PROBABILISTIC RISK ASSESSMENT AND SLAUGHTERHOUSE PRACTICES: MODELLING CONTAMINATION PROCESS CONTROL IN BEEF DESTINED FOR HAMBURGER

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ABSTRACT

The art and science of risk assessment as applied to foodborne pathogens is still in its infancy and limited to what can be measured and quantified.[1] Many important process components are omitted from models, including this one, because of lack of data. Still the models may yield insights into process control and evaluation and/or into data collection priorities and need to be proposed for scientific evaluation and further refinement.

This paper models four beef slaughterhouse events with two levels of process control of generic *E. coli*. Monte Carlo simulation is used to characterize the distribution of contamination of average raw burgers. For slaughter plants with each process at "level 1" control, <1.5% of raw hamburgers have >4 $\log_{10}$ colony forming units (CFU) of generic *E. coli* per quarter-pound hamburger. In contrast, plants with all "level 2" processes produced >93% of raw hamburgers with this level of generic *E. coli*. Sixteen scenarios are used to measure the sensitivity of the output distribution to changes in process control regimes at each step.

I. INTRODUCTION

Forty foodborne pathogens are estimated to cause 6.5 million to 33 million human illnesses annually with up to 9,000 deaths and unquantified chronic illnesses.[2] Medical costs and productivity losses for seven foodborne pathogens are estimated at $6.6 billion to $37.1 billion annually.[3] In response to increased public health concerns about foodborne pathogens, both the USDA and the FDA have instituted mandatory and voluntary pathogen reduction programs, such as Hazard Analysis and Critical Control Point (HACCP) systems, for foods under their jurisdiction.

In the summer of 1998, the National Academy of Sciences studied how to improve the U.S. food safety system. Their most important conclusion[4] was that the food safety system: "…be science-based, with a strong emphasis on risk analysis, thus allowing the greatest priority in terms of resources and activity to be placed on the risks deemed to have the greatest potential impact (p. 5)."

This paper develops a process model that includes the major functions of beef slaughter plants. Average carcass contamination is modeled as the sum of random variables that represent either contamination or decontamination of the carcass surface. The probability distributions of the component variables are roughly estimated from the available literature, with an emphasis on identifying the range of values. For each step in the process, two different levels of practice indicating level of process control are defined. The data available on slaughter operations is scarce, and subject to both variability and uncertainty in each step. Since the focus of this work is on identifying opportunities for process control, no attempt is made to separate variability and uncertainty.

The output of the model is a distribution of contamination of an average raw hamburger. Monte Carlo Simulation is used to create this distribution and assess the control of the process. Output process control is defined to mean the probability that an average burger is below some specified level of contamination. By comparing the levels of output process control under combinations of process control for the component steps, the contribution of changes in process control regimes at each step can be evaluated.

II. SLAUGHTER PLANT PROCESS

To identify the most important steps in the slaughter process, from a risk perspective, a flow diagram was constructed for live cattle entering the slaughter plant and going through typical U.S. commercial butchering procedures (fig. 1):

- cattle are transported to holding pens and handled prior to stunning
- cattle are stunned, hung from an overhead rail, bled, and hides are removed
- carcasses are trimmed and spot steam vacuumed to remove visible contamination
- the gastrointestinal (GI) tract is removed and carcasses are sawed in half
- carcasses are decontaminated via a combination of spot steam vacuum, hot water washes, steam pasteurization of the whole carcass, and organic acid rinses
- carcasses are chilled for 18-48 hours
- carcasses are fabricated to remove meat from the bones and package it in boxes or 2,000 pound combo bins
- meat is transported for grinding into hamburger either in the slaughter plant or another facility.

While the contamination status of the incoming cattle is critical,[1] differences in plant size, plant procedures, general sanitation practices, worker training, auditing and management competency may account for the wide range of observed contamination of beef carcasses among plants. In a study of 7 beef slaughter plants, plant characteristics and practices were found to be the most statistically significant determinant of generic *E. coli* levels on the carcass.[7] The data, while reported by plant, do not identify how the specific practices vary by plant. Gill found that changes in plant operating procedures during dehiding can significantly change the level of generic *E. coli* on the carcass.[8]

Because few samples are usually taken for pathogen monitoring, the uncertainty about the values obtained tends to be high.[a] Ideally, a model should separate the variability of the data from uncertainty, however, the limited data available on slaughterhouse practices and attendant pathogen levels or generic *E. coli* associated with the specific practices means uncertainty and variability are often commingled in models. Furthermore, plants vary in the sources of incoming animals, which makes measuring the impact of specific plant practices more complex.

