FIRST CONCEPTUAL CONSIDERATIONS OF ECONOMIC OPTIMISATION OF MONITORING AND SURVEILLANCE SYSTEMS FOR ANIMAL HEALTH AND FOOD SAFETY

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Introduction and background

The mission of food safety authorities (FSAs) is to assure to the safety of food and animal health. A vast amount of biological agents, chemical contaminants and residues can adversely affect animal and human health. The socio-economic impacts of the presence of some hazards in food production chains are substantial. FSAs aim to minimize these impacts by legislation enforcement and assessing risks, as well as risk management. Their tasks centre on prevention, monitoring and control. This research focuses on monitoring only.

Monitoring and surveillance systems (MOSSs)[1] serve various objectives including early detection (e.g. of an animal disease or medical residue), detection of threshold violations, free status substantiation, determining hazard characteristics, providing baseline prevalence estimates and monitoring trend development. Many actors are involved, such as individual farmers, laboratories, veterinary services, product boards and authorities. FSAs have monitoring responsibilities for a large hazard portfolio.

Monitoring and surveillance is costly and it is simply impossible and undesirable to monitor any hazard at any stage at any time. Consequently, an economic optimisation problem exists for FSAs. The performance of both single and portfolio MOSSs must be maximized under budget constraints.

To address this optimisation problem a PhD project was initiated. The problems are formulated from the perspective of the Dutch and German FSAs. The project is executed within the large German-Dutch project Safeguard. The aim of this paper is to describe the global set-up of the research and to present conceptual considerations of the optimisation problems.

Research definitions

Terminology surrounding monitoring and surveillance is inconsistently used, both in the literature as in practice. It is not the purpose of this research to enter in semantic discussions; it suffices to provide some definitions as they are used in this research.

Monitoring and surveillance are used interchangeably. Nevertheless, it is worthwhile to note that some authors make distinctions. According to Noordhuizen et al. (2001) monitoring is the process of “collecting data about animal health, disease and their determinants” and surveillance may be seen as “an extension of monitoring” whereby information is linked to thresholds. Similar remarks can be made for other terminology such as programme, system, component, instrument and methodology.

The term MOSS is arbitrarily adopted to indicate the total set of system components (cf. Doherr and Audigé, 2001; Martin et al., 2007). Examples of system components are e.g. clinical surveillance, blood sampling at a chain stage, ante-mortem inspection, post-mortem inspection, a sentinel network and entomological surveillance. To specify in detail what a component comprises the term instrument will further be used instead of system component.

A MOSS summarises the total set of employed system components for one or several hazards. The term ‘single MOSS’ is used to indicate the total set of system components employed for the monitoring of one specific hazard, or hazard class when used in the context

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[1] Terminology is generally not consistently used; the term MOSS is adopted to indicate the total set of system components. This is explained in the research definitions’ section.

of generic model formulation. Some monitoring activities are shared per definition; in that case they are separated as much as possible and treated as if only used for the particular hazard. ‘Portfolio MOSS’ refers to the monitoring of a specific set of hazards.

A generally accepted mathematical definition of risk is probabilistic variability of events to happen whereas uncertainty refers to unknown variability. Given the context it is generally more appropriate to “define uncertainty as imperfect knowledge, and risk as uncertain consequences” (Hardaker, 1997).

Approach and scope

The research consists of four stages: the development of a conceptual framework, the formulation of single MOSS models and analysis of results, the development a tool for decision support and MOSS portfolio optimisation.

To enable model building a thorough understanding of the decision problems is essential. A conceptualisation should include the formulation of single MOSS classes for which generic performance criteria, indicators and models can be formulated. Other elements are stakeholder analyses and analysis of inputs.

Generic combined epidemiological-economic single MOSS optimisation models are developed and tested for specific hazards. The next step is to interpret these results to come to decision support. After single MOSS optimisation the problem of portfolio MOSS optimisation will be addressed.

The research scope is limited to single and portfolio MOSS prioritised in legal sense for which FSA cq. product boards have responsibilities. Various biological and chemical hazards are considered.

Research outline

Figure 1 shows a stepwise approach to arrive at decision support for the budget allocation problems. In this section the building blocks are explained in a general way to clarify the rationale of the research. In the next section a brief overview is given of some of the relevant aspects of the budget allocation problems.

Ultimate research objective is to provide information on optimal budget allocation on monitoring and surveillance which is of use for FSAs. Single and portfolio MOSS are considered. Decision support will at least consist of: suggestions for cost-effective monitoring protocols, analysis of performance sensitivity for budget changes and insights in the impact of performance perception on optimal MOSS design and configuration.

