# Draft Interagency Risk Assessment – *Listeria monocytogenes* in Retail Delicatessens Technical Report

**The Interagency Retail *Listeria monocytogenes* Risk Assessment Workgroup**

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# Interagency Retail *Listeria monocytogenes* Risk Assessment Workgroup

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## List of Abbreviations

| | |
|---|---|
| AFDO | Association of Food and Drug Officials |
| AMIF | American Meat Institute Foundation |
| ARS | Agricultural Research Service |
| cfu | Colony Forming Units |
| CDC | Centers for Disease Control and Prevention |
| CFA | Consumer Federation of America |
| CFR | Code of Federal Regulations |
| CFSAN | Center for Food Safety and Applied Nutrition |
| CSPI | Center for Science in the Public Interest |
| DHHS | Department of Health and Human Services |
| EHS-Net | Environmental Health Specialists Network |
| EO | Eating Occasion |
| FAO | Food and Agriculture Organization of the United Nations |
| FCS | Food Contact Surface |
| FDA | Food and Drug Administration |
| FMI | Food Marketing Institute |
| FSIS | Food Safety and Inspection Service |
| GI | Growth Inhibitors |
| GMA | Grocery Manufacturers Association |
| GT | Generation Time |
| IAFP | International Association for Food Protection |
| NAFSS | National Alliance for Food Safety and Security |
| NCBI | National Center for Biotechnology Information |
| NFCS | Non-Food Contact Surface |
| NFPA | National Food Processors Association |
| NHANES | National Health and Nutrition Examination Survey |
| NIFA | National Institute of Food and Agriculture |
| OMB | Office of Management and Budget |

| | |
|---|---|
| ppm | Parts Per Million |
| QRA | Quantitative Risk Assessment |
| RAC | Raw Agricultural Commodities |
| RTE | Ready-to-Eat |
| sd | Standard Deviation |
| U.S. | United States |
| USDA | United States Department of Agriculture |
| Virginia Tech | Virginia Polytechnic Institute and State University |
| WHO | World Health Organization |

# List of Abbreviations for Baselines and Mitigations

The Table below introduces the abbreviations used to identify the various risk assessment model baselines and scenarios denoted in the figures of the Results and Discussion section of this report (Section 7).

| Abbreviations | Description |
|---|---|
| **Baselines** | |
| Multiple Niche 100W | A retail deli with multiple niches on slicers, utensils, food contact surfaces (FCSs) and non-food contact surfaces (NFCSs). Each niche contaminates its associated site at a mean frequency of once per week with a mean of 100 colony forming units (cfu) per event. |
| No niche | A retail deli without any niches or environmental *L. monocytogenes* transfer. |
| Temperature Control | A retail deli without any niches that maintains its deli case to ≤5°C (≤41°F) |
| Incoming Growth Chub | A retail deli without any niches with an incoming ready-to-eat (RTE) product that supports the growth of *L. monocytogenes* and has a mean incoming *L. monocytogenes* concentration increased from the observed -9.2 $\log_{10}$ cfu per gram to -5 $\log_{10}$ cfu per gram. |
| Incoming Non-Growth Chub | A retail deli without any niches with an incoming RTE product that does not support the growth of *L. monocytogenes* and has a mean incoming *L. monocytogenes* concentration increased from the observed -9.2 $\log_{10}$ cfu per gram to -5 $\log_{10}$ cfu per gram |
| Niche & Temperature Control | A retail deli with "Multiple Niche 100W" (see above) that maintains the temperature of the deli case to ≤5°C (≤41°F) |
| **Scenarios: Worker Behaviors, Sanitation, and Cross contamination** | |
| Wash & Sanitize | Increase the effectiveness of retail deli cleaning from simply washing to washing and sanitizing. |
| Clean 8 Sporadic | Doubling the number of retail deli sites sporadically cleaned from 4 to 8. |
| No Sanitation | Do not conduct any wiping, washing or sanitizing. |
| No Sporadic Cleaning | Retail deli workers clean FCSs as required by the 2009 FDA Food Code, but do not conduct any additional sporadic cleanings. |
| No Glove | Retail deli workers do not use gloves when serving customers. |
| Gloves Every Serving | Retail deli workers change gloves for every sale of RTE products. |
| NFCS as FCS | Retail deli workers clean deli NFCSs as if they were FCSs (i.e., every 4 hours in accordance with the 2009 FDA Food Code). |
| Transfers to 0 | Scenario where *L. monocytogenes* cross contamination in the retail deli would only result from the deli slicer (i.e., set cross contamination transfer coefficients to 0 for all sites except the slicer). |
| Transfers and Slicer to 0 | Scenario where there is no *L. monocytogenes* cross contamination in the retail deli (i.e., set cross contamination transfer coefficients to 0, i.e., no cross contamination occurs for all sites, including the slicer). |
| No Contact Glove Case | Retail deli workers do not use their hands (gloved or ungloved) to open the retail deli case (e.g., if a floor switch is used). |
| Reduce Level | Lower the mean incoming *L. monocytogenes* concentration on all RTE products from the observed mean of -9.2 $\log_{10}$ cfu per gram to a mean of -9.5 $\log_{10}$ cfu per gram. |
| Preslice | Retail deli workers pre-slice all chubs of RTE product (deli meat and deli cheese) in the morning after cleaning. |

| | |
|---|---|
| **Scenarios: Worker Behaviors, Sanitation, and Cross contamination (Continued)** | |
| Separate Slicer | Retail deli workers use a separate slicer for RTE products that support growth of *L. monocytogenes* versus those RTE products that do not. |
| Separate Slicer Case | Retail deli workers use of a separate slicer and a separate deli case for RTE products that support the growth of *L. monocytogenes* versus those RTE products that do not. |
| Lower Env Cont | Reduce transfer of *L. monocytogenes* among RTE products, FCSs, and NFCs (i.e., reduced transfer coefficients by 50%) in the retail deli. |
| Do Not Slice On Gloves | Retail deli workers collect the slices of RTE products directly on tissue paper rather than on his or her gloves. |
| **Scenarios: Temperature Control and Growth Inhibition** | |
| Temp = 5°C | Set the retail deli case temperature for all retail delis to 5°C (41°F) (i.e., in compliance with the 2009 FDA Food Code) rather than utilizing real-world deli case temperatures reported by Ecosure. |
| No Growth (T = -5°C) | Set all retail deli case temperatures to -5°C (23°F). At this temperature, no *L. monocytogenes* growth will occur. |
| Temp <= 5°C | Use the retail deli case temperatures observed in the Ecosure dataset at or below 5°C (41°F). This implies that all retail delis with deli case temperatures exceeding the 2009 FDA Food Code recommendation come into compliance |
| Shorten time in retail deli | Retail delis reduce the length of time RTE products are held before they are sold or disposed from 7 to 4 days. |
| All GI | Reformulate all RTE products sold at the retail deli that would otherwise support *L. monocytogenes* growth to include growth inhibitors to restrict the growth (same growth inhibitor (GI) formulation as cured ham with GI). |
| No GI | Reformulate all RTE products that support *L. monocytogenes* growth that are sold at the retail deli to not include GI to restrict *L. monocytogenes* growth. |

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## Executive Summary

The Draft Interagency Risk Assessment - *Listeria monocytogenes* in Retail Delicatessens provides a scientific assessment of the risk of foodborne illness associated with consumption of ready-to-eat (RTE) foods commonly prepared and sold in the delicatessen (deli) of a retail food store and examines how that risk may be impacted by changes to common or recommended practices. This quantitative risk assessment (QRA) was conducted collaboratively by the Department of Health and Human Service (DHHS), Food and Drug Administration's Center for Food Safety and Applied Nutrition (FDA/CFSAN), and United States Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS), in consultation with the DHHS Centers for Disease Control and Prevention (CDC) and input from industry, academic institutions, and consumer advocacy group stakeholders. The White House Food Safety Work Group identified this risk assessment as a priority. It provides information useful to those responsible for implementing policies, programs and practices that target the prevention of listeriosis in the population.

**Background**

*Listeria monocytogenes* (*L. monocytogenes*) is a food safety concern, and control of this pathogen has long been an objective of the public health community. The CDC has estimated that *L. monocytogenes* causes approximately 1,600 illnesses, 1,500 hospitalizations, and 260 deaths annually. When compared with other major foodborne diseases, listeriosis is a rare occurrence, but the fatality rate is very high (i.e., approximately 16%, compared with 0.5% for either *Salmonella* or *Escherichia coli* O157:H7).

Cross contamination in the deli environment is thought to contribute to *L. monocytogenes* contamination of RTE foods, but little is known about the transfer of this pathogen in the retail setting. *L. monocytogenes* is present in the environment and can survive and grow in foods held at ambient and refrigeration temperatures. Therefore, adequate preventive controls must take into account contamination as well as survival and proliferation of the organism. *L. monocytogenes* can contaminate foods via cross contamination from one product to another or through contamination from the environment, or both.

**Overview of Risk Assessment**

The QRA simulates the retail deli environment and evaluates how various sanitary and food handling practices may influence the U.S. risk of listeriosis associated with consuming RTE foods that are sliced, prepared or packaged in retail grocery delis. The model is unique in its ability to quantitatively link activities within a retail deli directly to predicted public health outcomes. The model simulates the *L. monocytogenes* concentration and prevalence in products sold to customers, predicts changes in concentrations during customer home storage, and finally estimates the risk of listeriosis from consumption of these products in the home. The population was divided in two subpopulations for purpose of this risk assessment: (1) the population with increased susceptibility (including neonates, older adults, and the immunocompromised) and (2) the remaining population (i.e. referred to as the general population).

**Risk Management Questions**

The questions initially posed to the Interagency Retail *L. monocytogenes* Risk Assessment Workgroup were:

1. What is the exposure to *L. monocytogenes* from consuming RTE foods prepared in retail delis?
2. What are the key processes that increase contamination of RTE foods at retail delis?
3. How much is the relative risk per serving reduced according to specific risk management options?

The above questions are very broad in nature and were further refined to a list of risk mitigations evaluated through scenario analyses within this risk assessment. Some of the specific ‘what if’ scenarios were generated by FSIS and FDA risk managers while others were provided by stakeholders. Examples include:

- What impact does improved compliance with the cold holding and storage duration requirements found in the FDA Food Code have on the predicted listeriosis risk?
- What impact does improved compliance with food contact surface sanitation have on the predicted listeriosis risk?
- What impact does using dedicated slicers for specific products have on the predicted listeriosis risk?
- What impact does reducing the presence and level of *L. monocytogenes* on incoming RTE foods have on the predicted listeriosis risk?

**Key Findings of the Risk Assessment**

The key findings from this assessment of risk of listeriosis associated with RTE foods prepared and served in retail deli operations include:

- **Control Growth**. Employing practices that prevent bacterial growth dramatically reduced the predicted risk of listeriosis, as observed in other *L. monocytogenes* risk assessments. The use of growth inhibitors for suitable products prevents growth of *L. monocytogenes* in RTE foods both at retail and during consumer home storage, leading to an overall dramatic reduction in the predicted risk of listeriosis (ca. 95%). The strict control of temperature during refrigerated storage in retail delis did reduce the predicted risk. The impact of this control is nevertheless lower as it reduces growth only during this specific storage (5-20% reduction according to the baseline and the scenario).
- **Control Cross Contamination**. Cross contamination of *L. monocytogenes* in the retail environment dramatically increases the predicted risk of listeriosis. Cross contamination during the routine operation of the retail deli is not amenable to a simple solution.
- **Control Contamination at its Source**. Increasing the concentration and transfers of *L. monocytogenes* from incoming products, the environment, or niches directly increases the predicted risk of illness. Increasing *L. monocytogenes* concentration in incoming product increased the predicted risk of listeriosis whether or not the contaminated RTE product itself supported growth. The increase in predicted risk was greater when the equivalent contamination occurred on product that supported the growth of *L. monocytogenes*.
- **Continue Sanitation.** Sanitation practices that eliminate *L. monocytogenes* from the deli area food contact surfaces results in a reduction in the predicted risk of illness. Cleaning and sanitizing food contact surfaces reduced the predicted *L. monocytogenes* levels in the deli area. Wearing gloves while serving customers reduces the estimated risk of listeriosis.
- **Identify Key Routes of Contamination**. The slicer (for deli meats and cheeses) and the salad utensils (for deli salads) are sources of *L. monocytogenes* cross contamination to RTE foods. Control of *L. monocytogenes* cross contamination at these points during retail preparation and handling of RTE foods reduced the predicted risk of listeriosis.

