highly-Pathogenic Avian Influenza (HPAI) in China, and Foot and Mouth disease (FMD) in the United Kingdom and South Korea in 2001 and 2010 respectively. Such crises resulted also in reduced public confidence in food production and products.

Although extensive research has been conducted to achieve surveillance improvement in livestock production chains, they have limitations in terms of coverage of economic aspects and in the level of detail in modelling the interactions between hazard dynamics and surveillance activities. Hence, the dissertation aims to (1) improve the understanding of hazard surveillance in livestock production chains from an economic perspective, and (2) to apply the obtained knowledge for better model-based in-depth analysis of livestock hazard surveillance. This overall objective was addressed in four research chapters.

Chapter 2 presents a conceptual framework for the economic analysis of single-hazard surveillance systems in livestock production chains which differs from most of the previous research focusing on the technical aspect of livestock hazard surveillance. This single-hazard analysis conceptual framework includes objective and subjective aspects of single-hazard surveillance system analysis. The objective analysis is a simulation model aimed at deriving an efficient set of surveillance setups based on the technical surveillance performance parameters and the corresponding surveillance costs, and the subjective analysis is a multi-criteria decision making model to evaluate the impacts of the hazard surveillance. This chapter also discusses the scientific validity of the conceptual framework and the availability of data in the framework's application. We conclude that that the conceptual approach is scientifically credible for economic analysis of single-hazard surveillance systems and that the applicability of the approach critically depends on data availability.

Chapter 3 presents a conceptual framework for the economic optimization of a surveillance-portfolio consisting of multiple livestock hazards to survey. This framework applies the portfolio perspective to investigate the surveillance resource allocation problem, which is beyond the state of art that mainly focuses on single hazard surveillance analyses. A multi-criteria surveillance-portfolio optimization model is proposed which uses the outputs of the single hazard surveillance analysis as inputs. This chapter also discusses the scientific and data validity of the conceptual approach, as well as its practical use.

Chapter 4 applies the single-hazard surveillance framework to conduct a comprehensive economic analysis of CSF surveillance in the Netherlands. It takes into account the specialized structure of Dutch pig production, differences in virulence of CSF strains, and a complete list of possible surveillance activities. This chapter uses the current Dutch CSF surveillance system (i.e. the default surveillance setup) as the starting point, and investigates a number of alternative surveillance setups using cost-effectiveness and cost-benefit analyses. Managerial insights are provided that can facilitate the decision making of policy makers. The results of the cost-effectiveness analysis show that the alternative surveillance setups with "PCR on rendered animals" are effective for the moderately virulent CSF strain, whereas the surveillance setups with "routine serology in slaughterhouses" or "routine serology on sow farms" are effective for the low virulent strain. Moreover, the current CSF surveillance system in the Netherlands is cost-effective for both moderately virulent and low virulent CSF strains. The results of the cost-benefit analysis for the moderately virulent CSF strain indicate that the current surveillance system in the Netherlands is adequate. From an economic perspective, there is little to be gained from intensifying surveillance.

Chapter 5 applies the surveillance-portfolio analysis framework to conduct economic optimization of a pig-hazard surveillance-portfolio, consisting of five pig-related hazards, in a Dutch food company. In this chapter, each hazard is first analyzed using the single hazard surveillance analysis model to derive the technical surveillance performances and annual surveillance costs for each investigated surveillance setup. Then, the impact parameters corresponding to certain technical surveillance performance are estimated by experts. Together with the elicited stakeholder's weights, the surveillance portfolio optimization model is parameterized. Managerial implications are derived from the model's results to help the company improve its surveillance portfolio's performance. The first conclusion we can

draw from this chapter is that surveillance organizations should need to use a portfolio perspective to guide their surveillance resource allocation. This is because the case clearly shows that arbitrarily allocating surveillance costs can cause efficiency losses (either in terms of higher surveillance costs or low SP performance). Furthermore, eliminating legal constraints for some hazards in a SP may result in higher SP performance. Finally, when correlations of impact parameters between HIIs implies are high, results are robust to stakeholder's preferences regarding HIIs.