To enable this models are required since for most hazards there is too large a number of monitoring options to intuitively solve the problem. Combined epidemiological/economic modelling is applied to capture features of particular hazards. Consequently, a first category of parameter inputs comes from the hazard itself; few examples are infectivity and recovery rates, potential target group parameters and expected prevalence. Also, contact structures of the involved chains are important to investigate how a hazard spreads throughout the population.

Diverse other inputs are needed. Potential and current system components and the total set of available instruments must be analysed. Parameters on test performance must be obtained, as well as the economic aspects of the MOSS instruments. The available budget for the MOSS must be integrated as well as distributional defaults. The legal environment puts constraints on the feasible solution space. However, the models will be run with and without these constraints in order to be able to explore short-term possibilities as well as possibilities for longer-term MOSS configurations.

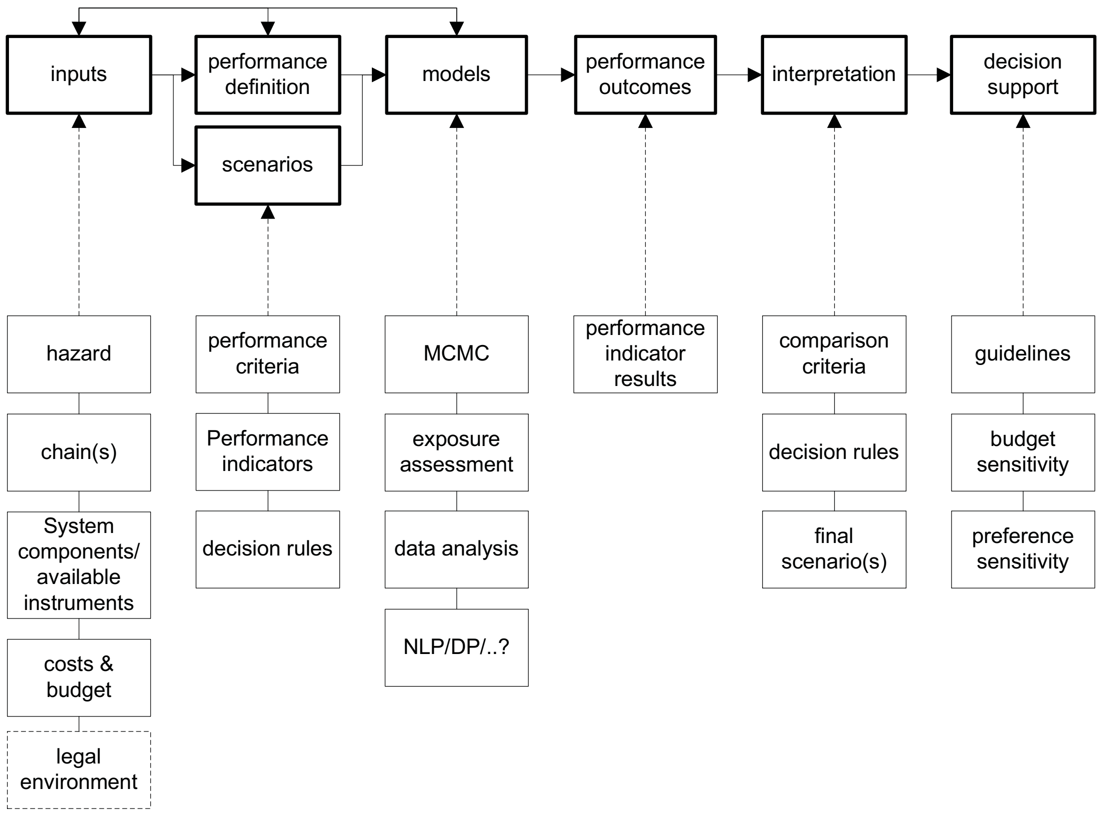

Figure 1 The building blocks of the research to arrive at decision support.

The models aim at demonstrating performance of different MOSS configurations. For this, dependent variables are obtained springing from the raison d'être of the MOSS which can be summarised in performance criteria (e.g. early detection). Performance indicators can e.g. be the number of infected herds at the end of the high-risk period and the confidence the average time to detect a hazard introduction.

With all the general parameter inputs, choice variables and performance variables a model can be constructed. It is not the intention to build a 'from scratch' model for any hazard. The holistic approach implies a forward and backward arrow in Figure 1 between inputs, performance definition and models. Suitable generic standard model structures can be adopted from the literature. These models can be calibrated for specific single hazards. A similar approach will be developed for portfolios.

