A MECHANISTIC SIMULATION MODEL TO STUDY THE EFFECTIVENESS OF INTERVENTIONS AGAINST *E.coli* O157 IN A DUTCH CATTLE SLAUGHTERHOUSE

B. Vosough Ahmadi[1], A.G.J Velthuis[1], H. Hogeveen[1], R.B.M Huirne[1]

[1] Wageningen University, Business Economics Group, Hollandseweg 1, 6706 KN Wageningen, the Netherlands

Background

Reducing the contamination level of beef carcasses with enteric pathogens such as *E.coli* O157:H7 (VTEC), by means of implementing preventive measures in the slaughterhouse, is regarded to be important. Cost-effectiveness analysis is a valuable tool to evaluate the existing preventive measures. For a reliable cost-effectiveness analysis, beside calculation of the costs for each intervention, a good insight into the benefits is needed. According to the definition of Food Safety Objectives (FSOs), any reduction in the frequency and/or concentration level of a microbiological hazard in a food product can be treated as an appropriate benefit for a certain intervention (Havelaar et al. 2004). Microbial decontamination methods are the commonly used preventive measures against the bacterial hazards in slaughtering plants. In the majority of studies in this field, scientists have been mostly interested on reduction in the number of bacterial Colony Forming Units (CFUs) on the surface of the meat, using interventions after experimentally contamination. Due to the essences and objectives of these types of studies, the effects of interventions, in terms of reduction in frequency of the contaminated beef units, will not be reported. Moreover, only few studies have been done to investigate the effectiveness (in terms of reduction in prevalence) of the intervention methods in the slaughtering process in real practice.

To fill this gap one can consider two approaches: 1) putting the interventions into practice in a slaughterhouse and observing the effects or 2) using computer simulations and performing sensitivity analysis. The first approach is not feasible to apply, because it is costly and disruptive (van der Gaag, 2003). Computer simulation is an attractive alternative to the implementation of explorative control strategies.

Objectives

The aim of the study presented in this paper is to build an epidemiological framework to investigate the effectiveness of different intervention methods along the beef slaughter line, in terms of reducing the frequency of contaminated beef quarters with VTEC. The result of this study will be used as a part of inputs needed for the cost-effectiveness analysis, which will be the next step in our research. Decision makers in the beef slaughtering industry are the potential users of the results.

Materials and methods

The general model described in this paper was build on a Microsoft Excel spread sheet using @Risk add-in software. In our model 500 cattle enter a typical Dutch industrial slaughterhouse on a daily basis. Two main sources of VTEC in/on the body of cattle on the farm can be recognized: 1-In the gastrointestinal tract (GI) and 2- On the hide (Heuvelink, 2001). Animals entering to the slaughterhouse can be grouped in the four groups, based on their GI tract and hide status: 1- [GI^+ H^+] 2- [GI^+ H^-] 3- [GI^- H^+] 4- [GI^- H^-].

Slaughter process

The following stages have been included in the model: *de-hiding*, *evisceration*, *splitting*, *fat/tail removing*, *trimming* (as a decontamination method), *washing with cold water* (for cooling down purpose) and *chilling*. Because the main possible interventions on the slaughter line are applied before the de-boning and fabrication stages, the beef carcass quarters (hind-quarters and fore-quarters), which are produced after the chilling stage, have been considered as the end product in our model. For each of the mentioned stages, a main risky event for VTEC transmission was identified from the literature: Direct contact of carcass surface with the hide of anus area for the de-hiding stage, rupture of the GI tract for the evisceration stage, contamination of splitter saw for the splitting stage, contact with contaminated knife for the fat trimming stage, spreading the bacteria from the hind-quarter to the fore-quarter for the washing stage and carcass-to-carcass contact for the chilling stage.

The output of the model is a distribution of the number of VTEC contaminated quarters of the beef carcasses, produced in one day at the end of *chilling* stage. Therefore, the prevalence of contaminated quarters in this model refers to the number of contaminated quarters out of 2000 produced quarters.

Stochastic Process of the model

Monte Carlo simulation with 10,000 iterations was implemented. One iteration of the model represents one day production of the slaughterhouse. As, during each slaughtering stage, two possible outcomes (contaminated versus not-contaminated) can be recognized, the *Binomial process* was chosen as the stochastic process of the model (Vose, 2000). In this model, quarters contaminated with no bacteria (zero CFU) are defined as negative, irrespective to the detection level of the routine bacteriological tests. In opposite, quarters with even one CFU contamination on their surface are treated as positive.