Chapter 6 presents a synthesis of different chapters and discusses the findings in the perspective of the existing literature. It also discusses the implications for future research and the efforts required for further implementing the conceptual frameworks for single hazard surveillance and surveillance portfolio optimization. The main conclusions drawn from this PhD dissertation are:

- The single hazard analysis conceptual framework improves the understanding of livestock hazard surveillance on the single hazard level and it has a relatively good applicability because it requires relatively few data for the application (Chapter 2).
- The surveillance-portfolio analysis conceptual framework improves the understanding of livestock hazard surveillance to a surveillance portfolio level but it requires more data for real application, compared to the single hazard analysis (Chapter 3).
- Adding serological surveillance to the current Dutch CSF surveillance system is ineffective for detecting the moderate virulence CSF but effective for low virulent CSF detection (Chapter 4).
- Adding the PCR testing on rendered animals to the current Dutch CSF surveillance system is effective for moderate virulence CSF detection but ineffective for detecting low virulence CSF (Chapter 4).
- The current Dutch CSF surveillance system is adequate and there is little to be gained economically by implementing more intensified surveillance setups (Chapter 4).
- The Dutch food company can improve the performance of its current surveillance portfolio by better allocating its surveillance resource or can reduce its annual surveillance costs but still maintain the same level of surveillance performance (Chapter 5).
- Surveillance in livestock production chains by the Dutch food company should be addressed from a portfolio perspective, instead of a single hazard, because addressing

single hazard surveillance separately could result in sub-optimal surveillance resource allocation. (Chapter 5)

- The results of the pig-hazard surveillance portfolio optimization are robust with respect to the changes of stakeholder's weights to hazard impact indicators (HIIs) due to the high correlations of impact scores among the HIIs (Chapter 5).
- Relaxing legal constraints for livestock hazard surveillance could improve the overall surveillance portfolio performance (Chapter 5).

Samenvatting

"Hazard surveillance" in dierlijke productie ketens is een essentiële activiteit die meestal door toezichthoudende organisaties wordt uitgevoerd. Het belang van toezicht wordt benadrukt door de grote crises die de laatste decennia hebben plaatsgevonden in de veehouderij alsmede met betrekking tot de voedselveiligheid. Voorbeelden zijn de uitbraken van klassieke varkenspest (KVP) in 1990 in Nederland, België en Duitsland, boviene spongiforme encefalopathie (BSE) in 1990 in het Verenigd Koninkrijk, en meer recent aviaire influenza (HPAI) in China, en mond- en klauwzeer (MKZ) in het Verenigd Koninkrijk en Zuid-Korea. Dergelijke crises resulteerden ook in een verminderd publiek vertrouwen in de voedselproductie.

Ofschoon uitgebreid onderzoek is uitgevoerd naar het verbeteren van het toezicht op dierlijke productieketens, is er nog relatief weinig aandacht besteed aan de economische aspecten en een meer gedetailleerde modellering van risico ("hazard") en bewakingsactiviteiten. Vandaar dat dit proefschrift gericht is op (1) het verbeteren van het inzicht in "Hazard surveillance" in dierlijke productie ketens vanuit een economisch perspectief, en (2) om de verworven kennis toe te passen ten einde model gebaseerde analyses in dierlijke productie ketens te verbeteren. Deze algemene doelstelling is aangepakt in een viertal hoofdstukken.

In hoofdstuk 2 wordt een conceptueel raamwerk voor de economische analyse van "single-hazard" bewakingssystemen in veehouderijketens gepresenteerd. Dit raamwerk verschilt aanzienlijk van bestaande studies. Tot nu toe is het onderzoek vooral gericht op technische aspecten van "Hazard surveillance" in de veehouderij. Het conceptuele kader voor "single-hazard surveillance" omvat daarentegen zowel objectieve als subjectieve aspecten van "single-hazard" detectie analyse. De objectieve analyse is via een simulatiemodel vormgegeven en is gericht op het afleiden van een efficiënte verzameling van toezicht setups op basis van technische prestatie parameters en de bijbehorende kosten voor bewaking. De subjectieve analyse omvat een multi-criteria besluitvormingsmodel om de gevolgen van "Hazard surveillance" te evalueren. Dit hoofdstuk bespreekt ook de wetenschappelijke validiteit van het conceptuele raamwerk alsmede de beschikbaarheid van gegevens. We concluderen dat de conceptuele benadering bruikbaar is voor de economische analyse van

single-hazard bewakingssystemen en dat de toepassing van de aanpak sterk afhankelijk is van beschikbare data.

