Model Overview: In-Plant Deli Meat Model

I. Purpose: In-plant model on the effectiveness of the *Listeria monocytogenes* control interventions in RTE plants

Purpose

The "In-Plant Deli Meat Model" is a quantitative microbial risk assessment developed to evaluate the effectiveness of *Listeria monocytogenes* control interventions (e.g., use of growth inhibitors and post-lethality interventions) in mitigating the risk of listeriosis from ready-to-eat (RTE) meat and poultry products.

Introduction

Foodborne illness caused by *Listeria monocytogenes* is a serious public health issue due to its high hospitalization (94%) and mortality (16%) rates (CDC 2009; Rocourt 1999). Because *L. monocytogenes* is destroyed by cooking, *Listeria*-contaminated ready-to-eat (RTE) foods, consumed without further cooking, are the primary foods responsible for human illnesses associated with this pathogen. According to a risk assessment performed by the Food and Drug Administration (FDA) and the U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS), deli meats represent the highest risk of *listeriosis* among all RTE food categories (FDA/FSIS, 2003).

Prevention and control of *L. monocytogenes* is a challenge. This pathogen is widely distributed along the supply chain, and can survive for long periods of time in niches within the food processing environment. *L. monocytogenes* are a pyschrotrophic pathogen that can grow at low temperatures (less than 4°C). For this reason, contamination of RTE foods with *L. monocytogenes* within the processing environment can result in extremely high concentrations of *L. monocytogenes* in these foods at the time of consumption. These potentially high levels of contamination make processes directly preceding packaging of RTE meat and poultry products the critical control points for *L. monocytogenes*.

Several predictive microbiology models and risk assessments of varying scope have been developed in order to guide food safety decision- making and risk management strategies addressing *L. monocytogenes* control at various points from the processing establishment, at retail, or in consumer's home (Haas et al. 1999; Augustin et al. 2000; Bovill et al. 2000; FSIS 2003). Schaffner developed a mathematical framework based on simplified parameters (transferability, persistence and cross-contamination rate) for modeling *Listeria* cross-contamination in food processing plants (Schaffner 2004). Endrikat et al. conducted a comparative quantitative microbial risk assessment and found that the majority of listeriosis cases attributed to deli meats are associated with those sliced and sold at retail delicatessens (Endrikat et al. 2010). To assess the cross-contamination at the consumers' home, Yang et al. used one-dimensional Monte Carlo simulation to develop the risk assessment focusing on the consumer handling practices in the home (Yang et al. 2006) and Zhao et al. developed the cross-contamination model in the kitchen (Zhao et al. 1998).

In 2003, FSIS developed a probabilistic risk assessment model (an initial "In-Plant Deli Meat Model") to evaluate the effectiveness of product and food contact surface testing, formulation RTE meat and poultry products with growth inhibitors, and use of post-lethality interventions. This risk assessment showed that processing controls were significantly more effective in mitigating the risk of listeriosis from RTE meat and poultry products compared to either product or environmental testing. Moreover, formulation of RTE meat and poultry products with growth inhibitors and use of a post-lethality treatment (e.g., high pressure processing) was more effective in mitigating the risk of listeriosis from RTE meat and poultry products than either of these interventions used separately. The results from this In-Plant Deli Meat risk assessment provided the scientific basis FSIS' *Listeria Rule* (Interim Final Rule, 9 CFR Part 430), which required all establishments that produce post-lethality exposed RTE meat and poultry products to choose one of the three processing control alternatives to maintain sanitary conditions (Figure 1)

These risk-based regulations identify three alternative means of controlling *L. monocytogenes*: Alternative 1 – use of a post-processing treatment and a growth inhibitor; Alternative 2 – use of either a post-processing treatment (Alternative 2a) or a growth inhibitor (Alternative 2b); or Alternative 3 – use of sanitation and testing to control *L. monocytogenes*. To encourage adoption of more effective *L. monocytogenes* processing controls, FSIS also advised establishments that it

would conduct more verification testing at establishments with less effective *L. monocytogenes* control measures, based on the findings of the In-Plant Deli Meat risk assessment. Thus, the regulations provide that FSIS will conduct more verification testing of product at an establishment that chooses Alternative 2 and used a post-lethality treatment of product than if it has chosen Alternative 1. Similarly, FSIS will conduct more verification testing at an establishment that has chosen environment testing (Alternative 3) than an establishment that has chosen Alternative 1 or 2 (9 CFR 430.4(b)(3)(iii)).

The regulations also require validation of the effectiveness of any post-processing treatment used for controlling *L. monocytogenes;* and the treatment must be included in an establishment's Hazard Analysis and Critical Control Points (HACCP) plan. In addition, establishments that produce high risk RTE meat and poultry products (i.e., deli meats and hot dogs) and use Alternative 2b or Alternative 3 must include food-contact surface (FCS) testing for *Listeria* in their sanitation programs at a minimum frequency, for example, of four samples per month for large establishments. If an establishment producing high risk product chooses Alternative 3, then it must withhold affected product from commerce after two consecutive *Listeria*-positive tests of FCS. The establishment may release the held product only after testing shows the product not to be adulterated with *L. monocytogenes*, or after the product has been reworked using a process that destroys *L. monocytogenes*.