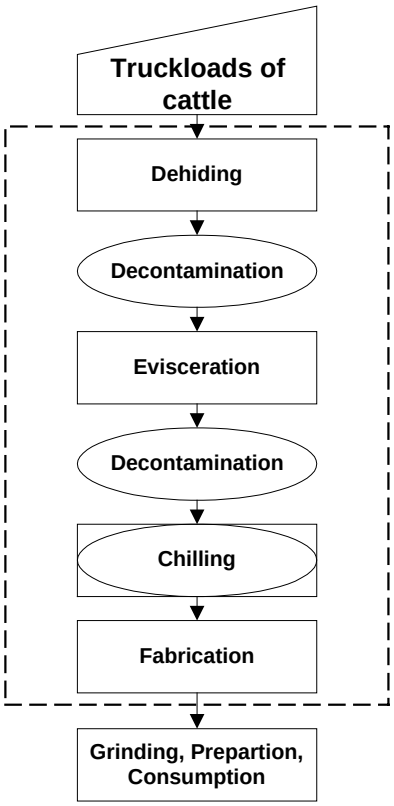


Figure 1: Steps in the ground beef production process (Boxes represent contamination, ovals represent decontamination).

It should also be recognized that the most critical steps in Fig. 1 partly depend on the pathogen of concern. For example, *Listeria monocytogenes* can survive in the plant environment, particularly in the drains and refrigerators, and can be spread through the air from other parts of the plant to clean rooms for cooked products.[9] Parasites, such as *Trichinella spiralis* and *Toxoplasma gondii*, cannot replicate outside a host and cannot grow in the plant environment, although cysts are likely to survive.

While it is difficult to develop a "template" model that applies to all pathogens and all animal products, most enteric pathogens, such as *Salmonella*, *Campylobacter*, and *E. coli* O157:H7 are most likely brought into the slaughter plant on the interior or exterior of live animals. We have chosen generic *E.*

[a] However, because pathogens are generally of low prevalence, large numbers of samples may be required for statistical process control. Firms may be reluctant to test for pathogens because tests are expensive or take too long and interfere with perishable meat products moving to market. Firms may also avoid pathogen tests because of liability concerns.

coli as an indicator of process control in this model for two reasons:

- the prevalence of generic *E. coli* is relatively high in the GI tract of cattle and on the hide of cattle,
- presence or absence of generic *E. coli* on a carcass can indicate whether fecal contamination of the carcass has occurred and the possibility that other GI tract contaminants could also be on the carcass.

In 1996, FSIS mandated HACCP for meat and poultry plants and required that plants regularly test for generic *E. coli* as an indicator of process control. Statistical Process Control is being used in poultry inspection by Agriculture and Agri-Food Canada to demonstrate to consumers and trading partners that transferring responsibility for inspection of some processes to industry will "have no adverse impact on safety."[10]

III. MODEL STRUCTURE

The slaughter plant is modeled as a simplified version of the process described above. The four steps included are dehiding (d), steam pasteurization (s), chilling (c), and fabrication (f). Monte Carlo simulation is used to compute the average contamination level per combo bin (X). In each iteration of the model, this value (expressed as $\log_{10}$ CFU) is determined by the net contribution of the four steps:

$$X = d + s + c + f$$

The average number of contaminants per burger (expressed as $\log_{10}$ CFU) is given by:

$$N = \log_{10}((A * SA * (\%SA) * 10^{X})/8000)$$

where A is the number of animals contributing to a 2000 pound combo bin, SA is the surface area of the animal, %SA is the percentage of the surface area that ends up in the combo bin. There are 8000 quarter-pound burgers per combo bin. Multiple iterations of the model produce a probability distribution of N.

To illustrate the impact of plant practices on process control and contamination with generic *E. coli*, we have modeled a series of plant scenarios so as to compare and contrast the results. The output of each model is the $\log_{10}$ CFU of generic *E. coli*. The plant categories are:

- cow slaughter plant with "level 1" control practices
- cow slaughter plant with "level 2" control practices
- steer/heifer plant with "level 1" control practices
- steer/heifer plant with "level 2" control practices

Cow plants differ from steer/heifer plants in the portion of the carcass that goes into hamburger. Most of the steer/heifer carcass becomes steaks and other cuts and only 20% ends up as trim going into hamburger or other ground products. In contrast, only a few select roasts of the cow are left intact with 80% of the carcass destined for grinding.[11]

Most contamination occurs on the surface of the carcass. This surface area is more likely to become contaminated during dehiding, or from workers hands, other contaminated carcasses, equipment, or aerosols. For steer/heifers, an estimated 75% of the surface area (54,000 cm^2) contributes to ground products.[12] For the cows, we estimated 90% or more of the surface area (40,000 cm^2) is destined for grinding. In each case, the surface area goes into 2,000 pound combo bins ready for grinding into hamburger. On average 6 2/3 animals contribute to a combo bin in a cow plant and 20 animals contribute in a steer/heifer plant. Because of these differences, steer/heifer and cow plants are modeled separately.