In summary, this QRA improves our understanding of *L. monocytogenes* in the retail deli and should encourage improvements to retail food safety practices and mitigation strategies to further control *L. monocytogenes* in RTE foods. The 'what if' scenarios modeled in this QRA provide insight on how cross contamination, sanitary practices, and temperature control impact the predicted risk of listeriosis. This QRA is based on an extensive amount of information gathered through partnerships with academia and input from stakeholders. Additional data would be useful to further explore how more specific retail practices and conditions (e.g., equipment design) impact the risk of listeriosis.

# Draft Interagency Risk Assessment - *Listeria monocytogenes* in Retail Delicatessens

The Interagency Risk Assessment - *Listeria monocytogenes* in Retail Delicatessens provides a scientific assessment of the risk of foodborne illness associated with consumption of ready-to-eat (RTE) foods prepared in retail delicatessens (delis) and examines how that risk may be impacted by changes to current practices. This risk assessment was conducted collaboratively by the Department of Health and Human Service (DHHS), Food and Drug Administration's Center for Food Safety and Applied Nutrition (FDA/CFSAN), and United States Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS), in consultation with the DHHS Centers for Disease Control and Prevention (CDC), and input from industry, academic institutions, and consumer advocacy group stakeholders. The conduct of this risk assessment was identified as a priority by the White House Food Safety Work Group [1] and will be used to evaluate current policies, programs, and practices intended to protect public health through the prevention of listeriosis.

## 1. Background

*L. monocytogenes* is a food safety concern, and control of this pathogen has long been an objective of the public health community including government, academia, industry, and consumer advocacy groups. The CDC [2] has estimated that *L. monocytogenes* causes approximately 1,600 illnesses, 1,500 hospitalizations, and 260 deaths annually. When compared with other major foodborne diseases, listeriosis is a rare occurrence, but the fatality rate is very high (i.e., approximately 16% compared with 0.5% for either *Salmonella* or *Escherichia coli* O157:H7).

To prevent listeriosis in the United States, it is important to identify the foods that pose the greatest risk of listeriosis, the most effective mitigation in controlling *L. monocytogenes*, and the changes in processing, handling and/or preparation practices can improve the safety of foods associated with listeriosis. Risk assessment provides a useful framework to integrate scientific research, data, and evaluate the public health implications of changes in food safety practices and policies.

During the past decade, FSIS and FDA have conducted several risk assessments to guide federal policies intended to control and prevent listeriosis in the United States. In 2003, the FDA and FSIS developed a

QRA to determine the relative risk of listeriosis among 23 categories of RTE foods to the total U.S. population and 3 age-based subpopulations [3]. This 2003 risk assessment supported the findings of epidemiological investigations of sporadic illnesses and outbreaks of listeriosis. The risk assessment identified and quantified the factors that affect exposure to *L. monocytogenes* including: (1) amount and frequency of consumption of the food; (2) frequency and levels of *L. monocytogenes* in the food; (3) potential of the food to support growth of *L. monocytogenes*; (4) refrigerated storage temperature; and (5) duration of refrigerated storage before consumption. This 2003 risk assessment identified several RTE foods as having a high risk per serving, including deli meats, soft cheeses, pate, and smoked seafood. Of these RTE foods, deli meats were estimated to account for the most – approximately 67% – of all listeriosis cases per year in the United States [3].

Following the release of the FDA/FSIS risk assessment in 2003, FDA and CDC issued an Action Plan to reduce the risk of *L. monocytogenes*, which was subsequently updated in 2008 [4]. The 2008 update provides a list of FDA's activities within six areas: (1) develop and revise guidance for processors that manufacture or prepare RTE foods, retail and food service, and institutional establishments; (2) develop and deliver training and technical assistance for industry and food safety regulatory employees; (3) enhance consumer and health care provider information and education efforts; (4) review, redirect, and revise enforcement and regulatory strategies; (5) enhance disease surveillance and outbreak response; and (6) coordinate research activities to refine the risk assessment, enhance preventive controls, and support regulatory, enforcement, and educational activities. FDA's activities related to the 2008 Action Plan are publicly available [4]. Examples of these activities include (1) two draft guidance documents issued for public comment in 2008: a draft “Compliance Policy Guide Sec. 555.320 *Listeria monocytogenes*” and a draft “Guidance for Industry: Control of *Listeria monocytogenes* in Refrigerated or Frozen ready-To-Eat Foods”; (2) modification of the 2005 FDA Food Code to amend the date marking provisions and cold-holding times and temperatures; and (3) a public health educational campaign to provide advice to consumers on refrigerator temperatures to prevent foodborne illness, including listeriosis.

Also, in response to the findings of the 2003 FDA/FSIS risk assessment, FSIS conducted a complementary risk assessment to evaluate which food safety interventions during the processing of RTE meat and poultry products are most effective in preventing listeriosis [5]. This FSIS QRA revealed that formulating RTE products with growth inhibitors and the use of post-lethality interventions was more effective in preventing foodborne illness compared to using either of these interventions alone or testing and sanitizing food contact surfaces (FCSs). These findings directly formed the scientific basis of FSIS’s interim final rule for *L. monocytogenes* encouraging federal establishments to adopt more effective food

safety interventions during the production of RTE meat and poultry products (9 CFR 430, 68FR 3422; June 6, 2003). FSIS also used these findings and those from the 2003 FDA/FSIS risk assessment to guide its verification sampling programs whereby RTE meat and poultry processing establishments (9 CFR 430) with less effective *L. monocytogenes* controls are sampled more frequently [6]. These findings were used to inform FSIS' compliance guidance to industry [7]. Finally, to aid in implementation of the interim final rule, FSIS provided specialized training to its inspection workforce. These policies and programs have resulted in industry adoption of more stringent *L. monocytogenes* controls during the processing of RTE meat and poultry products in the United States. Correspondingly, FSIS has observed a steady decline in the number of *L. monocytogenes* positive samples from its in-plant testing programs, an indication that interventions during processing to mitigate risks from RTE meat and poultry products were succeeding (Figure 1).

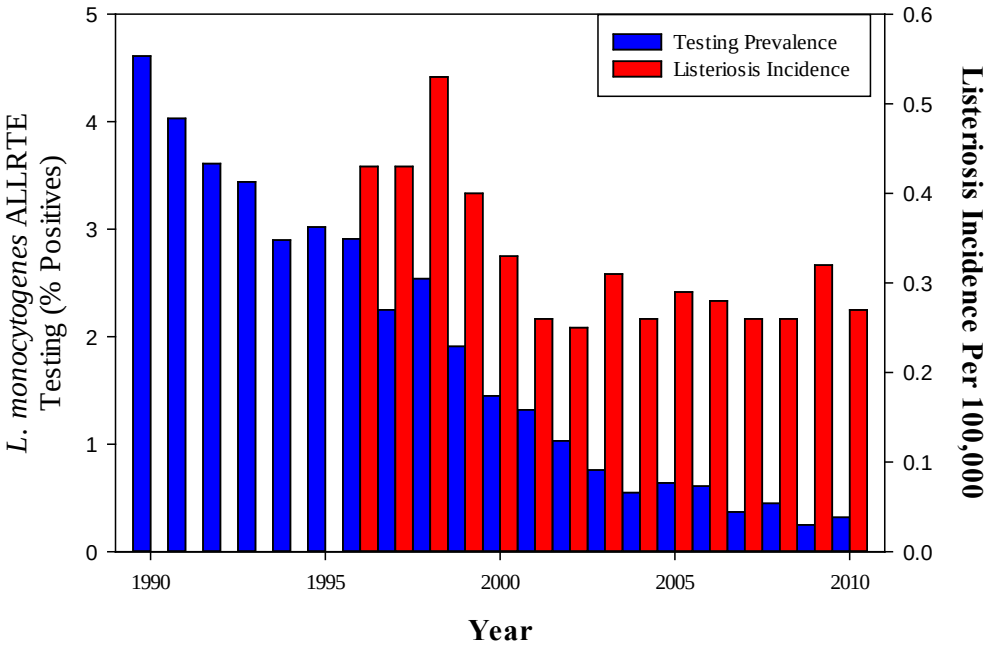



**Figure 1: Percentage of RTE meat and poultry products testing positive for *L. monocytogenes* in FSIS inspected facilities compared to the incidence of listeriosis per 100,000 from CDC FoodNet surveillance.**
(Source: [8] and [9]).

Despite a decline of *L. monocytogenes* in RTE meat and poultry products over the past several years, epidemiological data from the CDC have shown a steady incidence of listeriosis in the United States [10, 11] (Figure 1). Recent estimates of listeriosis incidence did not meet the Healthy People 2010 target of 0.24 cases per 100,000 population [12]. [Note: The 2020 target is 0.20 cases per 100,000 population [13].]

The lack of a decline in listeriosis cases in the United States despite a corresponding dramatic decline of the percentage of RTE meat and poultry products (primary foodborne vehicles for *L. monocytogenes* [3]) testing positive for *L. monocytogenes* at producing establishments suggests contamination of RTE products at retail or in the consumer's home. Surveillance studies conducted by industry and academia [14, 15] have indicated that the prevalence of *L. monocytogenes* is approximately seven times higher in deli meats sliced at retail, compared to those sliced and packaged at federally inspected facilities. These surveys also indicated higher levels of *L. monocytogenes* on RTE meats sliced or packaged at retail. This difference in *L. monocytogenes* contamination was further quantified by an FSIS comparative risk assessment that indicated that approximately 83% of the listeriosis cases attributed to deli meat were associated with deli meats sliced at retail [6, 16]. An independent study by Cornell University also showed that the majority of listeriosis cases attributed to deli meats were associated with those sliced and packaged at retail [17].

In addition, as part of a ten-year study of the occurrence of foodborne illness risk factors in retail and foodservice establishments, FDA collected data on food safety practices in food stores, including retail delis, in 1998, 2003, and 2008. They looked for trends that would indicate whether practices were improving or regressing over the ten year timeframe. The report on the 2008 data collection revealed that for retail delis, the foodborne illness risk factor most in need of attention was "Improper Holding for Time and Temperature" [18]. In 60% of the 98 delis visited, at least one observation was made in which food requiring temperature control was not held at 41ºF (5ºC) or below as specified in the FDA Food Code [18]. Similar non-compliance with temperature control of retail deli cases was suggested in a study by Ecosure [19].

Moreover, the analysis of trends in retail practices during the 10-year study period revealed no statistically significant change in the overall percentage of compliance with the FDA Food Code for all risk factors combined [20]. However, a statistically significant improvement in the poor personal hygiene risk factor was observed, including an improvement in preventing bare hand contact with RTE foods. Despite this positive trend, in roughly 50% of the 98 delis visited in 2008, at least one employee was observed failing to wash his or her hands at the time or in the manner recommended in the FDA Food Code. Also, improper temperature holding is one of several factors that may contribute to an increased risk of listeriosis [3]. Another is improper sanitation of slicers [21-23]. The extent to which these contribute to listeriosis is not well understood.

Little is known about how *L. monocytogenes* contamination of RTE foods occurs in retail delis. *L. monocytogenes* strains are regularly found and often widely distributed in retail facilities [24, 25]. Retail practices may result in either cross contamination from one RTE product to another, or through contamination from the retail environment, or both. Retail practices may also contribute to higher levels of *L. monocytogenes* on RTE foods [14, 15]. A recent QRA suggests that retail cross contamination of RTE foods has the potential to increase the risk of listeriosis considerably, and that frequency of cross contamination has the greatest impact on the risk [26]. In addition to cross contamination, improper holding temperatures, and insufficient sanitary practices are all likely contributors to *L. monocytogenes* contamination and growth of *L. monocytogenes* on RTE foods at retail [27]. Concurrently, retail food establishments are required to comply with a number of food safety requirements that are designed to mitigate the risk of foodborne illness (e.g., cold holding, date marking, specified methods and frequency of cleaning surfaces). However, the extent to which these requirements and other industry best practices mitigate to the risk of listeriosis is not well understood.