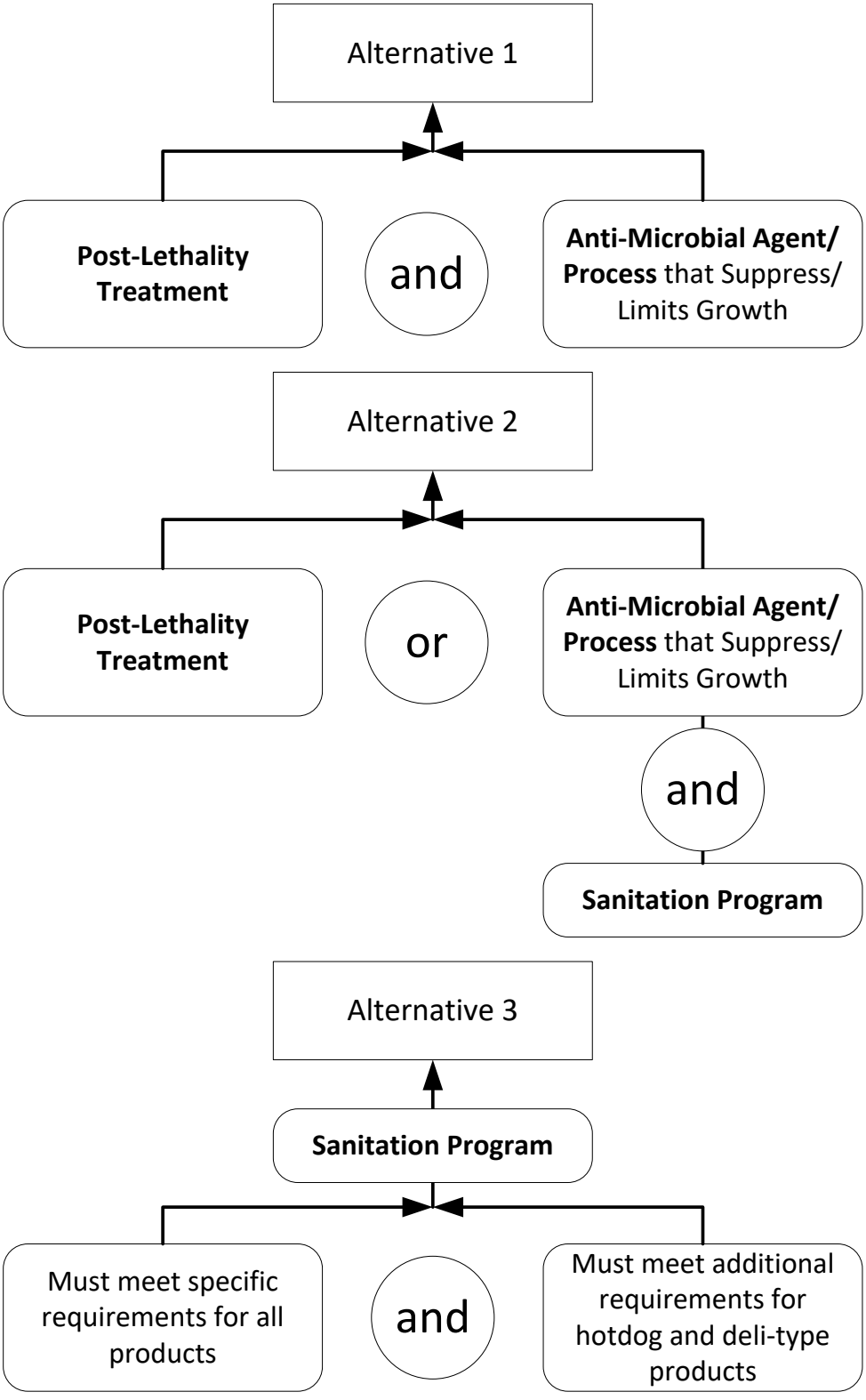

Figure 1. Alternatives to control *L. monocytogenes* in ready-to-eat food processing operations outlined in FSIS's *Listeria* Rule (9 CFR 430).

The In-Plant Deli Meat Model has been updated with newer data, with more fully integrated exposure modules (from food processing to the point of consumption), updated dose-response relationship (WHO/FAO, 2004), and enhanced modeling of cross-contamination at retail. This risk assessment model can be used to explore the influence formulation of products with growth inhibitors, post-lethality processing interventions, and product testing and plant sanitation have in mitigating the risk of listeriosis associated with RTE meat and poultry products.

The In-Plant Deli Meat Model is being made publicly available along with annotated model code, input data files and corresponding output results, and a training video to facilitate model use, reproducibility of results, and resources to support development of expertise in the field of quantitative microbial risk assessment.