Three different stochastic processes are distinguished that determine the contamination status of a quarter in a stage. These processes are modelled as from equations 1 to 6. Let N denote the total number of quarters entering stage, $S_{(j)}^{+}$ the number of positive quarters after modelling the stochastic process by either $(j=1)$ the main risk factor or $(j=2)$ the environment or $(j=3)$ decontamination processes. $S_{(j)}^{-}$ is thus the number of negative quarters after each stochastic process. Considering Pr and Pe as probabilities of changing the status of a quarter from negative to positive due to the risky event or/and environment , and denoting Pd for changing the status from positive to negative by decontaminations, three levels of the model are written as:

1- Contamination due to the Risky Event of the stage

$$S_{(1)}^{+} = \text{Binomial}\ (S_{(0)}^{-}\ ;\ Pr) + S_{(0)}^{+} \qquad (1)$$

$$S_{(1)}^{-} = N - S_{(1)}^{+} \qquad (2)$$

2- Contamination by the Environment of the stage

$$S_{(2)}^{+} = \text{Binomial}\ (S_{(1)}^{-}\ ;\ Pe) + S_{(1)}^{+} \qquad (3)$$

$$S_{(2)}^{-} = N - S_{(2)}^{+} \qquad (4)$$

3- Decontamination

$$S_{(3)}^{-} = \text{Binomial}\ (S_{(2)}^{+}\ ;\ Pd) + S_{(2)}^{-} \qquad (5)$$

$$S_{(3)}^{+} = N - S_{(3)}^{-} \qquad (6)$$

The yearly prevalence of VTEC infection of dairy cattle (0.0096) in the Netherlands, infected in the GI, was used in the model to determine the number of infected cattle entering into the slaughtering line (Nauta, 2001). The other mentioned probabilities have been estimated based on available data found in the literature and experts opinion, which the list of these references is available with the authors.

Interventions

Interventions can reduce transmission probabilities of VTEC in certain stages of the slaughtering process. They also can reduce the transmission probability from the environment to the carcass and can change the contamination status of the quarters itself. Interventions can be categorized in three groups: *a*- cleaning and hygienic interventions; *b*- decontamination methods (and combinations); *c*- other interventions (e.g. replacing a stage by another or stopping a risky event).

We mainly focused on the decontamination methods and tried to compare their effectiveness, when they are used individually or in combination with other interventions. A linear relation between the reduction of CFUs and the reduction factor for the changing status probability (from positive to negative) was assumed. Using the data reported by Phebus et al (1997) for the level of reduction in number of CFUs in experimental studies, and mentioned linear relation, the level of reduction on changing the status probability for the five important decontamination methods were determined (the estimated reduction factors are given as: 0.0 for no intervention; 0.12 for hot water wash (H); 0.43 for lactic acid rinsing; 0.5 for trim (T); 0.51 for steam-vacuum (V); 0.57 for steam-pasteurization (S) and 0.99 for irradiation). Irradiation has been known as the most effective decontamination method by reducing the numbers of CFUs of VTEC by 10^6 CFU/cm^2 (Molins, 2001). Therefore irradiation was chosen for the upper bound of reduction factor. The default situation, where no intervention is applied, represents the lower bound. In total 18 interventions (including combinations) were examined in our model.

