Hazard analysis of salmonella in pork using tree diagrams

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Introduction

A series of graphical methods are routinely applied in safety analysis in the process industry (1). These techniques are intuitive because they are graphical, and they provide good communication tools as they allow the display of relationships between events and a dynamic analysis of how the coinciding occurrence of events can lead to undesired outcomes, such as salmonella infection.

Despite these advantages, these methods have only rarely been applied in food safety risk assessments. This paper describes the application of graphical hazard analysis tools for the further characterisation of salmonella transmission and contamination in the Danish pork production chain.

The objectives of this part of the project were:

1) To explore the applicability of graphical techniques for analysing food safety hazards in a ‘stable-to-table’ setting.

2) To gain insight into the hazardous processes related to salmonella transmission and contamination in pork production.

Only results of the analysis at the farm level are presented in this paper.

Short description of tree-based methods

Event tree analysis

An event tree evaluates the potential for an undesired event (accident, e.g. salmonella contamination of a carcass) to happen using inductive reasoning (1). The analysis starts with an initiating event. The possible consequences of events (system response) that may lead to a potential failure are then developed. At each node control steps that may or may not be successful can be included. Event trees are well suited for analysing initiating events that could result in a variety of outcomes and to model the time relationship between failures and events in an event sequence.

A similar type of tree, the scenario tree, is often used in risk assessments (2,5). Again, the tree starts with an initiating event that may lead to a series of outcomes (scenarios). However, the focus is not so much on potential failures as on the documentation of all possible outcomes, including the desired scenario, where nothing goes wrong.

Fault tree analysis

A fault tree is a graphical model that illustrates combinations of events that will cause one specific failure (undesired event, e.g. salmonella infection of an animal), called the ‘top event’ (3). Fault tree analysis represents a top-down approach. It is a deductive technique that uses Boolean logic symbols (‘AND’ gates, ‘OR’ gates). It can be used to identify both technical failures as well as human errors. The analysis begins with the setting of the undesired event (top event). Then, the immediate causes of this event are identified. Each of the immediate causes is subsequently examined further in the same manner until the basic failure is found.

A fault tree model can be used to create a list of event combinations that can cause the top event. These combinations are also called ‘cut sets’. The minimal cut set is the smallest combination of failures that can cause the top event. If the frequencies of the basic failure events are known, fault trees can be used quantitatively.

Cause-consequence analysis

A cause-consequence analysis incorporates features both of both fault tree and event tree (1). This technique is particularly suited to communicate the relationship between failure causes and consequences.

It starts with the selection of a ‘central’ event, that would be suitable both as a starting point for an event tree (initiating event) or a fault tree (top event). The tree is then developed in two directions, considering the causes (fault tree) and the consequences (event tree) of the central event.

Results

All trees were developed in close collaboration with various people involved in salmonella control in Denmark. Preliminary versions were prepared, discussed and altered according to the feedback received in an iterative fashion. The versions presented here represent our current knowledge of salmonella transmission and contamination.

The event tree at the farm level starts with a salmonella-free pig coming out of the nursery (Figure 1). It is then either exposed or not exposed to salmonella during growing-finishing and then during transport. Given an exposure, the
possibility to prevent infection, for example, by protective feed is considered and also the possibility of recovery. An exposure on a transport truck can result in infection with and without shedding, depending on the transportation time. Exposure can also result in contamination of the skin. If the pig is transported to another farm, the tree can be re-applied considering chance of exposure for salmonella-free pigs and chance of recovery for infected pigs. If data to estimate the probabilities of all chance nodes (p1-p10, Figure 1) are available, the probability of each branch or scenario can be calculated. This has not yet been performed as part of this project.

The undesired top event of the fault tree analysis at the farm level was a salmonella-infected pig at the point of unloading in the abattoir. This tree includes all processes on the farm(s) of origin of this pig and the transport to the abattoir. The fact that the pig could have been kept on several farms during its life is represented in Figure 2.