Model development

Model features

The updated In-Plant Deli Meat Model was developed in the statistical programming language R (R Core Team, 2011). The conceptual model is similar to that developed by FSIS in 2003[1] with some inputs updated to reflect more recent research. It is a Monte Carlo simulation model of *Lm* concentrations at different stages in the food distribution chain, including post-processing, arriving at retail, leaving retail and at the time of consumption (Figure 2). Bacterial concentrations on FCS, and in each lot of RTE product, are modeled dynamically to estimate the resultant risk of human illness on a per serving basis. Model inputs include random processes defined from the literature or reasonable assumptions.

A mass balance approach is used to model contamination of product in establishments. The number and disposition of *Listeria* organisms are tracked for both food contact surface area and the product over time. *Listeria* organisms originate from the harborage sites that serves as sources, move on to the food contact surface, transfer to the product, grow during storage and transportation, cross-contaminate at retail and finally are consumed.

[1] https://www.fsis.usda.gov/wps/wcm/connect/b5027918-ee69-475e-acc9-a07c642f13b6/Lm_Deli_Risk_Assess_Final_2003.pdf?MOD=AJPERES

Deli meats were treated as the weighted combination of the three largest deli meats by sales: turkey, ham and beef. Each had their own specific growth rates and lag times, which were influenced by whether the product contained growth inhibitor or not.

Listeria organisms may die-off or be removed by sanitation, grow at different rates, or be discarded by the consumers when concentrations reach a maximum limit (spoilage). The model estimates the effects of food contact surface testing, product testing, sanitation, pre- and post-packaging interventions and growth inhibitors on *Lm* risk of illness per serving of RTE product, as well as on the annual illnesses from this product-pathogen pair.

Because *Lm* is considered an adulterant, any positive finding at a food processing establishment has regulatory implications. Many establishments prefer to test environmental and FCS samples for the presence of *Listeria* species, (*L. spp.*) instead. These results can indicate the need for enhanced sanitation by the establishment without regulatory implications, and the FCS testing proposed by FSIS is based on *L. spp.* rather than *Lm*. Thus the model tracks *L. spp.* within the establishment and switches to *Lm* only at retail.

The key input parameters and data sources for to the model are provided in Table 1.