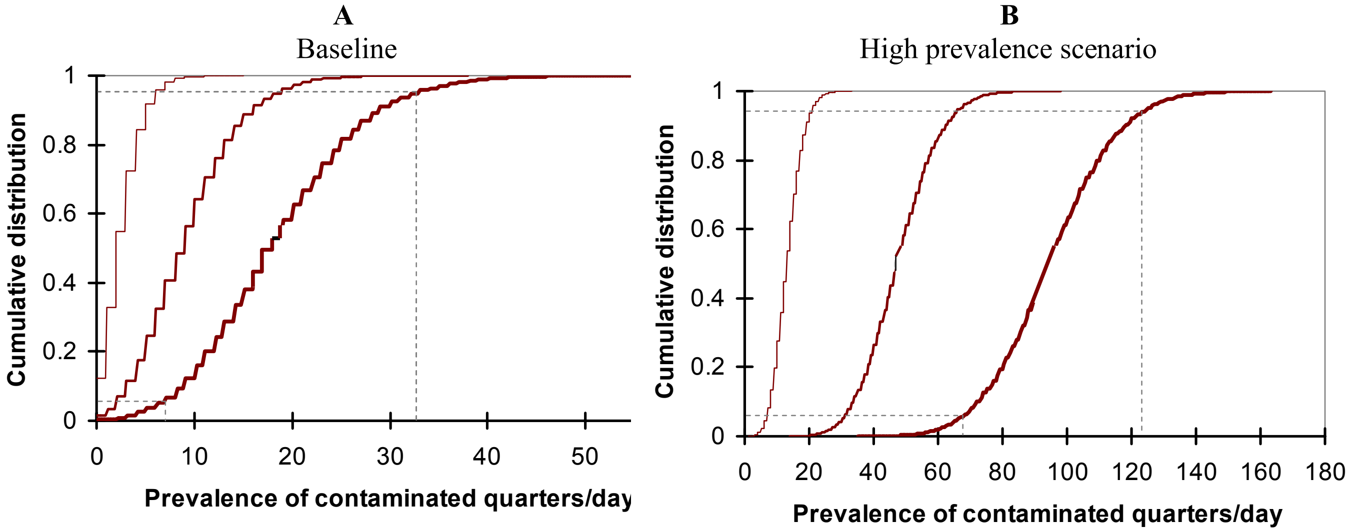
Results and discussion

Table 1 shows the baseline output of the model as well as the effects of implementing the interventions on the output. In the baseline situation, on average 18 contaminated beef quarters are produced in a working day. The distribution of the number of contaminated quarters in the baseline situation shows that in 95 % of the working days, the number of contaminated quarters is less than 33 quarters. Besides that, in 5% of the working days less than 6 contaminated quarters are produced. As it is expected, irradiation shows the highest effectiveness. In opposite hot water wash has the lowest effectiveness to reduce the frequency of contamination.

To make a comparison with the baseline situation, the distributions of two interventions, one from the middle of the table 1 (TW) and one from the top (VWLS) are illustrated in figure 1A. Applying TW and VWLS, the 95th percentiles values reduce to 18 and 6 quarters. In general a combination of interventions gives a better effect.

A comparison between our results and the study of Phebus et al (1997) shows an almost similar ranking order (table 1). However some differences exist. In the mentioned research, hot water washing of the carcasses after trimming (TW), had the first place of their list and applying only hot water wash was the least effective method to reduce the number of CFus/cm^2 of the meat surface. The most important difference is that, the combined intervention TWLS showed the most promising results in our study whereas, it's in the fifth place in their list. A possible reason for this is that in the laboratory trimming, freshly sanitized instruments are used and great control to prevent cross contamination is applied.

In a higher prevalence scenario (0.05), illustrated in figure 1B, the mean number of contaminated quarters will increase up to 95 quarters per day (125 quarters for 95 percentile). The TW and VWLS can reduce the mean number to 45 and 18 quarters, with 95 percentile as 68 and 20 respectively. This implies that the prevalence of infections at the farm is important and application of interventions at the slaughterhouse in such a situation would play a crucial role to keep the frequency of contaminated product in the acceptable level.



Default (no intervention)
TW (trim & washing)
VWLS (Steam Vacuum, Washing, Lactic acid, Steam-Pasteurization)

Figure 1 Distribution function for the number of contaminated beef quarters per day in with and without intervention situations. Graph A: baseline results, using yearly prevalence of GI infection for incoming animals to the slaughterhouse. Graph B: higher prevalence scenario (0.05).

Table 1 Baseline output of the model and the effects of interventions.

Interventions	**Stage**	**Mean**	**5th & 95th percentiles**	**Rank order in this study**	**Rank order in Phebus's study**
Irradiation	washing	00.22	0 – 1	1	na*
VWLS	de-hide/evisc/wash/split	02.58	0 – 6	2	2
TWLS	de-hide/evisc/wash/split	02.57	0 – 6	2	5
VWS	evisc/split/wash	04.16	1 – 9	3	6
TWS	de-hide/evisc/wash	05.00	1 – 11	4	3
TWS	de-hide/evisc/split	05.14	1 – 11	4	3
WS	evisc/wash	07.97	2 – 15	5	4
WS	evisc/split	08.21	2 – 16	6	4
VW	evisc/wash	09.13	2 – 17	7	7
Steam Pasteurization (S)	splitting	09.17	2 – 17	7	7
TW	de-hid/evisc	09.20	2 – 18	7	1
Trim (T)	de-hiding	10.38	3 – 20	8	9
Steam Vacuum (V)	evisceration	10.20	3 – 20	8	8
Trim (T)	splitting	10.46	3 – 20	8	9
Steam Vacuum (V)	splitting	10.40	3 – 20	9	8
Acid Lactic (L)	washing	11.36	3 – 21	10	na
Move chest opening**	de-hiding	15.34	5 – 28	11	na
Hot water wash (W)	washing	16.33	6 – 29	12	na
Hot water wash (W)	splitting	16.67	9 – 29	12	10
Baseline (without)		**18.42**	**6 – 33**	**-**	**-**

*na: These interventions either have not been considered in study of Phebus (1997) or have been applied in other sequence.

** Brisket region is opened in the de-hiding stage in our visited slaughterhouse.

Conclusions

Firstly, the results of this study show that, the use of computer simulation to evaluate the effectiveness of interventions along the slaughter line is a promising approach.

Secondly, the combinations of decontamination methods have more positive effect on reduction of frequency of contaminated quarters than individual interventions.

Thirdly, in a high prevalence scenario, application of interventions in the slaughterhouse plays a crucial role to keep the frequency of contaminated product in the acceptable level.

The forth and the last conclusion of this study is that, changing the place of the individual interventions in the slaughtering line has not a significant effect on the frequency of contamination. However the effectiveness of interventions is slightly increasing toward the end of the slaughter line.

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