Given several studies identifying retail delis as contributing to the risk of listeriosis from RTE foods in the United States and limited understanding of the extent to which certain retail food safety practices mitigate these food safety risks, the White House Food Safety Work Group identified the conduct of a food safety risk assessment as a priority to guide efforts to prevent *L. monocytogenes* cross contamination at retail to protect public health[30]. This interagency risk assessment fulfills this White House priority through in-depth evaluations of the extent to which certain retail food safety practices mitigate the risk of listeriosis and identifies those practices that contribute to this risk.

[30] In 2009, the Federal Food Safety Workgroup identified the conduct of this interagency risk assessment as a food safety priority involving efforts to collaborate across federal agencies, with industry and consumer groups, and with the states. This risk assessment has remained a priority as highlighted in the Federal Food Safety Work Group Progress Report (December 2011).

# 2. Process for Conducting This Risk Assessment

In the planning and conduct of this risk assessment, a unique partnering of government agencies, academia, industry, and consumer groups was actively pursued. FSIS and FDA had four primary goals for the conduct of this risk assessment:

1) Shared partnership between FSIS and FDA in all aspects of the development of this risk assessment (e.g., planning, budgeting, data acquisition, model development, peer review, and outreach);
2) Engagement of consumer groups, retail and food industry (including Consumer Federation of America (CFA), Center for Science in the Public Interest (CSPI), American Meat Institute Foundation (AMIF), Food Marketing Institute (FMI), Grocery Manufacturers Association (GMA), and the Association of Food and Drug Officials (AFDO) ) from the initiation to the completion of this risk assessment;
3) Collaboration with academia and researchers (including Cornell University, the University of Maryland, Virginia Polytechnic Institute and State University (Virginia Tech)) to fill specific data needs identified in analyzing the framework for this risk assessment; and
4) Scientific input and review through frequent presentations of this risk assessment model and data analyses at scientific conferences and through a rigorous independent peer review of this risk assessment.

### *2.1. Partnership*

FSIS and FDA formed an interagency workgroup, shared resources, and collaborated in the development of this retail risk assessment. The interagency workgroup met frequently; worked together to commission, collect, and analyze data; obtain stakeholder and public input; develop and refine the risk assessment model; co-funded the peer review of this risk assessment, and, together; developed presentations, written communications and reports.

### *2.2. Ensuring public participation in the process*

In June 2009, FSIS and FDA held a meeting to garner input from the public and engage stakeholders at the onset of the development of this risk assessment. The Agencies discussed the scope and objectives of this interagency risk assessment (74 Federal Register, Vol 74, No 109, June 9, 2009 27276-27278) and invited public comment and submission scientific data and information project (Federal Register Notice, Vol 74, No 12, January 21, 2009. 3617-3619; Federal Register Notice, Vol 74, No 165, August 27, 2009. 43714-3619) . Comments were received from the AMIF, the GMA, and the CSPI.

During the course of conducting the risk assessment, the project was presented to various stakeholders notably the AMIF, the FMI, the GMA, the CSPI, the CFA, and the AFDO. During these meetings, the interagency work group received recommendations and suggestions from the stakeholders that were considered in the development of this risk assessment.

### *2.3. Collaboration with academia*

Studies to collect data for this risk assessment were undertaken in collaboration with the University of Maryland, Virginia Tech, and Cornell University. Trade associations, including the FMI and AMIF contributed to the planning and conduct of some of these studies. Specific studies include:

- **Retail employee behavior studies.** FDA, the University of Maryland, and the Joint Institute for Food Safety and Applied Nutrition conducted an observational study of retail deli food handling and sanitation practices in nine retail delis in the D.C.- metro area [28]. This time-series study of retail behaviors over the course of a day formed the basis for the sequential "events" modeled at retail in this risk assessment. The FMI was instrumental in facilitating the conduct of this study. Additional data from 300 retail delis in 5 states (New York, including New-York City, Tennessee, California, Minnesota, and Rhode Island) is currently being gathered through a follow-on study conducted through a collaborative effort between FSIS and the CDC with Environmental Health Specialists Network (EHS-Net) state partners. This subsequent study was cleared by the Office of Management and Budget (OMB) in December 2012 and data from this study will be used in future updates of this risk assessment.

- ***L. monocytogenes* transmission studies.** A mock deli was set up at Virginia Tech to study the dynamics of *L. monocytogenes* by evaluating semi-quantitatively transfer during events and actions as RTE deli products are prepared, sliced, and/or packaged in retail delis [29]. Additional work was funded by the National Institute of Food and Agriculture at the University of Arkansas [30].

- ***L. monocytogenes* Contamination in the Retail Environment**
    - A risk mapping of *L. monocytogenes* in a retail environment was developed by Cornell University through elicitation of expert opinion to validate where *L. monocytogenes* occurs in a retail facility [31];
    - Cornell University also collected data on environmental *L. monocytogenes* contamination in 30 retail delis in Indiana, New York, and North Carolina, during

pre-operational and operational activities. This study has been completed and a manuscript is in preparation. AMIF and FMI have extended this study, in collaboration with Purdue University, to further evaluate the effectiveness of interventions to prevent or control *L. monocytogenes* in retail delis.

### *2.4. Scientific input and peer review*

As described in OMB's Final Information Quality Bulletin for Peer Review (Federal Register Notice, Vol 70, No 10, January 14, 2005. 2664-2677,), FDA and FSIS are committed to ensuring the quality, objectivity, utility, and integrity of all agency disseminated scientific information. Peer review is one of the important procedures used to ensure that the quality of published scientific information meets the standards of the scientific and technical community. The OMB bulletin describes the peer review requirements for influential scientific information. A scientific assessment is defined by OMB as "an evaluation of a body of scientific or technical knowledge that typically synthesizes multiple factual inputs, data, models, assumptions, and/or applies best professional judgment to bridge uncertainties in the available information."

Consistent with the OMB peer review guidelines, the draft model of the Interagency Risk Assessment - *L. monocytogenes* in Retail Delicatessens - was independently peer reviewed in 2010, through an external contract with Versar, Inc. This review focused on an evaluation of the design, logic, and mathematics of this risk assessment. The risk assessment model was further amended and modified in response to peer-reviewer comments and input received from the scientific community. The reports of this external peer review, as well as the specific FSIS and FDA answers to the various comments, are publicly available[31].

This interagency risk assessment model and related analyses also were presented at technical scientific meetings including the 2009 and 2012 Society for Risk Analysis annual meetings (December 8, 2009, Baltimore, Maryland.; December 11, 2012, San Francisco, California), the XVII$^{th}$ International Symposium on Problems of Listeriosis (May 6, 2010, Porto, Portugal), the 2010 Conference on Modeling

[31] FDA Risk Assessment website: http://www.fda.gov/ScienceResearch/SpecialTopics/PeerReviewofScientificInformationandAssessments; FSIS Risk Assessment website: http://www.fsis.usda.gov/Science/Risk_Assessments/index.asp; FSIS peer review plan for this risk assessment: http://www.fda.gov/ScienceResearch/SpecialTopics/PeerReviewofScientificInformationandAssessments/

for Public Health Action (Centers for Disease Control and Prevention, December 10, 2010, Atlanta, Georgia), the 2010 and 2012 IAFP International Association for Food Protection (IAFP) annual meetings (June 1-4, 2010, Anaheim, California; July 22-25, 2012, Providence, Rhode Island) and the 2012 Conference for Food Protection (April 13-18, 2012, Indianapolis, Indiana).

# 3. Scope and Objectives / Risk Management Questions

## *3.1. Charge for the Interagency Risk Assessment and Risk Management questions*

Some of the essential duties of risk managers are to determine what hazards or practices present more risk than society is willing to accept and to consider what control options are available [32]. These options need to be effective and efficient in mitigating risks in order to determine the appropriate actions that are feasible to implement for the assurance of food safety. To accomplish this task, several options are usually provided in the form of questions to be modeled. The risk management questions are answered by converting them to the model framework and the results are compared to evaluate to what extent the proposed mitigation strategies may reduce the relative risk.

At the onset of this risk assessment, three questions important to risk managers were considered:

1. What is the exposure to *L. monocytogenes* from consuming RTE foods prepared in retail facilities?
2. What are the key processes that increase RTE food contamination at retail?
3. How much is the relative risk per serving reduced when specific risk management practices are implemented?

These broad risk management questions were further expanded to a list of proposed risk mitigations to be evaluated (e.g., via scenario analyses) within the interagency risk assessment. Some of the questions were generated by FDA and FSIS risk managers while others were provided by stakeholders. These include risk management questions related to sanitation, retail behavior, and levels of *L. monocytogenes* on RTE products entering retail delis for further preparation.

1) What is the public health impact of more frequent or extensive retail deli cleaning procedures than those specified in the 2009 FDA Food Code?
2) What is the potential public health impact of increasing the use of single-service gloves in the retail environment?
3) What if scale touch pads, refrigerator and deli case handles, and other frequently touched non-food contact surfaces were considered food contact surfaces and were therefore required to be cleaned and sanitized at a minimum frequency?
4) What if practices were in place so that no cross contamination occurred in delis (i.e., no additional *L. monocytogenes* added to incoming RTE products)?

5) What if display cases were not touched with gloved or bare hands (i.e., used tissues or had automatic door open/shut)?
6) What would be the potential public health impact if the level of *L. monocytogenes* contamination on RTE foods coming into the retail deli were at higher level (cfu/gram)?[32]
7) What would be the potential public health impact of "pre-slicing" all RTE products *vs*. "slicing to order" (hypothesis: less cross contamination occurring in the morning prior to other cross contamination events)?
8) What would be the potential public health impact of using separate slicers and/or separate counters for RTE products that permit growth of *L. monocytogenes* and for those RTE products that do not support the growth of *L. monocytogenes*?
9) What would be the potential public health impact of lowering the level of environmental transfers from environment to food?
10) What if food workers do not slice RTE products directly onto their gloved hands?
11) What is the potential public health impact of *L. monocytogenes* growth in retail delis?
12) What would be the potential public health impact of complete compliance to the cold holding requirements for certain RTE foods in deli cases (i.e., 2009 FDA Food Code guidance: hold at 41°F (5°C) or less)?
13) What would be the public health impact of shortening the time a RTE product can be used in a deli department (i.e., before it is discarded)?
14) What would be the potential public health impact if all (or no) RTE products (e.g., deli meats and deli salads) coming into the deli were formulated with growth inhibitors?

### *3.2. Scope and objectives of the risk assessment*

The objective of this risk assessment is to assess the risk of foodborne illness associated with current practices and to examine how that risk may be impacted by mitigations that may reduce or prevent *L. monocytogenes* growth or contamination in RTE foods prepared in retail deli settings.

The risk assessment is designed to cover RTE foods that are: *i*) regulated by both FSIS and FDA; *ii*) sliced, prepared, and/or packaged in the retail deli environment and consumed in the home such as deli meats, cheeses, and deli-type salads; *iii*) sold in a retail deli environment, which refers to a range of retail

[32] This scenario would evaluate the potential increased risk posed from an increased contamination level of *L. monocytogenes* in RTE foods at retail delis.

types, such as delicatessen departments of major and large grocery chains, supermarket facilities and other groceries (i.e., multipurpose, independent, small or local facilities). Restricting the scope of the risk assessment to foods that are intended to be "consumed in the home" means that restaurants or other establishments where the RTE foods are consumed on-site were not included.

The risk assessment model simulates the retail environment and evaluates how changes in various retail sanitary and food handling practices may influence the U.S. risk of listeriosis from consuming RTE foods that were sliced, handed, or prepared in retail grocery delis. The model also predicts which mitigation strategies confer the greatest benefits in reducing the risk of listeriosis. This may provide risk managers with information needed to inform retail food safety decisions regarding the policy changes in retail facilities and promotion of industry "best practices."

This risk assessment could be used to refine retail food safety practices and mitigation strategies to control *L. monocytogenes* in RTE foods further.