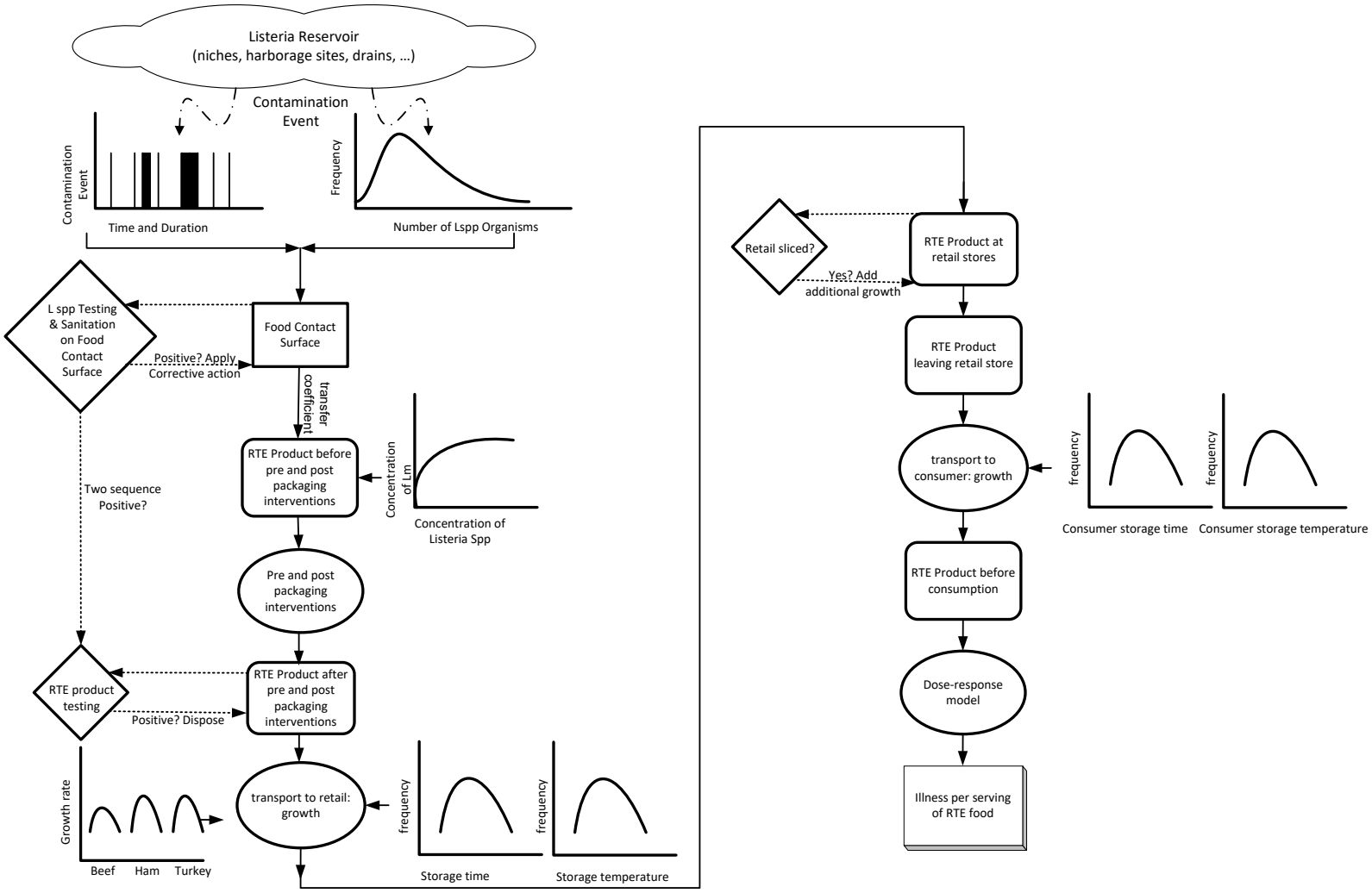

Figure 2. Flowchart of the In-Plant Deli Meat Model

Table 1. Key input parameters in the model

Parameter and Data Source	Value	Units
Contamination event frequency (*Listeria* species prevalence data taken from an FSIS in-depth verification)	normal(1.077, 0.456)	$\log_{10}$ days
Contamination event duration (number of establishments with successive weekly positive *Listeria* samples of food contact surfaces (Tompkin, 2002).	normal(0.602, 0.573)	$\log_{10}$ days
Daily added concentration during contamination event (Calibrated by FSIS plant data. See Methods section)	normal(-6.3, 2.6)	$\log_{10}$ cfu/cm^2
Lot mass (FSIS RTE survey results (FSIS, 2003))	Large: normal(8787, 6350) Small: normal(3221, 4808) Very small: normal(1270, 4309) Truncated to minimum of 454	kg
Sanitation timings (Assumed)	between shift and at the end of the day	
Sanitation effectiveness (Assumed)	0.9, 0.95, 0.999 for between lots, between days and enhanced sanitation respectively	
Transfer coefficient (Hoelzer et al., 2012)	$\log_{10}$ normal (-0.28, 0.20) Truncated to maximum of 1	
Ratio of *L. monocytogenes* to *Listeria spp*. (Tompkin, 2002)	N(0.52, 0.26) Truncated to minimum of 0 and maximum of 1	
Post processing lethality efficiency (FDA, 2014)	0.99	
EGR @ 5ºC product without GI (Pradhan et al., 2009)	Turkey: logistic(0.2755, 0.0723) Ham: logistic(0.1941, 0.0472) Beef: logistic(0.2722, 0.0646)	$\log_{10}$ cfu/g/day
EGR @ 5ºC product with GI (Pradhan et al., 2009)	Turkey: logistic(0.0975, 0.0253) Ham: logistic(0.1065, 0.0282) Beef: logistic(0.1258, 0.0517)	$\log_{10}$ cfu/g/day
Lag times, product without GI (Pradhan et al., 2009)	Turkey: triangular(0.46, 0.46, 5.55)	days

	Ham: triangular(0.40, 0.40, 16.94) Beef: triangular(2.68, 2.68, 22.81)	
Lag times, product with GI (Pradhan et al. 2009)	Turkey: triangular(2.39, 2.39, 23.87) Ham: triangular(6.11, 6.11, 34.62) Beef: triangular(1.12, 1.12, 13.06)	days
Fraction of deli meats (IDDBA 2009)	Turkey: 0.45 Ham: 0.41 Beef: 0.14	
Sampling frequency (FSIS's minimal frequency under Interim Final Rule, by alternatives)	4, 2, 1 times/shift/plants for large, small and very small plants, respectively	
Sample mass	25	grams
Consumer storage time (Pouillot et al., 2010)	Retail-sliced: weibull(1.830, 7.777) Prepackaged: weibull(1.137, 18.39)	days
Consumer storage temperature (Pouillot et al., 2010)	logistic(40.15, 3.193)	^{o}F
r parameter (FAO/WHO, 2004)	Healthy: 2.37e-14 Susceptible: 1.06e-12	
Proportion of susceptible and non- susceptible population (FAO/WHO, 2004)	Susceptible: 0.175 Healthy: 0.825	
serving size (FDA-FSIS, 2003)	Empirical cumulative serving size from 0.00 to 648	grams

Establishment Contamination

This model assumes that *Listeria* move from an environmental reservoir onto the food contact surfaces during a "contamination event" in processing establishments. The key parameters defining a contamination event are composed of the frequency of the event, the duration of the event, and the amount of *L. spp.* transferred from the reservoir to the food contact surface.