At the second level after the top event the branch 'EXPOSURE' and the primary event 'INFECTION' are listed. Both have to occur ('AND' gate) in order to lead to the top event. This accounts for the fact that not all exposures actually lead to infection. The pig may be protected by, for example, high immunity or protective feed. The factors leading to infection are however not further developed. If infection does not take place, the outcome could be either a contaminated or a salmonella-free pig.

For clarity reasons, the tree is split up into several sub-trees, only one of which is presented in Figure 3. Exposure with salmonella can originate from the environment, the feed, other pigs, during transport or from people or any combination of these ('OR' gate). The environment was divided into equipment and pen. The latter can be contaminated from equipment, liquid manure reflux, infected pigs, wildlife or people, if it is not cleaned sufficiently. Further sub-trees develop the causes of contamination from feed, during transport and from other pigs.

If following a series of events from the end of a branch to the top event, the event combination that can cause the top event, called 'cut sets', can be identified. Among the events in a cut set, two types can be distinguished: Initiator events and enabler events. An initiator event is an event that will only contribute to a system failure when it is the last event to occur in an event sequence. An enabler event is an event that will only contribute to a system failure when it is not the last event to occur. An example of an enabler event is 'INFECTION'. And an example of an initiator event is 'INFPPIG'.

A common cause failure is defined as the occurrence of more than one failure event due to the same cause. In this fault tree, some event patterns can be identified. For example, there are some recurring sources of salmonella as initiators (pigs, wildlife, people) resulting in contamination and the contamination is not removed by, for example, effective cleaning or heat treatment of feed. Another pattern is the failure to prevent contact with a possible salmonella source by, for example, mixing of infected and not-infected pigs (sub-tree not shown).

Most obviously, the event 'INFECTION' is a common cause failure as it is listed in all cut sets. This can be interpreted such that if this event – theoretically – can be completely prevented, salmonella infection could not occur (only contamination). These results are consistent with observations from the field showing that changing the feeding system (and hereby influencing the prevention of infection) is most effective, while management measures alone (increased hygiene, all-in/all-out system, reduced stocking density) will not achieve an equally good result (4).
Figure 1: Partial event tree for salmonella infection and contamination from the farm level until unloading at the slaughter plant, 6 outcome combinations (infected +/-, shedding +/-, contamination +/-)
To illustrate the application of a cause-consequence analysis, the situation of a contaminated feed pipe was used (Figure 4). The specific consequences of the central event ('salmonella exposure from contaminated feed pipe') are linked with the possible causes and consequences. Similar as with a fault tree, the diagram can be interpreted as a series of 'cut sets', representing the combination of basic causes resulting in a event sequence.
Discussion

The use of fault trees has been described in principle for risk assessments in the veterinary field (5), but no applied examples have been published to our knowledge. We found fault trees to be a useful tool for documenting possible causes of undesired events and the relationship between sets of factors. The extent of the trees was reasonable, and they could still be handled manually, although software packages are available.

The results of the fault tree analysis were consistent with observations from the salmonella control programme in Denmark (4). It was possible to provide complementary logic for experience from the field. The potential to use the fault tree quantitatively was not used in this project. It is obvious that the quantification of basic events poses a considerable challenge for any fault tree analysis. It is therefore an accepted practice to prune fault trees at a level of detail at which information can be obtained. Although it would be feasible to use fault tree analysis in this way within this project, this was not conducted, primarily due to lack of data.

Marks et al. (6) argued that the application of fault trees to food safety risk assessment was limited because the dynamics of microbial growth cannot be included. We believe that the scope of microbial growth from slaughter to chilling is limited due to the relative short duration of the process. This limitation of fault tree analysis is therefore considered negligible.

The use of event or scenario trees is well established in the risk assessment community, both in the engineering and biological fields. The event trees can be used quantitatively, and they are a good basis for further modelling using, for example, Monte Carlo simulation, as they outline the structure of the risk model and the data requirements. This is how the event tree presented in this paper will be used in the salmonella risk assessment project.

The use of cause-consequence analysis appears to be more suitable for communication tasks than as an analytical tool as only simple models can be displayed easily.
References