# 4. Conceptual Model and Framework

The risk assessment model is unique in its ability to quantitatively link activities and mitigations within a retail deli directly to public health outcomes. Model inputs are the stochastic working routines of deli workers, *L. monocytogenes* concentrations of incoming product, environmental contamination to food contact sites, and cross contaminations among those sites. The model simulates the *L. monocytogenes* concentrations and prevalences in products sold to customers, predicts changes in concentrations during customer home storage, and finally estimates the risk of listeriosis from these sales. By serving as a "virtual deli," the model allows for quantitative assessment of listeriosis risks from activities or proposed changes to the retail deli operation.

In order to estimate the risk per serving and the prevalence, the processes that lead to the level of bacterial contamination when the RTE product is sold, notably cross contamination, bacterial growth, and/or bacterial inactivation/removal in the deli-department have to be considered. A specific discrete-event simulation model was developed for this purpose. The output of the discrete event model is a distribution of number of *L. monocytogenes* per RTE product sold by the retail deli. An estimate of growth of *L. monocytogenes* on RTE product includes growth during the transport from the retail deli to the home, as well as growth during the storage in the refrigerator at home. The risk of listeriosis per serving is eventually derived from the concentration in the RTE product at the time of consumption, the serving size, and a dose-response model.

## *4.1. A discrete-event simulation to track* L. monocytogenes *in the retail environment*

Cross contamination is defined here as the transfer of bacteria from one food compartment or site to another. It is commonly used to describe the transfer of pathogens among different food groups and environmental surfaces during food production. Cross contamination models affect the analysis of exposure in the risk assessment directly. In addition to the time-temperature growth modeling common to most risk assessments, models of cross contamination in food usually distinguish between variables or compartments that need to be simulated and events or handling procedures that allow the bacteria to transfer from one compartment to another [e.g., 33, 34-37]. For each compartment, the bacterial concentrations are modeled through time. Examples of compartments for a retail environment might include:

- different food groups with possible distinction of surface concentrations versus interior concentrations;

- workers hands and clothing;
- slicers and other equipment;
- food contact surfaces, such as countertops; and
- other environmental locations (e.g., refrigerated storage areas and floors).

The compartments established for a food processing plant may be different from those established when modeling a retail deli environment.

Events over time that cause bacteria to be transferred from one compartment to another also must be simulated. Examples of events in the retail environment might include

- handling chubs while transferring from storage to countertop and then from countertop to slicer;
- slicing a chub;
- washing hands;
- cleaning equipment; or
- cleaning food contact surfaces.

The compartments that are impacted and the frequency of each event are part of the cross contamination model input.

Cross contamination is important because it leads to a greater number of contaminated servings of food leaving the retail deli. Because *L. monocytogenes* can grow at refrigerated temperatures, initially low levels of contamination could grow to high levels during retail storage and consumer transport and storage, thereby increasing the risk of illness. Cross contamination at retail has the potential to change the final dose at consumption. Cross contamination has the potential to impact the risk to increase the level of *L. monocytogenes* on foods further, resulting in a higher consumer exposure and ability to increase the risk of foodborne illness. As a result, cross contamination is an important process to model in food safety risk assessments. However, risk assessments that incorporate cross contamination modeling have greater data needs and require simulating a broader number of variables than typical quantitative microbial risk assessments.

A discrete event type model was selected as the most appropriate framework for the charge of this risk assessment. In discrete-event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. Cross contamination occurs when specific sites are brought in contact (e.g., when a chub is placed on a

slicer). Bacterial transfer occurs only at these discrete events. A major advantage of this framework is the flexibility and granularity that the approach provides. Additional events can be inserted or several events merged into one without changing the overall model. The process is illustrated in Figure 2. A major event is selected stochastically (e.g., serving a customer or cleaning the deli area). If appropriate, this major event can be broken down into a series of more granular activities (e.g., removing a chub from the case or slicing a chub). This sequence of events can also be developed stochastically, as shown in Figure 3.
Each 'YES/NO' branch can be based on probabilities. The level of granularity can be modified as needed. This flexibility is especially important because risk management questions may be added.

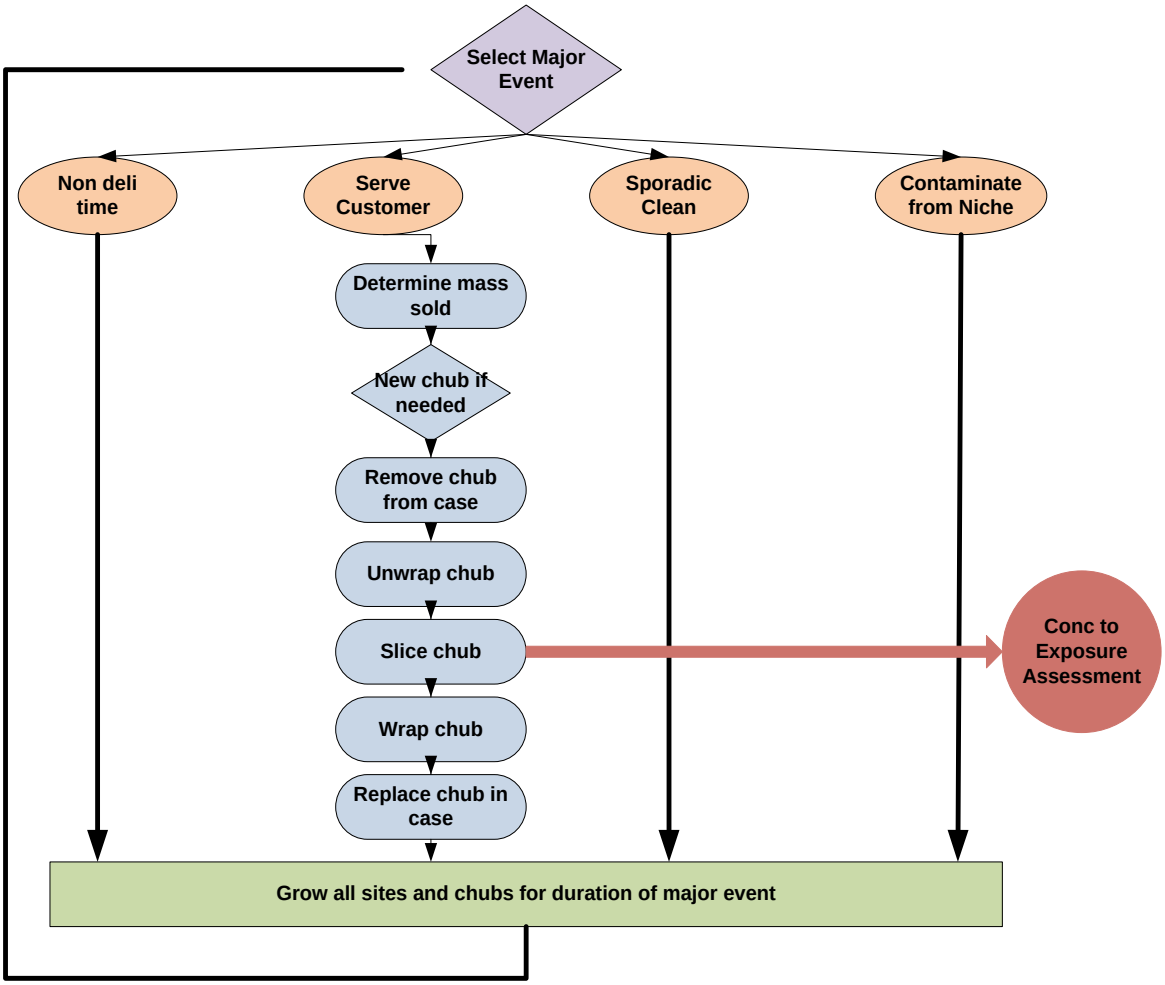



**Figure 2: Illustration of the discrete event cross contamination model component of the Interagency Risk Assessment - *L. monocytogenes* in Retail Delicatessens.**

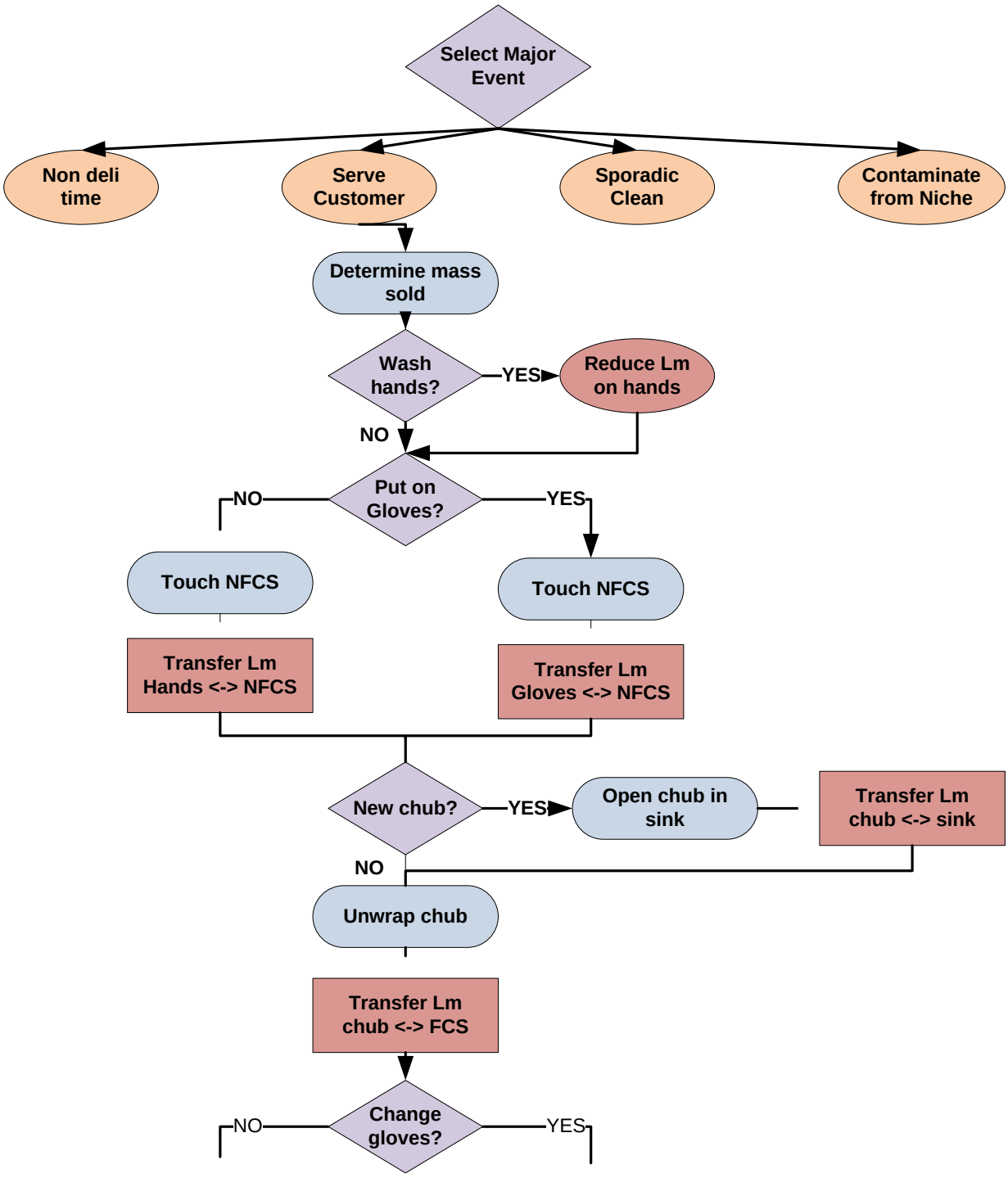



**Figure 3: Illustration of stochastic decision tree within the discrete event model of the Interagency Risk Assessment - *L. monocytogenes* in Retail Delicatessens.**

[Note Figure 3 is only an illustrative example of a part of the time sequence of serving a RTE food to a consumer.]

### *4.2. Overview of the "virtual deli," its operation and the impact on* L. monocytogenes

A graphical depiction of the "virtual deli" model, along with possible *L. monocytogenes* transfer routes is provided in Figure 4. The retail deli food worker is depicted on the lower left.