Frequency. The frequency of a contamination event was estimated based on time series *L. spp.* prevalence data taken from an FSIS in-depth verification conducted in an establishment that was associated with an *Lm* outbreak in humans. The data were analyzed using survival analysis and distribution fitting using NCSS statistical software package (Hintze, 2004). Based on this analysis, the lognormal was the best fitting distribution to the data.

Duration. The duration of a contamination event was estimated based on sequential weekly *Listeria* species testing results (Tompkin, 2002). These data provided the number of consecutive weeks that *L. spp.* positives persisted during the weekly testing, allowing the duration of a contamination event to be estimated. These data were also fitted to a lognormal distribution using a maximum likelihood fitting routine that accounted for the censored nature or the data (Helsel, 2005).

Amount added. As there was no reported literature available to estimate the amount of *L. spp.* transferred from a harborage site to a FCS during a contamination event, the model was calibrated so that the distribution of *L. spp.* concentration on food contact surfaces matched FSIS surveillance data of the concentration of *Lm* on the products in establishments. During a contamination event, the model increases the concentration of *L. spp.* on the food contact surface by a stochastic amount for each RTE lot simulated to account for the transfer of organisms from the harborage site to the food contact surface. Total food contact surface area is assumed to range from 10 to 100 m^2 for large establishments.

Contamination from FCS to Lots

Transfer coefficient. The amount of *Listeria species* transferred from the food contact surface to the RTE product were assumed to be mainly influenced by the transfer coefficient for *Listeria species* and the effectiveness of in-plant sanitation procedures. The transfer coefficient ranges from 0 to 1 and indicates the fraction of *Listeria species* transferred from the food contact surface to the product lot being processed. Many studies have been done on the investigation of transfer coefficient of *Listeria species* from various food contact surface to the meat. The transfer coefficient of *Listeria* from stainless steel to meat (Hoelzer et al., 2012) was used in our model as the transfer coefficient from FCS to RTE products.

Sanitation. Sanitation effectiveness measures the proportion of bacteria on the FCS that is removed through sanitation procedures. A summary analysis of the effectiveness of two typical sanitizers (hypochlorite and quaternary ammonium compounds) found that the effectiveness for these two sanitizers was reduced dramatically when protein was present (Hoelzer et al., 2012). This model assumes that protein was present for sanitation between lots but that protein was absent during sanitation at the end of the day (more intensified cleaning at the end of the day). No growth of *Listeria* was assumed on the FCS during the contamination events.

Ratio of Lm to L. spp. The ratio used in this model was estimated by comparing the prevalence of *Lm* to *L. spp.* species available from the published literature (Tompkin, 2002), which indicated whether or not a food contact surface was positive for *Lm* when a surface was positive for *L. spp*. The mean ratio of *Lm/L. spp.* was found to be 52% and the standard deviation was 26%.

Post-lethality treatment. The model considers the effect of post-lethality (also called post-processing) treatments and growth inhibition in controlling *Lm* concentrations during the shelf life of the RTE food products. Post-processing treatments (Pasteurization, ultraviolet treatment etc.) reduce the concentration of *Lm* in the product and growth inhibitors limit the growth of *Lm* during storage from establishment to consumers. The

regulation requires a minimum 1 log (90%) kill of *Lm* but 2 log kill of *Lm* is recommended; our model assumes that post-processing lethality is 2 logs kill of *Lm*.

Growth from plant to consumer

Growth of L. monocytogenes. *L. monocytogenes* has been shown to grow at temperatures ranging from -0.4 to 45ºC (Keskinen et al. 2008; Jordan et al. 2010). It is considered a psychrotolerant organism as its optimum growth temperature is in the range of 30 to 37ºC, while it has the ability to grow at temperatures <15ºC (Keskinen et al. 2008; Jordan et al. 2010). Previous researchers found that the *L. monocytogenes* can grow at refrigeration temperatures for 3 days to 3 months (Gray et al. 1948) and *L. monocytogenes* can survive at cold temperatures in soil, cattle feces, pond water and animal silage for up to 6 years (Fenlon, 1999). A large number of studies have shown that *L. monocytogenes* can proliferate in many refrigerated RTE foods (Dufour 2011).

This model considers the growth of *Lm* during the storage of RTE product at retail and in consumers' refrigerators. An exponential model predicts the evolution of the size of the bacterial population at time t in a given environment;

$$y_t = \begin{cases} Log\, y_0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots t<\lambda \\ \min(Log\, y_0 + \mu\cdot(t-\lambda), Log\, y_{\max}) \ldots\ldots\ldots t\geq\lambda \end{cases}$$

where y_t (cfu/g) is the bacterial concentration at time t (d), λ (d) is the lag time, y_{max} (cfu/g) is the maximum achievable concentration in the media and μ is the specific growth rate (log cfu/g/d). Growth only occurs once the cumulative time from leaving the establishment for each serving exceeded the respective lag phase (Figure 3). All time units in the model are days.