Hoofdstuk 3 presenteert een conceptueel raamwerk voor de inspectie en voor de economische optimalisatie van een surveillanceportfolio die meerdere risico factoren omvat. In tegenstelling tot de gangbare praktijk van inspectie gaat het raamwerk niet uit van een "single hazard" benadering, i.e. een enkelvoudig risico, maar juist van meerdere risico's. Het ontwikkelde conceptuele raamwerk beoogt een optimale toewijzing van beperkt beschikbare middelen te realiseren voor de simultane inspectie van meerdere risico's. Dit hoofdstuk stelt een multi-criteria surveillance-portfolio optimalisatie model voor waarbij de inspectie op enkelvoudige risico analyse als input is gebruikt. Dit hoofdstuk bespreekt zowel de wetenschappelijke validiteit, de validiteit van data als de toepassing van het concept in de praktijk.

In hoofdstuk 4 wordt het ontwikkelde "single hazard" toezichtskader uit hoofdstuk 2 als uitgangspunt genomen voor de toepassing van een uitgebreide economische analyse voor CSF (varkenspest) in Nederland. De toepassing houdt rekening met de specifieke structuur van de Nederlandse varkenshouderij, de verschillen in virulentie van CSF stammen en een volledige lijst van mogelijke bewakingsactiviteiten. Dit hoofdstuk neemt het huidige Nederlandse CSF bewakingssysteem (d.w.z de standaard surveillance setup) als uitgangspunt en maakt een kosten effectiviteit en kosten baten analyse van een aantal alternatieve surveillance setups. Management inzichten worden gepresenteerd die besluitvormingsprocessen door beleidsmakers kunnen ondersteunen. Uit de resultaten van de kosten-batenanalyse blijkt dat alternatieve surveillance setups met "PCR testen op destructiebedrijven" effectief zijn voor matig virulente CSF stammen, terwijl surveillance setups met een "routine serologie in slachthuizen" of "routine serologie op zeugenbedrijven" effectief zijn voor laag virulente stammen. Bovendien blijkt het huidige CSF surveillance systeem in Nederland kosteneffectief te zijn voor zowel matig virulente als laag virulente CSF stammen. De resultaten van de kosten-baten analyse voor matig virulente CSF stammen geven aan dat het huidige bewakingssysteem in Nederland volstaat. Vanuit een economisch perspectief gezien is weinig toegevoegde waarde te behalen met het intensiveren van toezicht.

In hoofdstuk 5 wordt het ontwikkelde conceptuele raamwerk voor surveillanceportfolio toegepast. De doelstelling is om de economische optimalisatie van een detectiesysteem voor een vijftal risico's (hazards) in de varkenshouderij te analyseren voor een Nederlands voedingsbedrijf. In dit hoofdstuk wordt elk risico in eerste instantie geanalyseerd met behulp van het enkelvoudige (i.e. "single hazard") surveillance model om zowel de technische prestaties als de jaarlijkse kosten van het toezicht voor elke setup af te leiden. Vervolgens zijn de noodzakelijke parameters die overeenkomen met bepaalde technische prestaties door experts ingeschat. Tezamen met de geëliciteerde gewichten van diverse belanghebbenden is het surveillanceportfolio model geparametriseerd. Met behulp van het model zijn effecten en resultaten afgeleid die het management binnen het bedrijf kunnen ondersteunen om de surveillance portfolio's te verbeteren. De eerste conclusie die we kunnen trekken uit dit hoofdstuk is dat het toezichthoudende organisaties een portfolio benadering dienen te hanteren om de toewijzing van beperkt beschikbare middelen voor de surveillance van risico's te begeleiden. De case studie laat duidelijk zien dat het willekeurig toerekenen van kosten voor surveillance een reductie van de efficiëntie kunnen veroorzaken (hetzij in termen van hogere kosten voor bewaking danwel van lagere SP prestaties). Bovendien blijkt dat het elimineren van wettelijke beperkingen voor sommige risico's tot hogere SP prestaties kan leiden. Ten slotte blijkt dat de resultaten voor de preferenties van belanghebbenden robuust zijn met betrekking tot de HII's als de correlaties van parameters tussen HII's hoog zijn.