Food RTE products are shown on the left. The current model is designed for three major food categories: deli meats, deli cheeses, and deli salads. Although not shown here, each of these food categories is broken down into more specific types. Each of these specific RTE products has associated growth rates and probability of being sold. Each RTE food also is tracked for age of the product. Older product is disposed of in this model (see section 6.5.2).

Sites within each retail deli are shown on the right. Vertical arrows at a site indicate the possibility of *L. monocytogenes* growth (up arrow) or removal by cleaning (down arrow). In practice, only *L. monocytogenes* growth for RTE products was actually used for model scenarios. Asterisks at a site indicate the possibility of a niche. The model is flexible in that any site may harbor a niche. Those shown are illustrative of the multiple niche scenarios describe below. Arrows between sites, workers, and RTE products indicate the potential cross contamination routes. RTE food servings leaving the retail deli (i.e., RTE products sold) are depicted in the upper left.

The risk assessment model is flexible in that it readily allows the addition of new RTE products, sites, or transfer routes. For example, this risk assessment model currently includes a floor as one of the sites, but no transfer of *L. monocytogenes* route exists from the floor to RTE food based on an retail deli observational study [28]. However, such a site, event, and transfer could be readily added to this flexible risk assessment model.

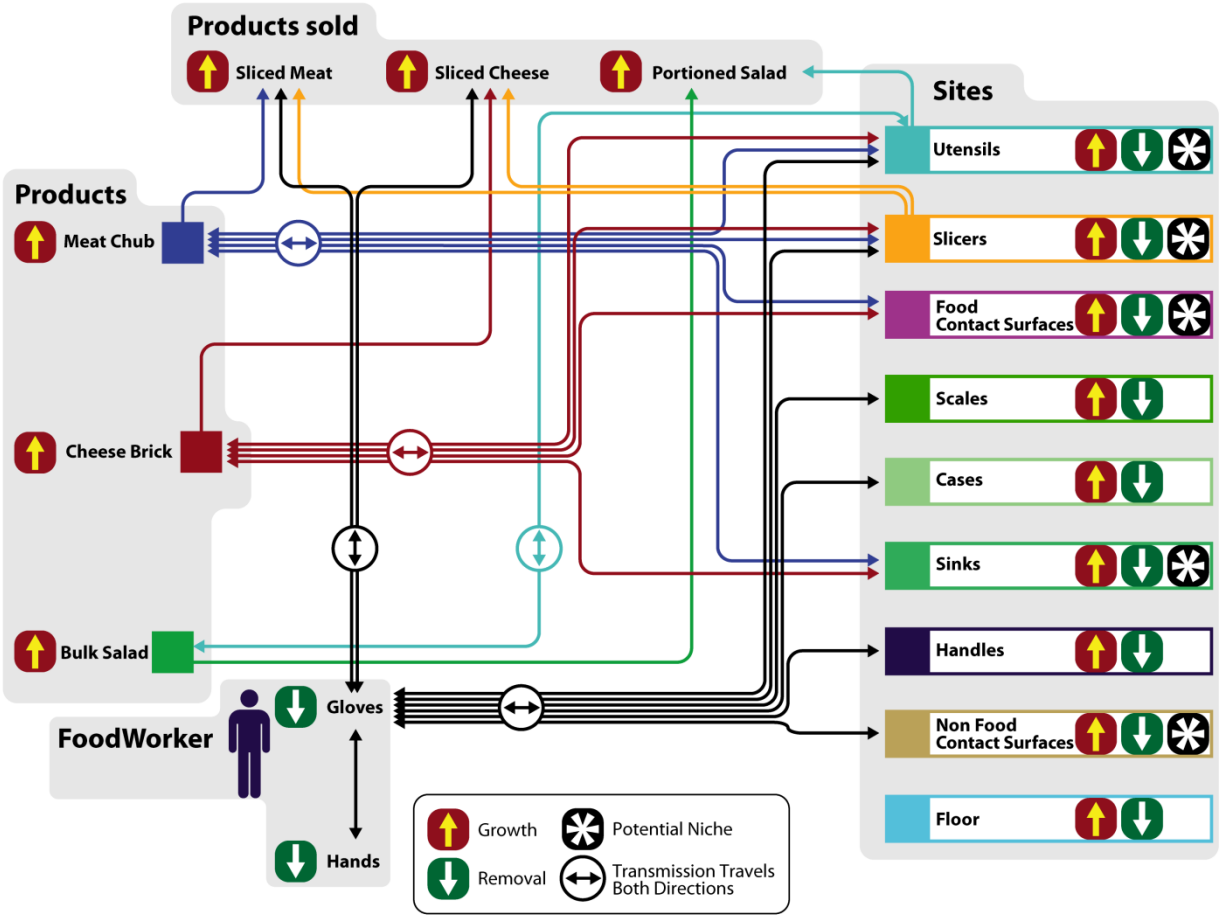


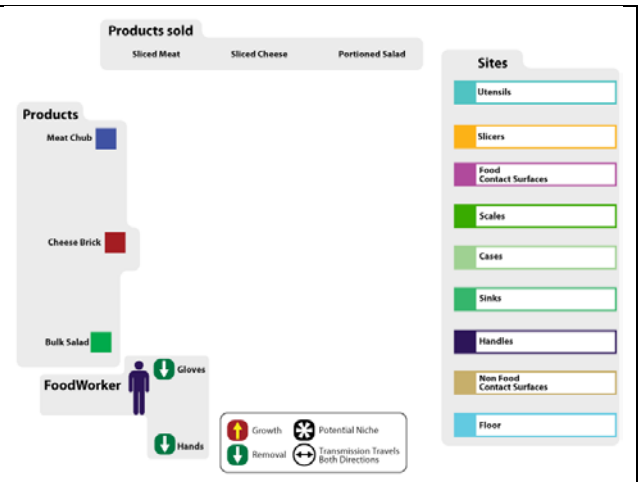
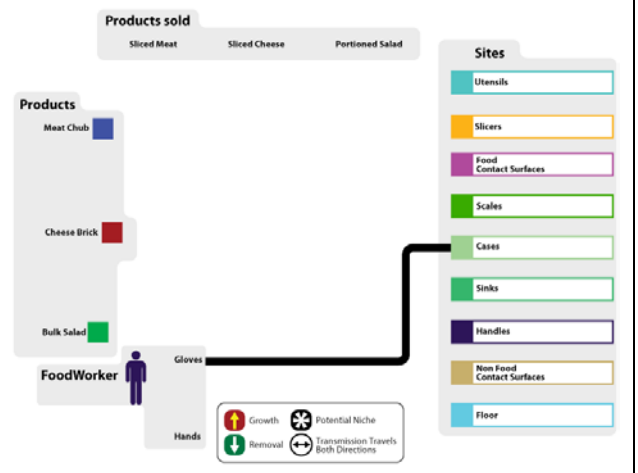
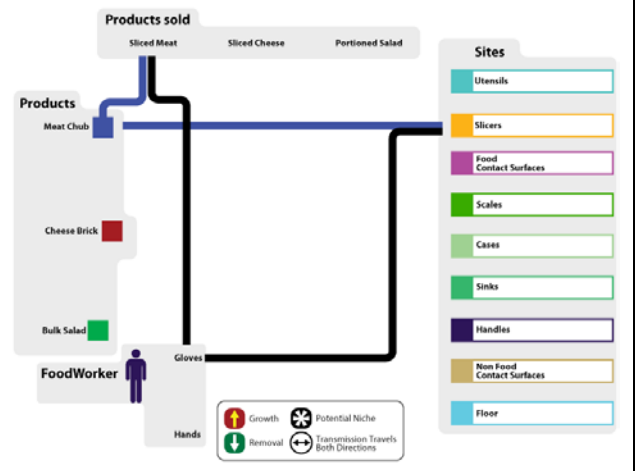

**Figure 4: Diagram of "virtual deli" and cross contamination routes within the model of the Interagency Risk Assessment - *L. monocytogenes* in Retail Delicatessens.**

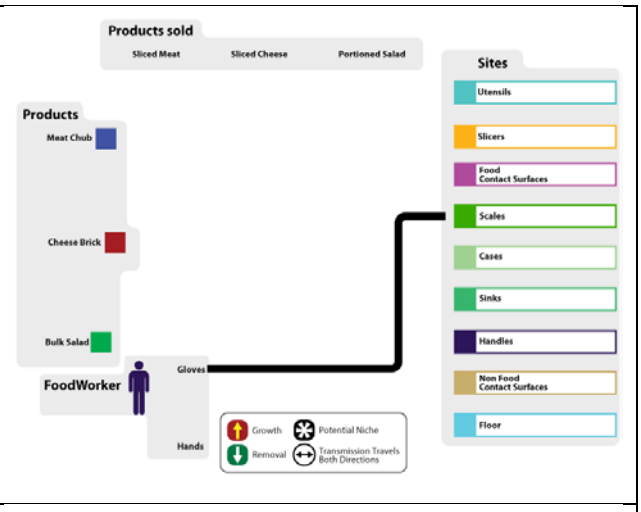
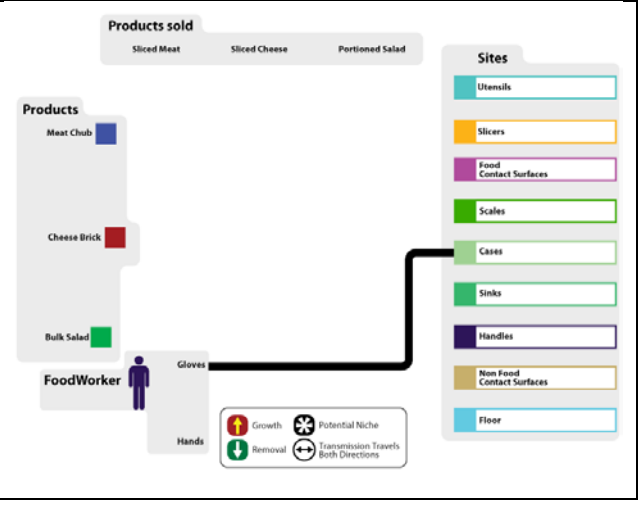
The diagram in Figure 4 appears complicated with a large number of cross contamination routes. However, the discrete event model framework considers a limited number of site interactions at any time, over a long period. Table 1 depicts this scenario for a "serving a customer" event. At the beginning of the event, the *L. monocytogenes* concentrations for each site and chub are known. The first activity is to wipe down the slicer, which reduces the concentration of *L. monocytogenes* at that site (note the down arrow). The next activity is for the worker to wash his hands and put on gloves. This reduces the concentration on the worker's hands and adds a new location (glove) to track. The third activity is to get the chub from the case. This brings in contact the worker's gloves and the case handle with subsequent potential cross contamination between worker's gloves and the case handle. The fourth activity is to slice the chub. This allows cross contamination among the worker's gloves, slicer, chub, and future serving. The fifth action is to weigh the serving and touch the scale. Cross contamination can occur between the worker's gloves and

the scale. Finally, the chub is placed back in the case, with a contact between the gloves and the case. At each stage, the number of sites involved and level of contamination being updated is small, but the cumulative effect is a mechanistic model of cross contamination over time in a retail environment.

**Table 1: Illustration of site interactions and cross contamination while serving a customer**

| | |
|---|---|
| **Example: Serve Customer Event.** | |
| **1. Wipe Slicer.**<br>Removes some bacteria from the slicer. | |

| | |
|---|---|
| **2. Wash hands and change gloves.**<br>Removes some bacteria from hands. |  |
| **3. Open case, remove chub, and close case.**<br>Cross contamination between gloves and case. |  |
| **4. Slice on gloves.**<br>Cross contamination among gloves, slicer, and chub. |  |

| | |
|---|---|
| **5. Touch scale.**<br>Cross contamination between gloves and scale. |  |
| **6. Open case, replace chub, and close case.**<br>Cross contamination between the gloves and the case. |  |

### *4.3. Considering model variability and uncertainty*

According to international scientific recommendations [38, 39], a quantitative food safety risk assessment should reflect the variability in the risk and evaluate separately the uncertainty associated with the risk estimates. Variability represents temporal, geographical, and/or individual heterogeneity of the food safety risk for a given population. Uncertainty is understood as stemming from a lack of perfect knowledge about the risk assessment model structure and associated parameters. Variability and uncertainty should be treated separately because each has different risk management implications.