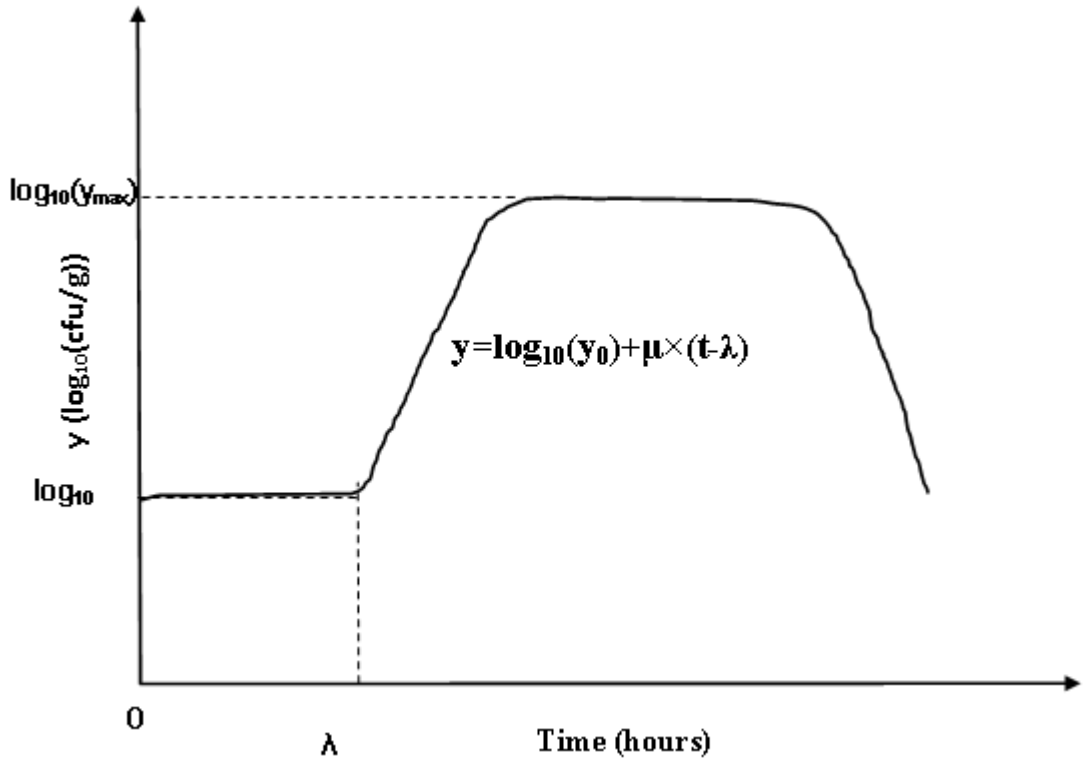

Figure 3. The microbial growth model in the media with limited nutrition sources.

The growth of *L. monocytogenes* during shipment from the plant to retail depends on the growth rate of *L. monocytogenes* and the storage time from plant to retail. The Food Code 2009 requires the shelf life of RTE food less than 14 days (FDA 2009). Considering the consumers' storage time, shelf life at retail of 5 to 10 days was assumed. The lag time and the growth rate of the three deli meats (ham, beef and turkey) were taken from a previous study and adjusted to account for the use of growth inhibitors (Pradhan et al., 2009) and by the storage temperature (FDA/FSIS, 2003). Although the lag time was related to storage temperature and pH of deli meats (Ransom 2005), this model ignored this relationship because it is difficult to monitor the pH and these relationships were not well-established quantitatively.

$$EGR_t = (\frac{T+1.18}{6.18})^2 \times EGR_5$$

Cross-contamination. Cross-contamination at retail is found to increase the prevalence and concentration of *Lm* in deli meats sliced at retail, compared to deli meats sliced and packaged at the processing establishment without further processes when sold at retail (Draughon, 2006; Gombas et al., 2003). Within the model, product entering retail is split into prepackaged (i.e., sliced at the processing establishment) or retail-sliced based on the ratio of these two categories. We assumed retail-sliced products are subject to cross contamination while prepackaged product *Lm* concentrations remained unchanged during the retail stage of the model.

This study uses a simplified approach to modeling the increase in concentration due to retail-cross contamination. Retail-sliced concentrations are adjusted by the mean and standard deviation of the retail distribution, such that the z-score (or normalized cumulative percentile) of each serving is maintained before and after retail slicing. A z-scaling approach is applied to retail-sliced product according to the following equation:

$$z = \frac{\mathrm{Lm}_{\text{leaving}} - \mu_{\text{retailsliced}}}{\sigma_{\text{retailsliced}}} = \frac{\mathrm{Lm}_{\text{arrive retail}} - \mu_{\text{prepackaged}}}{\sigma_{\text{prepackaged}}}$$

$$\text{then } \mathrm{Lm}_{\text{leaving}} = \mu_{\text{retailsliced}} + \sigma_{\text{retailsliced}} * \frac{\mathrm{Lm}_{\text{arrive retail}} - \mu_{\text{prepackaged}}}{\sigma_{\text{prepackaged}}}$$

where $\mathrm{Lm}_{\text{leaving}}$ is the $\log_{10}$ concentration of retail-sliced product leaving retail, $\mu_{\text{retail-sliced}}$ and $\sigma_{\text{retail-sliced}}$ are the mean and standard deviation of the retail-sliced product, and $\mu_{\text{prepackaged}}$ and $\sigma_{\text{prepackaged}}$ are the mean and standard deviation of the prepackaged product (Endrikat et al. 2010).

