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A comparison of three modelling approaches for quantitative risk assessment using the case study of *Salmonella* spp. in poultry meat

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Abstract

A comprehensive review of both the scientific literature and industry practices was undertaken to identify and quantify all sources of contamination throughout the entire poultry meat production chain by *Salmonella* spp. This information was used to develop a quantitative risk assessment (QRA) model for *Salmonella* in the production chain from the breeder farm to the chilled carcass. This was subsequently used as the basis on which to compare the merits of three approaches to QRA modelling in such systems. The original model used a Bayesian Network (BN). The second method was a Markov chain Monte Carlo (MCMC) approach, a numerical Bayesian technique which retained a similar network structure but allowed further development, such as the separation of variability and uncertainty. The third method was a more detailed simulation model.

The BN responds immediately to changes, such as entering evidence, because it does not use simulation and can propagate information from any point in the network to all others by Bayesian inference. However, it requires all the variables to be discrete, which introduces errors if continuous variables have to be discretized. These errors can accumulate. The MCMC approach does not require discrete variables while retaining some of the properties of the BN model, such as the ability to draw inferences from evidence. Finally, the simulation offers greater flexibility, such as consideration of the individual carcass, but may be more complex to implement as a result and sacrifices the ability to propagate evidence.

Keywords: Quantitative risk assessment models; *Salmonella* spp.; Bayesian networks; Monte Carlo methods; Poultry meat

1. Introduction

In 1998–1999, a 1-year project was conducted to produce a comprehensive review of both the scientific literature and industry practices and identify and quantify all sources of contamination throughout the entire poultry meat production chain by *Salmonella* spp. The review also collated information on control measures and their effectiveness for this pathogen, utilising quantitative information wherever possible. This was used to develop an initial quantitative risk assessment (QRA) model of the production chain. The review found 906 publications on *Salmonella* from 1988 to 1998, of which 94 contained potentially useful quantitative data. On further examination, only about one-third could be used for model development;

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most of the others did not provide sufficient information on the effects of processes on the chain. In general, processing, especially operations such as carcass washing, received more attention than primary production.

The industry survey, which included representatives of all the large UK producers of chicken meat, found that there was widespread monitoring for *Salmonella* at all stages of production and implementation of HACCP procedures to control it. At that time, the contamination rate in final products was 3–20%, mainly in two clusters at the ends of that range. Since then, there has been progress in reducing these levels. The model was based on the information available at the time. WHO/FAO (2002) contains surveys of more recently published information on *Salmonella* in poultry.

The remainder of this paper will concentrate on the QRA model for *Salmonella* in the poultry meat production chain from the breeder farm to the chiller. It will outline the analysis methods leading to the qualitative model and describe three approaches to the quantitative model in order to compare their strengths and weaknesses for this type of work. The first—a Bayesian network (BN) or causal probability network (CPN)—was developed for the original study; the other two resulted from subsequent research on appropriate modelling techniques.

QRA is the study of decisions subject to uncertain consequences using the tools and techniques of probability theory and statistics (Royal Society, 1992). It is applied in many different fields; Hoornstra and Notermans (2001) looked at how to apply QRA to food safety. The typical products of a QRA exercise would be a series of statements of potential harms, whether expressed as financial costs or harmful consequences to the population, and the probabilities associated with them. Typical examples include the probability of death in middle age for male and female non-smokers and statements of the number of deaths per passenger mile or passenger journey for different types of transport. Related disciplines include: risk perception, the study of how people think about risk; risk communication, the effective transmission of information about risk; and risk management, taking decisions in uncertain situations so as to control risk to an acceptable level. Vose (1998) looked at modelling techniques and probability distributions that can be used in a Monte Carlo simulation QRA model. This paper looks at alternative ways of implementing QRA models.

One of the key features of QRA is that it attempts to look at whole systems and not at isolated parts. Each possible adverse event is followed through to its consequences, and the consequences of different adverse events can be combined. This is only possible using a quantitative approach which provides a common basis for the evaluation of risks and harms.

The final stages of transport, retailing, cooking and consumption were not within the scope of the study, so it was not possible to quantify harm in public health terms. This would require extensive studies of the handling and treatment of poultry products in domestic and commercial kitchens and the derivation of dose response functions for exposure to the pathogen; an example of a risk assessment that does this for *Salmonella* in chicken can be found in WHO/FAO (2002), which commences at the conclusion of slaughterhouse processing. Instead, harm was measured in terms of the carriage rate of the pathogen on the final product. Furthermore, the sampling and culturing techniques required for the pathogen of interest mean that, generally, it is not possible to estimate the number of organisms carried; the data are normally presented simply as the proportion of birds estimated to be positive, so this is the variable with which the model has to work.

2. Systems analysis

Although the qualitative and quantitative analysis of this section was done with the idea of a BN model in mind, it is relevant for all of the models used in this paper.

2.1. Qualitative analysis

The qualitative structure of the model as a network diagram was developed through a formal systems analysis procedure which was similar in many ways to the knowledge acquisition phase of an expert system development. A series of meetings was held with ‘domain experts’. These people were the partners and consultants to the project with specific expertise in the poultry industry and microbiology. In the first