A. Dehiding

The computation begins by assigning a level of generic *E. coli* in $\log_{10}$ CFUs reported by Gill[8] on the hindquarters during hide removal. Plants were initially reported to have 4.47 $\log_{10}$ CFU/100 cm^2 of generic *E. coli*, but improved skinning practices were able to reduce these numbers to 2.23 $\log_{10}$ CFU/100 cm^2. The lower mean was used to indicate "level 1" process control while the higher mean indicates "level 2" process control, reduced by 2 $\log_{10}$ CFU to adjust from 100 cm^2 to 1 cm^2. This level of contaminant initially deposited on the surface is likely to be highly variable. A normal distribution with a standard deviation of 0.5 is assumed for the purpose of this model. Since the Gill data are for hindquarters which are likely to be more contaminated than other parts of the carcass, this overestimates somewhat the level of generic *E. coli* on carcasses. Much of the data used in building this model is from Canadian plants.

B. Steam Pasteurization

The next step modeled is the effectiveness of carcass decontamination before going into the

chiller. Both steam pasteurizers and hot water washes have highly variable applications. Sub-optimal operation of equipment may result in reduced effectiveness. There may be no impact in plants with "level 2" process control.[13] Conversely, plants with "level 1" process control can consistently achieve a 2 $\log_{10}$ CFU reduction of generic *E. coli.*[14] This difference is modeled as a triangular distribution in the model with reductions ranging from 0 to 1 $\log_{10}$ CFU in "level 2" plants and a 1-2 $\log_{10}$ CFU reduction in "level 1" plants.

C. Chilling

Studies of plants have found great variability in their ability to control their chilling operations.[13] Typically carcasses are chilled for 18-48 hours after slaughter. In this model, "level 2" plants are modeled as a triangular distribution with a range of 0 to a 1 $\log_{10}$ CFU increase in CFU/cm^2 (both sets of data are from Gill and Bryant[13]). "Level 1" plants are modeled using a triangular distribution ranging from 0 to a 1 $\log_{10}$ decrease in CFU/cm^2 (Ibid.).

D. Fabrication

After chilling, the carcasses are fabricated into steaks, roasts, etc. and the remaining trim goes into ground beef. Gill's analysis of a group of plants[8] suggests that plants which have good control of plant sanitation, temperature, and cross-contamination, often experience no increases in generic *E. coli* while plants with poor process control may have increases up to 5 $\log_{10}$ CFU. Using a conservative interpretation of Gill's data, "level 1" plants are modeled here to have a zero mean with a standard deviation of 0.5. Conversely, "level 2" plants are modeled to have an increase in generic *E. coli* of 1 $\log_{10}$ CFU/cm^2 with a standard deviation of 0.5. Only positive values are allowed; the distributions are truncated at zero.

The values used in the model for plants with "level 1" and "level 2" process control are summarized in Table 1. The values include an unspecified mix of the variability and uncertainty that can occur within slaughter plants.

So that sensitivity of the component processes may be examined, scenarios are created and evaluated for the 16 combinations of "level 1" vs. "level 2" practices at the four steps in the slaughterhouse: dehiding, steam pasteurization of the carcass, chilling, and fabrication. For a given step, sensitivity is measured as the change in output resulting from a switch in practice from "level 1" to "level 2." The other three steps are held constant giving a total of eight comparisons for each step. This provides a measure of the "conditional" sensitivity of the output to a major operational change, as opposed to a marginal change. For a given process if this value is high for each scenario, then the output can be said to be very sensitive to the process.