Variability explains differences from one retail deli to another – both in terms of size of the retail deli and corresponding amount of equipment (e.g., number of slicers, *etc*.) and the operating procedures used. Additionally, operations in the retail deli, bacterial growth, cross contamination, consumption, *etc*. are simulated individually using stochastic processes. For each retail deli, a time-series (i.e., a series of

*L. monocytogenes* concentrations at each location within the retail deli and for all servings sold chronologically) is developed. The time series includes a sufficiently large number of servings to evaluate specific operating practices (i.e., the statistics of the time series have stabilized).

The model is written as a full second order Monte Carlo model that distinguishes variability from uncertainty [40] (Figure 5). It was assumed that the uncertainty surrounding the existence and the "behavior" of the niches overwhelmed the other sources of uncertainty. It was thus decided to illustrate this uncertainty through the comparison of various baselines (e.g., by comparing the various scenarios within a retail deli with multiple niches *versus* within a retail deli without niches) (see section 7).

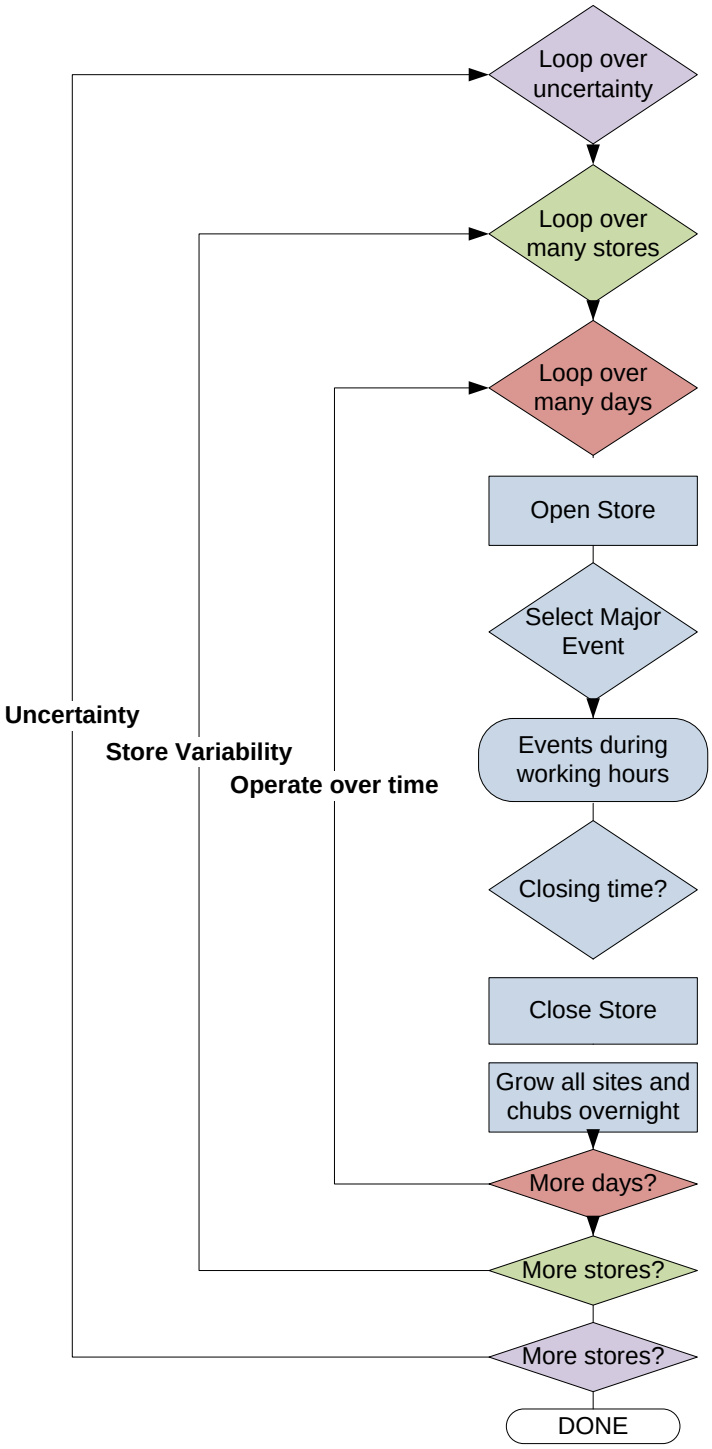



**Figure 5: Illustration of developed time-series based on variability within and among retail delis and uncertainty of existence and location of niches within the retail deli.**

# 5. Data Collection

The Interagency Retail *L. monocytogenes* Risk Assessment Workgroup commissioned a number of studies to fill specific data needs for the conduct of this risk assessment. These studies were listed in Section 2.3 and include: retail worker behavior data (University of Maryland and CDC/EHS-Net studies); environmental sources of *L. monocytogenes* in retail delis (Cornell University); and simulation of the transmission of *L. monocytogenes* in mock retail delis (Virginia Tech).

In addition, the Interagency Retail *L. monocytogenes* Risk Assessment Workgroup conducted a systematic review of the literature regarding the various domains covered by the considered model. This systematic review included scientific literature on bacterial transfer (including during the slicing process), bacterial growth, bacterial inactivation through cleaning and disinfection, retail data, and consumer handling of food. The group synthesized the available scientific evidence to derive probability distributions and mathematical models.

For that purpose, the relevant peer-reviewed scientific literature was identified using the National Center for Biotechnology Information (NCBI) PubMed database, cross references in related published manuscripts, and auxiliary data sources such as the Google® search engine. Literature searches for transfer coefficients (including those specific to slicers) and for cleaning and sanitizing were performed in June 2009 and December 2010, respectively. Initial queries for transfer coefficients were run in the NCBI PubMed database using the terms 'cross contamination', 'transfer,' and 'bacteria,' followed by identification of additional manuscripts through cross-referencing in the studies identified in the initial query. For studies of cleaning and sanitization, the NCBI PubMed database and Google were searched using 23 relevant keywords, screening all NCBI PubMed results and the first 15 pages in the Google® database for each query. This meta-analysis of available data was published as a scientific paper in the International Journal of Food Microbiology [37]. The probability distributions and mathematical models derived within this study were used to predict *L. monocytogenes* cross contamination and inactivation in the current model.

Other in-house data collection and meta-analyses were developed in the framework of this study. These meta-analyses included studies on bacterial growth, including the presence of growth inhibitors, consumption data, temperature data, dose-response models, etc. The results are provided within this report in the corresponding sections or as appendixes.

# 6. Comprehensive Description of the Risk Assessment Model

## *6.1. Modeling the basic processes for* L. monocytogenes

Within an exposure assessment, Nauta [41, 42] suggests describing and modeling the RTE product pathway as a succession of "basic processes" impacting the prevalence and level of bacteria in the RTE product. The basic processes are the six fundamental events that may affect the prevalence and/or level of any microbial hazard in food process. The basic processes used in the current model are namely:

- cross contamination: a transmission of bacteria from one unit (object or food) to another one. The terms "cross contamination" and "transfer will be used interchangeably;"
- bacterial growth: the multiplication of microorganisms (or growth of the population); this basic process is a typical characteristic of quantitative microbial risk assessment;
- bacterial inactivation: sanitation process is frequently an applied food safety and food preservation strategy. The chemical inactivation and physical removal of bacteria *via* washing and wiping, as well as the removal of bacteria *via* the disposal of contaminated objects (e.g., putting gloves in the trash) are included in this basic process within this risk assessment;
- partitioning occurs when a large unit is split into several units.

In the current model, bacterial growth may occur in food all along the RTE product pathway, from entry into the deli through to consumption. Bacterial inactivation occurs during sanitizing, washing, and wiping. Partitioning will be encountered during the slicing of cheese and deli-meat, as well as during the scooping of salad from a bulk container. Eventually, transfer of bacteria from the environment, i.e., cross contamination, occurs in the deli.

This section describes the general rules, models and data used to model these basic processes. The transfer of bacteria is a transfer of a finite number of cells. As a consequence, the number of bacteria per site / food / niche is considered, and not the concentration of bacteria. In other words, bacteria are tracked as colony forming units (cfu) at a location, not as a representative mass or area based concentration.

### 6.1.1 Cross contamination

In this report, the definition of cross contamination is enlarged to include any transfer of bacteria from one site, food or niche to another.

*Cross contamination between two objects*

The probabilistic derivation of the model is as follow [37]: given $N_1$, the initial number of bacteria on a given object (#1), and $N_2$ the initial number of bacteria on another object (#2). $T_{12}$ is the transfer coefficient ($0 \leq T_{12} \leq 1$) from the object #1 to the object #2 and $T_{21}$ is the transfer coefficient ($0 \leq T_{21} \leq 1$) from the object #2 to the object #1. $F_1$, the final number of bacteria on the object #1, and $F_2$ the final number of bacteria on the object #2 are derived stochastically using the following algorithm:

$$x_{11} \sim \text{binomial}(N_1, 1 - T_{12})$$

$$x_{21} \sim \text{binomial}(N_2, T_{21})$$

$$F_1 = x_{11} + x_{21}$$

$$F_2 = N_1 + N_2 - (x_{11} + x_{21})$$

The underlying assumptions for this model are:

1) the two populations $N_1$ and $N_2$ "act" independently;
2) within each population ($N_1$ and $N_2$), each bacterium "acts" independently (i.e., the probability of transfer for all bacteria from one object to the other is equal and constant for a given cross contamination). Using a binomial process assumes that the result is the sum of $N_1$ independent Bernoulli assays;
3) no bacteria are lost during the transfer; and
4) the transfer coefficients $T_{12}$ and $T_{21}$ are independent of the initial number of bacteria.

Various transfer models have been developed and used in the literature [5, 33-35, 43-49]. In most, the independence of transfer (i.e., assumption #2) is assumed. The most discussed assumption is linked to the independence of the transfer coefficient and the initial number of bacteria (i.e., assumption #4). Montville and Schaffner [50] and Fravalo *et al.* [51] suggest that the transfer from contaminated objects is inversely related to the initial load. Rodriguez *et al.* [52] did not confirm this observation. Eventually, Nauta [53] shows that the observation of a relationship between the transfer rate and the initial level of contamination can be explained by an artifact linked to the limit of detection. He concludes that "so far there is no evidence that bacterial transfer rates are inversely related to the initial level of contamination," and this assumption is used in the model.

Transfer coefficients were thus considered as independent of the number of bacteria, while variable from transfer to transfer. A complete literature review was performed [37] to develop the distribution of

transfer coefficient for various source – recipient couples (e.g., Stainless steel - Meat). The $\log_{10}$[33] normal distribution was eventually chosen on the basis of published data, and our assays ability to reflect the variability of transfer coefficients for a given source – recipient couple. Given $M_{Tij}$ (i.e., the mean of the $\log_{10}$ of transfer coefficient from the object *i* to the object *j*) and $S_{Tij}$ (i.e., its standard deviation), a transfer coefficient $T_{ij}$ is sampled for each new transfer using:

$$\log_{10}(T_{ij}) \sim \text{Normal}(M_{Tij}, S_{Tij}).$$

If the sampled value leads to $T_{ij} > 1$, $T_{ij}$ is set to 1 (and thus all bacteria are transferred).