Consumer handling. Consumer storage time and temperature are based on an analysis of a web survey conducted by Pouillot (2010). The analysis found that consumers tend to use retail-sliced product more quickly than prepackaged product. Storage temperatures did not vary by product type.

The variability distribution of serving size (i.e., the grams of RTE deli meats that a consumer ingests in a single meal) was adapted from a previous risk assessment of deli

meats (FDA/FSIS, 2003). The same serving size distribution applies to both healthy and susceptible populations.

Sampling procedure

Sampling of Food Contact Surface (FCS). For both FCS testing and product testing, the modeled concentration of the organism is multiplied by the sample size to estimate the mean of a Poisson distribution, a probability distribution that is appropriate for modeling such concentrations. For food contact surfaces, the concentration is measured in cfu/cm^2 and the sample size is measured in cm^2. For RTE product, the sample size is measured in cfu/gram, and the sample size in grams. A random number is generated from this distribution that represents the number of cfus in the sample itself. The probability of detecting the presence of the pathogen via culture is determined using a binomial distribution: $1-(1-p)^n$, where p is the probability of detecting 1 cfu in the sample, and n is the number of cfus in the sample from the Poisson calculation. The probability p is based on the detection limit and test sensitivity of the culture assay.

Sampling of Lots. Lots are tested for *Lm* during either routine lot testing or additional testing as a result of the *Listeria*-positive FCS testing. The lot testing response is lagged by the time it takes to analyze and get the results of a FCS test. The model assumes a reporting time of two days for *Listeria* and four days for *Lm*. The model also assumes that product lots that test positive for *Lm* are removed from the food supply; this is accomplished by reprocessing the lot for human food, converting the lot into products not intended for human consumption, or disposing of the lot.

Production volumes by alternative, $\omega_i's$

The numbers of RTE deli meat establishments under Federal inspection were tabulated by the *Lm* alternative and establishment size category for 2003 and 2017 (Tables 2 and 3). In 2003, it was determined that large, small and very small establishments accounted for 48%, 48% and 4% of annual deli meat production volume, respectively. In 2017, the calculated shares of annual deli production were basically 49%, 49% and 2% for large, small and very small establishments. In addition, the number of establishments

comprising the industry decreased from 2,930 in 2003 to 2,113 by 2017. Nevertheless, there is no indication that deli meat production or consumption has changed dramatically. Therefore, production per establishment appears to have increased between 2003 and 2017.

FSIS data collected from RTE deli meat establishments in 2017 supports the assumption of increased mass of production per lot compared with the values in Table 1 (that reflect lot mass in 2003). Nevertheless, we have chosen to use the 2003 lot mass values for modeling both time periods so that risk comparisons will not be confounded by factors other than the relative distribution of establishments across the *Lm* alternatives. Analysis of risk estimates using larger lot mass values suggests that risk per serving decreases with increasing lot mass because the quantity of *Lm* transferred from FCS to RTE product is unchanged while an increased lot mass dilutes the concentration of *Lm* per serving.

For each size category, the share of production volume per establishment is calculated as the ratio of its annual production volume divided by the number of establishments in that size category. For example, in 2003 there were 144 large establishments that accounted for 48% of annual production volume; therefore, each large establishment accounted for 0.33% of total production of deli meats that year ($0.48/144 \times 100 = 0.33\%$). For a particular combination of size category and *Lm* control alternative, the share of production volume it represented was the product of the size share (calculated above) and the number establishments represented. For example, in 2003 there were 9 large establishments that used *Lm* control alternative 1; the share of total annual production represented by these establishments was 3% ($9 \times 0.0033 \times 100$). For each *Lm* control alternative, its share of total production volume is calculated as the sum across the three size categories.

Table 2. The numbers of RTE deli meat establishments by *Lm* control alternative and size category, based on the 2003 timeframe, are shown.

	Establishment size			
Lm control alternative	Large	Small	Very Small	Total

1	9	19	14	43
2a	34	80	48	162
2b	74	112	53	239
3	27	1,011	1,449	2,487
Total	144	1,222	1,564	2,930

Table 3. The numbers of RTE deli meat establishments by *Lm* control alternative and size category, based on the 2017 timeframe, are shown.