Table 1: Slaughter Plant Model Variables and Ranges

	Distribution*	
Process	"level 1" plant	"level 2" plant
Dehiding (d)	Normal(0.23,0.5)	Normal(2.47,0.5)
Steam Pasteurizing**(s)	Triangle(-2,-2,-1)	Triangle(-1,0,0)
Chilling** (c)	Triangle(-1,-1,0)	Triangle(0,1,1)
Fabrication**(f)	Normal(0,0.5)***	Normal(1,0.5)***

* Values given as $\log_{10}$ CFU of generic *E. coli*/cm^2 of carcass surface. The Triangle distribution parameters are minimum, most likely, and maximum values and the Normal distribution parameters are mean and standard deviation for changes in $\log_{10}$ CFU/ of generic *E. coli*/cm^2

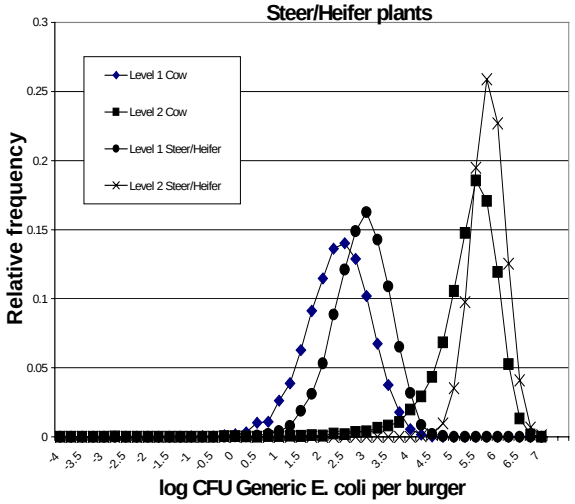
**change in $\log_{10}$ CFU of generic *E. coli*/cm^2 of carcass surface Note: References for these values are cited in the text.

***Truncated at zero

IV. MODEL RESULTS

The general model described above was built using @Risk. For each scenario the model was run for 10,000 iterations. The distribution of generic *E. coli* contamination in raw quarter-pound hamburgers from slaughterhouses with "level 2" process control was significantly greater than in plants with "level 1" process control. Figure 2 illustrates the output for each of the four scenarios for cow and steer/heifer plants.

Fig. 2: Contamination of raw beef patties from Cow and Steer/Heifer plants



Dramatic differences in the level of contamination are predicted in the simulations for plants with "level 1" vs. "level 2" process control. The mode for a "level 1" cow plant is 2.5 $\log_{10}$ CFU for generic *E. coli* per raw hamburger. For a "level 1" steer/heifer plant the mode is 3 $\log_{10}$ CFU per hamburger.

In contrast, a hamburger produced at a "level 2" cow plant has a mode of 5.5 $\log_{10}$ CFU of generic *E. coli*. A "level 2" steer/heifer plant has hamburgers with a mode of 6 $\log_{10}$ CFU. The minor differences in contamination of hamburgers from a cow vs. a steer/heifer plant are due to the different ratios of surface-contaminated vs. sterile-interior meat going into the combo bins.

We arbitrarily chose 4 $\log_{10}$ CFU (10,000 CFU) as a rough indicator of adequate process control. Slaughter plants with good process control were very effective in producing low levels of contamination in raw burgers. Only 0.16% of hamburgers were contaminated above 4 $\log_{10}$ CFU of generic *E. coli* in "level 1" process control cow plants and 1.5% in "good" steer/heifer plants (Table 2).

Table 2: Output for Assessing Process Control

Type of Plant & Level of Control	Slaughter Process P(N>4)
All "level 1" Cow	0.16%
All "level 2" Cow	93.66%
All "level 1" Steer/ heifer	1.50%
All "level 2" Steer/heifer	99.96%

Table 2 contrasts "level 1" vs. "level 2" plants for cows and steer/heifers. Table 3 shows the results of sixteen mixed scenarios where cow plants have some "level 1" and some "level 2" practices. Poor dehiding practices produced the eight scenarios with the highest levels of generic *E. coli.*

Failure in the fabrication room resulted in a 5.5% increase in hamburgers contaminated with more than 4 $\log_{10}$ CFU of generic *E coli* compared to a plant with all "good" practices. Both failures in chilling and steam pasteurization contributed to slightly less than a 2.5% increase.

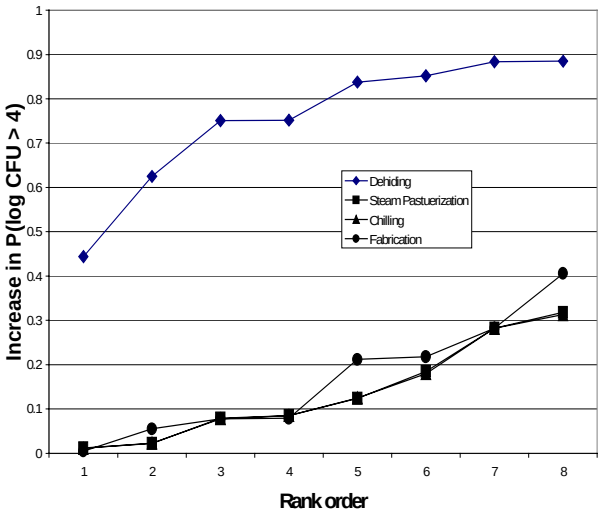
Figure 3 depicts the sensitivity of the four major steps in the slaughterhouse using pairwise comparisons for various scenarios. In each pair, one step changed from "level 1" to "level 2" to evaluate the increase in