*Cross contamination between more than two objects*

The model can be extended to transfers between *k* objects [37]. Let $N_i$ equal the initial number of bacteria on object *i* before transfer, and $N_j$ equal the initial number of bacteria on object *j* before transfer, with $i,j \in$ [1, k]. Following the same notation and rational as above,

$$x_{ii} \sim \text{binomial}\left(N_i, \prod_{j \in K, j \neq i}\left(1 - T_{ij}\right)\right)$$

with $K = (1, .., k)$, and $x_{ij,}$ the number of bacteria transferred to object *j* from object *i* is distributed as

$$x_{ij, j \neq i} \sim \text{multinomial}\left(N_i - x_{ii}, \frac{T_{ij, j \neq i}}{\sum_{j \in K, j \neq i} T_{ij}}\right).$$

For the same reasons as above, $F_{i,}$ the final number of bacteria on object *i* after transfer equals:

$$F_i = \sum_{j=1}^{k} x_{ji}.$$

*Cross contamination during the slicing process*

Slicing is a complex process in terms of bacterial transfer [54]. The objective here was to derive a model that could mimic the cross contamination linked to the use of a slicer in retail and that could be in accordance with the studies developed on the subject [21-23, 54-58]. Modeling the slicing process may indeed be challenging: "The following are the factors that can impact the transfer of *L. monocytogenes*: (1) the compositions of deli meat (moisture, fat content, formulation, and so on), (2) the cut surface characteristics (texture, homogeneity) of deli meat, (3) the rotational speed or revolutions per minute (rpm) of the cutting blade, (4) the diameter of the blade, (5) the sharpness (or profiles) and material of the

[33] Note: in this document, ln is the logarithm of base e (natural logarithm) and $\log_{10}$ is the logarithm of base 10.

blade, (6) the back pressure from meat loaf (weight force exerted to contact blade surface by gravity and/or the end weight attachment), (7) the slicing speed (for example, slices per minute), (8) the contact angle, area, and slice thickness, (9) the microorganism (age, strain, inoculum size, capability to adapt different stresses, adhesion to surfaces, and so on), and (10) the environmental condition (for example, temperature and so on)." [58].

The experimental assays provided in the literature are not sufficient to model the impact of all these covariates. The models that are developed in the literature are empirical and cannot be used in a stochastic discrete event model. A general compartmental model that is in accordance with the literature observations had to be derived instead.

The model considers two parts for the chub (both meat and cheese):

- the head of the chub (*HC*), contaminated by the blade during the slicing process,
- the remainder of the chub (named here "core of the chub" *CC*), which may be contaminated due to introduction of *L. monocytogenes* at the manufacturing stage or due to cross contamination after opening.

The bacteria that are involved in the system have three origins:

- the contamination of the core of the chub;
- the contamination of the head of chub;
- the contamination of the slicer.

The following simulation process is used:

1. Given $CC_0$, the number of bacteria in/on the core of the chub of mass $M_0$, given $m$ the mass of a slice and assuming a homogeneous distribution of the *L. monocytogenes* on/in the chub, the number of bacteria newly involved in the process is $I_0 \sim \text{binomial}(CC_0, m/M)$. The remaining number of bacteria in/on the core of the chub is then $CC_1 = CC_0 - I_0$. The remaining mass of the chub is $M_1 = M_0 - m$.
2. The number of bacteria from the chub, $C_0$, eventually involved in the slicing process is the newly involved number of bacteria $I_0$ and the number of bacteria on the head of the chub $HC_0$: $C_0 = I_0 + HC_0$.
3. During the slicing process,
    - a part of these $C_0$ bacteria are transferred to the slicer following $C_s \sim \text{binomial}(C_0, a)$, with $0 \leq a \leq 0.5$, a parameter. The remaining stay on what becomes the slice $C_y = C_0 - C_s$;

- a part of the $S_0$ bacteria stays on the slicer $S_s$ ~ binomial($S_0$, 1 - 2$a$). On average, half of the bacteria transferred from the slicer are transferred to the (new) head of the chub according to $HC_1$ ~ binomial($S_0 - S_s$, 0.5), and the remaining are transferred to the slice $S_y = S_0 - S_1 - HC_1$.
- $Y = C_y + S_y$ is the number of bacteria on the slice. $S_1 = S_s + C_s$ is the number of bacteria on the slicer at the end of the slicing process.

The process is repeated $n$ times to obtain $n$ slices.

Figure 6 illustrates this model, also described in Hoelzer *et al*. [37]. This process is in accordance with the experimental data that *i*) generally shows a log linear decrease of the number of bacteria, which contaminates successive slices of RTE products; and *ii*) suggest a cross contamination between the slicer, the chub, and the RTE product that is sold [21-23, 54-58].

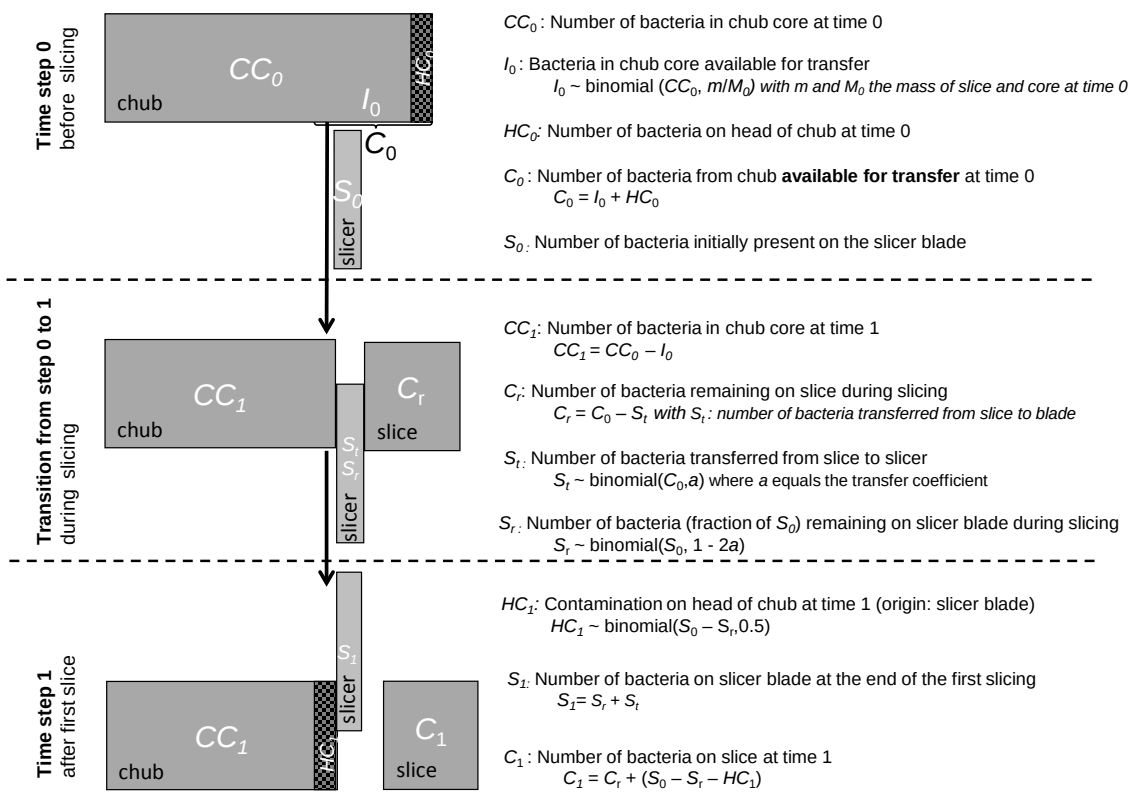



**Figure 6: The slicer model**

(Source: [37])

A literature review of the available scientific articles dealing with slicers was performed. The exhaustive review is detailed in Hoelzer *et al*. [37]. The only experimental designs considered were those where *i*) a blade is artificially contaminated, and *ii*) RTE products are contaminated by the blade during the slicing process [23]. The inferred distribution for the parameter $a$ is a logistic distribution with location parameter 0.07 and scale parameter 0.03. The mean and median of the distribution for $a$ are 8.1% and 7.7% respectively.

*Cross contamination during scooping process*

Similarly, a model was derived for the specific process of scooping deli salad from the bulk container.

The following simulation process is used:

1. Given $CC_0$ the number of bacteria in/on the salad bulk of mass $M_0$, and given $m$ the mass of the serving and assuming a homogeneous distribution of the *L. monocytogenes* on/in the salad, the number of bacteria newly involved in the process is $C_0$ ~ binomial($CC_0$, $m/M$). The temporary remaining number of bacteria in/on the core of the salad bulk is then ($CC_0 - C_0$). The remaining mass of the salad bulk is $M_1 = M_0 - m$.
2. During the scooping process:
   - The utensil contaminates the serving and the remaining bulk salad: a part of the $U_0$ bacteria present on the utensil will stay on the utensil according to $U_u$ ~ binomial($U_0$, $1 - TC_{us}$), where $TC_{us}$ is the transfer coefficient from the utensil to the salad. It is assumed that, on average, half of ($U_0 - U_u$) bacteria transferred from the utensil are transferred to the top of the salad according to $TS_1$ ~ binomial($U_0 - U_u$, 0.5), and the remaining are transferred to the serving $S_u = U_0 - U_u - TS_1$.
   - The serving contaminates the utensil: a part of the $C_0$ bacteria present in the serving are transferred to the utensil following $C_s$ ~ binomial($C_0$, $TC_{su}$), where $TC_{su}$ is the transfer coefficient from the salad to the utensil;
   - The remaining bulk salad contaminates the utensil: it is assumed that the utensil is in contact with a $m/M_1$ part of the remaining salad (i.e., to $R_0$ ~ binomial($CC_0 - C_0$, $m/M_1$) bacteria). A part of these bacteria, $R_1$ ~ binomial($R_0$, $TC_{su}$) will be transferred to the utensil;
3. The remaining number of bacteria in the bulk container of salad is the initial number of bacteria in the bulk minus the number of bacteria that were in the serving minus the number of bacteria that contaminates the utensil plus the number of bacteria transferred from the utensil, (i.e., $CC_1 = CC_0 - C_0 - R_1 + TS_1$);

4. The number of bacteria in the serving is the original number of bacteria from the bulk salad minus those that transferred to the utensil plus those that transferred from the utensil, (i.e., $S_1 = C_0 - C_s + S_u$).
5. The number of bacteria on the utensil at the end of the scooping process is the number of bacteria that were not transferred to the salad or the serving plus the number of bacteria transferred from the serving plus the number of bacteria that transferred from the remaining salad, (i.e., $U_1 = U_u + C_s + R_1$).

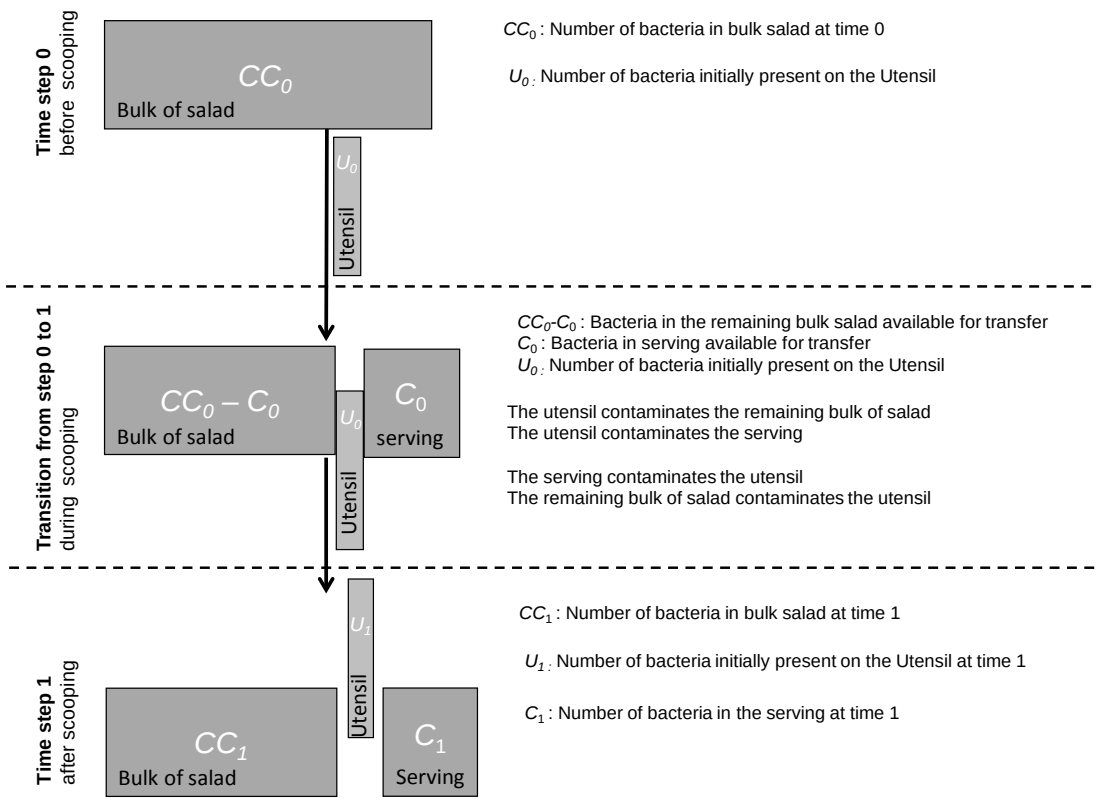



**Figure 7: Illustration of the scooping model.**

*Cross contamination from a niche / Contamination from the environment*

A niche or harborage site is a location associated with a site where bacteria can reside and resist normal cleaning and sanitation procedures. Existing literature provided little insight into the development of a conceptual model for the transfer of *L. monocytogenes* from niches to RTE foods. As such, a very simplified model was developed to consider the presence of niches in the retail environment:

- Each niche is associated with an existing site within the model. Transfer from the niche only occurs to its associated site. Once bacteria transfer out of the niche to the associated site, they

become part of the site's bacteria count and can move to other sites through classical cross contamination;

- The probability for a site to have a niche is specified by the user;
- From time-to-time, the niche releases a fixed number of bacteria to the site. This number is specified by the user; and
- The occurrence of release is assumed to follow a Poisson process. The time to the next release from the niche is then assumed to follow an exponential distribution with mean $\lambda$. $\lambda$ is also specified by the user.