	Establishment size			
Lm control alternative	Large	Small	Very Small	Total
1	12	15	6	33
2a	17	60	11	88
2b	152	309	73	534
3	58	709	691	1457
Total	239	1093	781	2,113

The values for $\omega_i's$ in 2003 and 2017 indicate how the RTE deli meat industry has shifted regarding the *Lm* control alternatives (Table 4). In general, the largest shift from 2003 is that more production volume comes from establishments using Alternative 2b (growth inhibitor); this shift results from less production volume emanating from the three other options with the biggest contributor being a reduction from 0.15 to 0.06 for Alternative 2a (post-processing treatment).

Table 4. The values of production volume share by *Lm* control alternative (ω_i) are given for 2003 and 2017.

Year	Lm control alternative			
	1	2a	2b	3
2003	0.04	0.15	0.29	0.52
2017	0.03	0.06	0.45	0.46

Dose-response model

The dose-response relationship used in the model is the exponential approach developed in the FAO/WHO (2004) risk assessment. This dose-response relationship assumes that each pathogen cell acts independently and the distribution of organisms from serving to serving follows a Poisson distribution (Haas et al. 1999). The model is expressed by $P(illness) = 1 - e^{-rD}$, where P(illness) is the probability of illness for a given dose D. The dose-response model parameter r is the probability that 1 pathogen cell initiates illness to the target population.

The FAO/WHO dose-response model separates the consumer population into two groups: a healthy population that is generally resistant to listeriosis and a susceptible population consisting of immune-compromised, elderly, or pregnant individuals. Based on susceptibility information available from the United States, it was determined that older adults (60 years and older) were 2.6 times more susceptible relative to the general healthy population, while perinatals were 14 times more susceptible (FAO/WHO 2004). The susceptible fraction of the population was set at 17.5% of the overall population and accounts for 80-98% of the listeriosis illnesses.

The dose-response model, along with the 95% confidence intervals, is shown in for both the susceptible and healthy populations (Figure 4). Only the median curves are used in the current model. Note that the median infectious dose for the susceptible population is on the order of $10^{11} – 10^{12}$ cfu, and illnesses are unlikely for population if the dose is less than 10^{10} cfu.

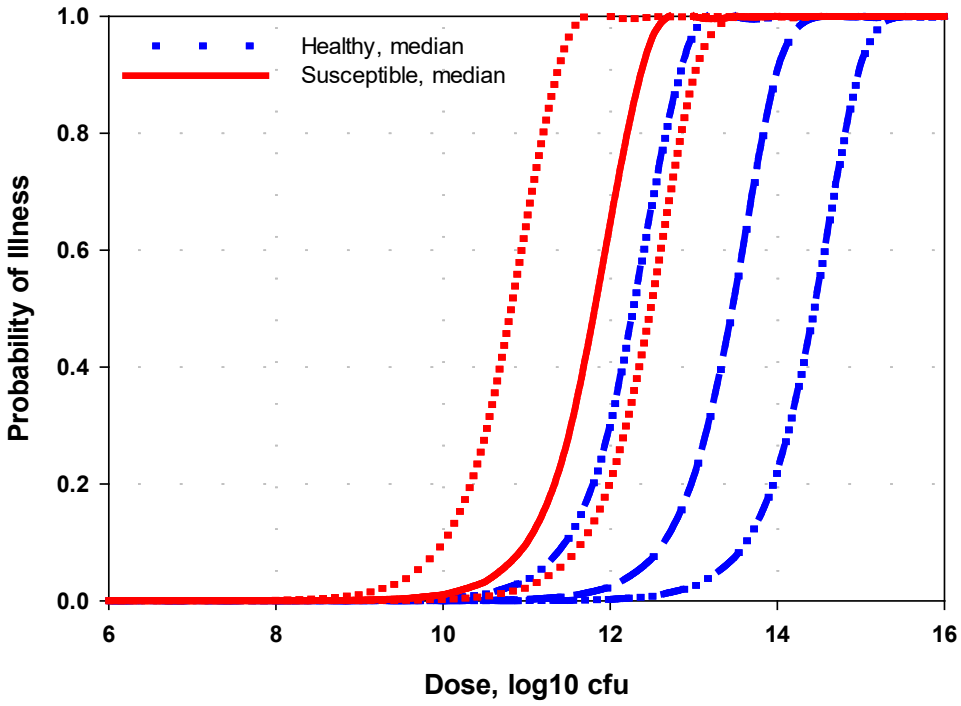

Figure 4. FAO/WHO dose response model for listeriosis. Median and 95% confidence intervals shown.

Limitations

Due to the lack of data in the literature, this model has the following limitations:

(1). The risk assessment model only considers food contact surfaces (FCSs) as the source of *Listeria species*/*L. monocytogenes* in product.

(2). The risk assessment model assumed that *L. monocytogenes* are evenly distributed on the FCS and the food product lots.

(3). FCS was simply treated as an integral entirety, without individual components, such as the prep table, dicing machine and convey belt.

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