Table 3: Effect of Cow Slaughter Plant Practices

Process Control Practice				
Slaughter Dehiding	Steam Pasteurization	Carcass Chilling	Fabri-cation	P(N>4)
2	2	2	2	99.9%
2	2	2	1	99.4%
2	2	1	2	98.8%
2	1	2	2	98.7%
2	1	1	2	90.9%
2	2	1	1	90.9%
2	1	2	1	90.9%
2	1	1	1	62.7%
1	2	2	2	55.5%
1	2	1	2	24.2%
1	1	2	2	23.7%
1	2	2	1	14.9%
1	1	1	2	5.7%
1	1	2	1	2.5%
1	2	1	1	2.4%
1	1	1	1	0.2%

in the percentage of hamburgers contaminated with more than 4 $\log_{10}$ CFU of generic *E. coli* in raw quarter-pound hamburgers. For example, the output process control improvement of fabrication in the scenario where all other processes are "level 1" is computed by subtracting the output from scenario "1111" from scenario "1112." In all cases, dehiding was the most important step. The other three steps are roughly equivalent.

Fig. 3: Conditional Sensitivity of Four Steps in Slaughter Process



V. DISCUSSION

These results of this model illustrate the potential for variability among slaughter plants on levels of generic *E. coli* levels on carcasses and in raw hamburgers. By segmenting the model into slaughter plants with levels of process control and by breaking slaughter plant activities into component parts, we have been able to identify combinations of practices that appear to make a difference.

Dehiding is the most important contributor to risk of *E coli* contamination in this model of the beef slaughter plant. The effectiveness of other steps is helped by providing a cleaner starting product. It would be useful if future work carefully evaluates how plants vary in their dehiding equipment, worker training, oversight and other operating procedures during dehiding.

Improved data on the relationship between generic *E. coli* levels and slaughter plant practices would permit the model to be more accurate and permit a partial separation of variability of plant practices from uncertainty in the data.

We chose a level of ≤ 4 $\log_{10}$ CFU of generic *E. coli* per hamburger as the indicator of good process control. This level may be too high or too low, depending on the goals of the system. Gill[8] states "…that it is possible to produce, in commercial circumstances, carcasses that are free of *E. coli* at the level of detection of 1 CFU/100 $cm.^2$"

The relationship of levels of generic *E. coli* to contamination with enteric pathogens remains to be evaluated. The impact of the different slaughter plant steps (Fig. 1) on the levels of various enteric and other pathogens also remains to be evaluated.

The cost of alternative methods of reducing generic *E. coli* contamination can be estimated. How does the cost of good process control and monitoring in the slaughter plant compare to other options? While thorough cooking of hamburger would seem a cheap solution, the cost is a loss of "taste, tenderness, and juiciness" to many consumers.[15] For those preferring rare burgers, this may be the case. For those preferring medium burgers, juiciness may be feasible even with cooking to 160^{O}F. Morrison *et al.* estimate the cost of irradiating hamburger is 2-5 cents/pound.[16] A further benefit of irradiation may also be shelf-life extension for both consumers and retailers, which could partially offset these costs. Consumer acceptance of irradiated hamburgers remains to be seen. IBP and Excel have announced[17] a plan to test-market irradiated hamburger meat in the Fall of 1999 or early 2000.

Another strategy that has not been included in our scenarios of processing control is testing for generic *E. coli* or pathogens. Some purchasers in the meat industry require testing as a requirement for doing business with them. Jack in the Box (FoodMaker) requires hamburger patty lines be tested every 15 minutes.[18]

The model indicates clear differences between plants with different process control systems. Unfortunately because of imperfect information, consumers are unable to differentiate these products in the marketplace. Because of lack of information, consumers are unable to trade off risks in an informed way. Future work needs to address ways consumer's preference affect choice of technology by plants or induce technological change.

NOMENCLATURE

CFU	Colony forming units of a pathogen
GI	Gastrointestinal tract
d	Initial contamination following dehiding
s	Steam pasteurization effectiveness
c	Change in contamination in chiller
f	Change in contamination during fabrication
X	Carcass surface contamination
N	Average CFU contamination per raw burger

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