Once performance indicator outcomes are obtained a subjective valuation of these outcomes must be made taking account for subjective preferences. Several methods are thinkable to further reduce the number of feasible solutions. By either deducting hard utility assumptions or with softer decision rules capturing shared performance perceptions final cost-effective solutions can be found.

Important issues to ensure cost-effective monitoring and surveillance

In this section a brief overview is given of some of the relevant topics important for determining the cost-effectiveness of a MOSS.

Sampling design

Overall cost-effectiveness of sampling depends on technical test performance measures (sensitivity, specificity, predictive values) and related costs. Choosing the optimal sampling size and sampling frequency is important. Literature on this topic is abundant. Cameron and Baldock (1998) note that disease prevalence is often clustered within herds and show optimal herd and individual sample size to substantiate disease freedom. Wagner and Salman (2004) propose a formula for herd level prevalence estimates when tests are not perfect.

Diverse ‘targeted’ or ‘risk-based’ sampling strategies have been proposed. Alban et al. (2008) e.g. find that Trichinella spp. could be monitored more efficiently when aimed at out-door reared pigs. Tavornpanisch et al. (2006) identify that cows in higher lactation have a higher probability of positive testing on paratuberculosis. Schwermer et al. (2009) analyse the value of earlier surveys to calculate new sample sizes, based on importation risk and the proportion of surviving animals within the subpopulations. Target groups may also be defined spatially. Salmonella monitoring may e.g. be targeted at farms in a high-density area of slaughter-pig farms (Benschop et al., 2009).

Legal environment and instruments

In many parts of the world monitoring and surveillance is formalised in a comprehensive legal framework. The OIE has listed notifiable diseases (OIE, 2009a). In the OIE Terrestrial Manual prescribed and alternative diagnostic tests and vaccines are specified for some listed diseases (OIE, 2009b). The Codex Alimentarius Committee prescribes maximum residue limits and test performance requirements. On European level, the EFSA has an important role in assessing and communicating risks associated with food production chains. Legislation is set in EC Directives and further specified in national programmes. On the national level, the ministries of agriculture and health as well as product boards have responsibilities regarding the formulation of legislation.

Performance indicators and modelling

With the percentiles of the number of infected herds at the end of the high-risk period as performance indicator Klinkenberg et al. (2005) calculate effectiveness and costs of some alternative surveillance programmes for CSF with a state-transition model. Similarly, Fischer et al. (2005) use a stochastic SLIR model to determine median time-to-detect and median number of infected farms for M. Bovis outbreaks under different surveillance strategies. Graat et al. (2001) use the basic reproduction rate between herds (R_h) as performance indicator to determine minimum surveillance requirements for BHV1. Martin et al. (2007) propose a scenario-tree approach with the inclusion of different data sources to estimate total system sensitivity to substantiate disease freedom.

The above examples show different modelling approaches and performance indicators to determine the effectiveness of a MOSS. Some of the authors also explicitly include economic aspects. Modelling approaches and performance indicators vary not only within hazard classes. Coffey et al. (2009) e.g. assess human exposure risks to mycotoxins in dairy milk with a simulation model.

Decision rules

The model outputs are probability distributions for multiple PIs. Trade-offs may become visible between PI outcomes. Ideally, MOSS alternatives could be ranked with full information about utility functions of decision makers. Since this will generally not be the case, decision rules are needed which specify the generally shared perceptions about the value of the PI outcomes.

Portfolio investment under uncertainty has been subject of much research in finance. Markowitz (1952) has introduced mean-variance analysis. The theory on stochastic dominance and asymmetric risk measures has evolved (e.g. Bawa, 1975).

The budget allocation problem of food-safety authorities is similar in nature. Budget is allocated on the basis of expectations about the benefits of monitoring activities. Also, food safety authorities show risk-averse attitudes. This is expressed in the amount of budget spent to limit risks: a risk premium is paid. An example is the observed unbalance in surveillance costs for BSE compared with the additional risks when some of the measures would be relaxed (cf. Adkin et al., 2009; Benedictus et al., 2009).

Conclusion and discussion

The cost-effective optimisation of MOSSs is complex. A stepwise approach is considered to determine cost-effective MOSSs; both the problem of single and portfolio MOSS optimisation are investigated.

The holistic approach comprises hazard categorisation, performance definition and generic model formulation. It is presumed that it is possible to formulate a limited number of hazard categories which can be made specific.

Much attention will be paid to the systematic interpretation of model outcomes.

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