Hoofdstuk 6 presenteert een synthese van de verschillende hoofdstukken en bespreekt de bevindingen in het perspectief van de bestaande literatuur. Ook wordt ingegaan op de implicaties voor toekomstig onderzoek en de inspanningen die nodig zijn voor verdere ontwikkeling van de ontwikkelde conceptuele raamwerken voor zowel enkelvoudige risico surveillance als voor de portfolio benadering. De belangrijkste conclusies van dit proefschrift zijn:

• Het ontwikkelde conceptuele raamwerk voor de economische analyse van "single-hazard" bewakingssystemen verbetert het inzicht voor surveillance van enkelvoudige surveillance in dierlijke productie ketens. Het raamwerk is relatief goed toepasbaar omdat relatief weinig gegevens vereist zijn (hoofdstuk 2).

• Het ontwikkelde raamwerk voor surveillance-portfolio-analyse verbetert het inzicht voor surveillance op portfolio niveau maar de aanpak vereist beduidend meer gegevens voor toepassing in de praktijk ten opzichte van analyses op "single-hazard" niveau (hoofdstuk 3).

• Het toevoegen van serologische surveillance aan het huidige Nederlandse CSF surveillance systeem is niet effectief voor het detecteren van matig virulente CSF stammen maar wel effectief voor laag virulente CSF detectie (hoofdstuk 4).

• De PCR-test op destructiebedrijven toevoegen aan het huidige Nederlandse CSF surveillance systeem is effectief voor matige virulente CSF detectie, maar niet effectief voor het opsporen van laag virulente CSF stammen (hoofdstuk 4).

• Het huidige Nederlandse CSF surveillance systeem is voldoende en er is, economisch gezien, weinig meerwaarde te realiseren via het intensiveren van toezicht (i.e. via alternatieve setups) (hoofdstuk 4).

• Het Nederlandse voedingsbedrijf kan de uitvoering van de huidige surveillance portfolio verbeteren middels een betere toewijzing van de beschikbare middelen of het kan de jaarlijkse kosten voor toezicht reduceren waarbij het niveau van de surveillance prestaties gelijk blijft (hoofdstuk 5).

• Toezicht in dierlijke productieketens door het Nederlandse voedingsbedrijf moet vanuit een portfolio perspectief worden benaderd omdat de aanpak via enkelvoudige risico detectie tot een sub-optimale toewijzing van de beschikbare middelen kan leiden. (Hoofdstuk 5)

• De resultaten van het risicodetectiesysteem voor de varkenshouderij zijn robuust met betrekking tot veranderingen van de gewichten door stakeholders voor HII's (Hazard Impact Indicators) gezien de hoge correlaties van parameters tussen HII's (hoofdstuk 5).

• Het reduceren van de wettelijke eisen voor risicodetectiesystemen kan de prestatie van de totale surveillance portfolio verbeteren (hoofdstuk 5).

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Xuezhen Guo
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Economics of Animal Health and Food Safety (BEC 52806)	WUR	2010	6
Advanced Macro-economics (ENR 30806)	WUR	2011	6
Economic models (AEP 30806)	WUR	2011	6
Writing proposal		2010-2011	4
Surveillance systems in livestock production chains: An approach for quantitative economic optimization.	25th European Conference on Operational Research, Vilnius, Lithuania	2012	1
Economic optimization of CSF surveillance in the Netherlands,	Foulum workshop in Denmark	2012	0.4
A Monte Carlo simulation model to evaluate Dutch classical swine fever surveillance.	26th European Conference on Operational Research, Rome	2013	1
B) General research related competences			
Introduction Course	WASS	2012	1
Attending PhD meetings in BEC group once per two weeks		2010-2014	4
A cost-effectiveness study for Dutch classical swine fever surveillance.	14th EAAE Congress, Ljubljana, Slovenia	2014	1
C) Career related competences/personal development			
Risk-based surveillance Design and Analysis at Pet Hand	Gent, Belgium	2012	1.4
Scientific writing	WGS	2011	1.8
Total			33.6

*One credit according to ECTS is on average equivalent to 28 hours of study load

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