As an example, the user can specify a probability of having a niche associated with a deli case as 0.5, a number of transferred bacteria as 1,000 cfus with a release of bacteria occurring on average every 168 hours of operation. In this context, if a niche is present, 1,000 cfus will be transferred to the corresponding case on average every 168 hours of operation.

Note that this concept could either simulate the presence of a niche or, similarly, the presence of a regular contamination from an external source. This could mimic, as an example, a food worker that would regularly (on average every 168 hours of operation) place a contaminated object such as a milk crate on the food contact surface with a transfer of 1,000 cfus.

### 6.1.2 Bacterial growth

Bacterial growth is one of the important basic process that leads the exposure and the risk to *L. monocytogenes* [3, 59].

*Growth models in food*

Predictive microbiology is a science whose object is to predict the size of a bacterial population according to the environment of the bacteria. Predictive microbiology in food has expanded in the last years and now provides interesting tools for risk assessment purposes [60, 61].

In predictive microbiology, a "primary model" is a model that predicts the evolution of the size of the bacterial population according to time in a given environment. The "secondary model" is a model that evaluates the evolution of the parameters of the primary model according to the environment.

## Primary growth model

The primary model predicts the number of cells with time. A popular growth model is the exponential "tri-linear" model [61, 62]:

$$\begin{cases} y(t) = y(0) & t < \lambda \\ y(t) = \min\left(y(0) + EGR \times (t - \lambda), y_{\max}\right) & t \geq \lambda \end{cases}$$

where $y(t)$ ($\log_{10}$ cfu/g) is the bacterial concentration at time $t$ (day), $\lambda$ (days) is the lag time, EGR is the exponential growth rate ($\log_{10}$ cfu day$^{-1}$), and $y_{\max}$ ($\log_{10}$ cfu/g) is the maximum achievable concentration in the media (Figure 8). $EGR = \frac{24 \times \mu}{\ln(10)}$, where $\mu$ is the specific growth rate (h$^{-1}$). This model has been described as a simple but sufficiently complex model to be used in predictive microbiology and in risk assessment [61, 62].

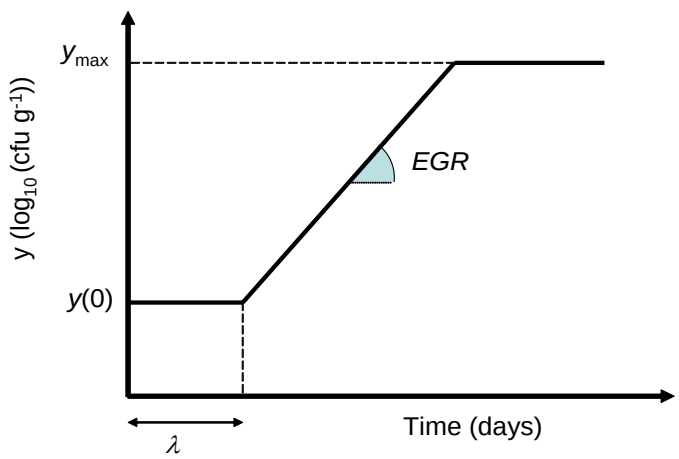



**Figure 8: The "tri linear" primary growth model and its parameters.**

A lag time in the growth is observed in case of rapid change in the bacterial environment.

This model is purely deterministic (i.e., is suitable for a large number of bacteria). The stochastic (i.e., for a small number of bacteria) analog of the exponential phase of this model is the Yule pure birth growth model [63] as described by Vose [64]; with the following premise: *i*) that individual bacteria have offspring on their own (e.g., by division); *ii*) that they procreate independently; *iii*) that procreating is a Poisson process in time; and *iv*) that all individuals in the population are the same. The expected number of offspring from an individual per unit time (over some infinitesimal time increment) is defined as $\mu$. This leads to the results that an individual will have, after time $t$, a number of offspring that follow a geometric(exp($-\mu t$)) distribution. Starting with $x(0)$ individuals (cfu),

$$x(t) \sim x(0) + NegBin(x(0), \exp(-\mu t))$$

where NegBin($n$, $p$) is the negative binomial distribution[34] with size parameter $n$ and probability parameter $p$. Note that, as desired, the expected value of $x(t)$ is[35] $x(0)\exp(\mu t)$. Then, $y(t) = y(0) + EGR \times t$ and the expectation of the stochastic model is the deterministic model.

## Secondary growth model on EGR or $\mu$

### The Gamma concept [65]

The secondary models predict the change in the primary model parameters according to a change in the growth environment. Many secondary models are available [60, 61]. Most of these models may be grouped either as polynomial models or models from the gamma concept family.

The gamma concept is a concept that considers the impact of multiple environmental factors on the bacterial growth. The principles of the gamma concept [65] are:

- A $\mu_{opt}$ (or an $EGR_{opt} = \frac{24 \times \mu_{opt}}{\ln(10)}$) parameter is specified. This is the growth rate obtained when all environmental parameters are optimal for the bacterial growth;
- For each considered environmental parameter $x_i$ (e.g., temperature (T), pH, water activity ($a_w$), nitrite concentration (*nit*), lactic acid concentration (LAC), and diacetate concentration (DAC)), a function $\gamma_i(x_i)$ is defined, with $0 \le \gamma_i(x_i) \le 1$ reflecting the impact of this environmental parameter on the growth. An additional function $\xi_{int}$ is defined to consider the interaction between parameters.
- Then, $\mu = \mu_{opt}\left(\prod_i \gamma_i(x_i)\right)\xi_{int}(x_1,...,x_n)$ in the considered environment, i.e.,

$$\mu = \mu_{opt} \cdot \gamma_T(T) \cdot \gamma_{pH}(pH) \cdot \gamma_{a_w}(a_w) \cdot \gamma_{nit}(nit) \cdot \gamma_{LAC}(LAC) \cdot \gamma_{DAC}(DAC) \cdot \xi_{int}(T, pH, a_w, nit, LAC, DAC)$$

The advantage of the gamma concept is that it allows independent consideration of a large number of environmental parameters. It is extensively used in the predictive microbiology domain and claimed to be universal, allowing *Listeria* growth to be modeled in a variety of different RTE products knowing some

[34] Because the sum of $n$ independent geometric distributions with parameter $p$ is a negative binomial distribution with parameter $n$ and $p$.

[35] The expected value of a NegBin($n$, $p$) distribution is $n(1-p)/p$. The expected value of $x(t)$ is then $x(0)(1-\exp(-\mu t))/\exp(-\mu t) + x(0) = x(0)(\exp(\mu t) - 1) + x(0) = x(0)\exp(\mu t)$

of their characteristics [66]. This gamma concept has already been used in QRAs (e.g., in an Australian risk assessment for *L. monocytogenes* in RTE meats [67]).

The alternatives would be:

- the use of one exponential growth rate per food category, as was done within the 2003 FDA/FSIS risk assessment [3]. Nevertheless, it might be difficult to obtain some data for all kinds of RTE food (e.g., with and without growth inhibitors);
- the use of only the minimum of the $\gamma_i$ factors. This is more common in environmental modeling because of concerns that the multiplicative model is overly restrictive as more factors are considered and that $\mu_{opt}$ thus becomes a function of the number of factors;
- the use of polynomial models that predict the bacterial growth. The major drawback of these later models is that they are only applicable to the situation for which they were developed [61]. The polynomial models are of great interest for one or a limited number of food RTE products but could not be incorporated into this model.

The disadvantage of this gamma concept approach is that the chemical characteristics of the RTE products are needed to evaluate the potential for *L. monocytogenes* growth in a RTE product, (i.e.at least the pH and $a_w$ if no preservative is present).

**The Mejlholm and Dalgaard model**

The gamma concept was extended over time to include more and more parameters, as well as their interactions [68-74]. In 2009, Mejlholm and Dalgaard gathered and evaluated those modules to build an extensive model for growth [75]. This model included the impact of temperature, the water activity (calculated from the concentration of NaCl in the water phase of the RTE product), the pH, the concentration in smoke components (phenol), the concentration in nitrite, the concentration of dissolved $CO_2$ at equilibrium, the concentrations of undissociated lactic acid, diacetate, acetic acid, benzoic acid, citric acid, and sorbic acid. The Mejlholm and Dalgaard model [75] was used in this study, but limited to temperature, pH, water activity, nitrites, sodium lactate, potassium lactate, and sodium diacetate concentration and their interactions. The model, its parameterization and its parameters are fully described in the Appendix 1.

**Validation of the model**

In the original paper, Mejlholm and Dalgaard [75] obtained bias and accuracy factors [76] of 1.4 and 1.6, respectively, after evaluating growth rates of *L. monocytogenes* in different types of meat products with added organic acids obtained by various authors [77-80]. A second publication from these authors

compared the predictive values of this model against concurrent ones [66, 81, 82] for various RTE food [83]. For that purpose, 1,014 growth responses of the pathogen in meat, seafood, poultry, and dairy products were used for validation. For the Mejlholm and Dalgaard [75] model, bias and accuracy factors for growth rate predictions were 1.0 and 1.5, respectively. The performance of three other models, including the effect of five to seven environmental parameters, was lower, with bias factors of 1.2 to 1.3. Less complex models that did not include the effect of acetic acid/diacetate and lactic acid were unable to predict growth responses of *L. monocytogenes* accurately in a wide range of food.

**Results**

Table 2 illustrates the use and the results of the growth model in various RTE foods simulated in this risk assessment (i.e., deli meat, cheese and deli salad). The growth rates ($h^{-1}$) and the generation time (time for the population to double) is affected by the intrinsic properties of the products, as well as the inclusion of growth inhibitors.

**Table 2: Growth rate ($\mu$, $h^{-1}$) and Generation Time (GT) of various RTE foods modeled in this risk assessment.**

| | | | | | | | | T = 4°C (39.2°F) | | T = 10°C (50°F) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RTE product Type (example*)** | | **pH** | **$a_w$** | **Nitrites (ppm)** | **Sodium Lactate (%)** | **Potassium Lactate (%)** | **Sodium Diacetate (%)** | **μ (/h)** | **GT (h)** | **μ (/h)** | **GT (h)** |
| Deli Meat | (Uncured Ham) | 6.4 | 0.97 | 0 | 0 | 0 | 0 | 0.015 | 47 | 0.052 | 13 |
| Deli Meat Low Growth | (Cured Ham) | 6.4 | 0.97 | 150 | 0 | 0 | 0 | 0.003 | 210 | 0.017 | 41 |
| Deli Meat No Growth | (Cured Ham w GI) | 6.4 | 0.97 | 150 | 0 | 1.65 | 0.12 | 0.000 | Inf** | 0.009 | 78 |
| Deli Meat | (Uncured Turkey) | 6.3 | 0.96 | 0 | 0 | 0 | 0 | 0.012 | 60 | 0.041 | 17 |
| Deli Meat Low Growth | (Cured Turkey) | 6.3 | 0.96 | 150 | 0 | 0 | 0 | 0.002 | 376 | 0.013 | 52 |
| Deli Meat No Growth | (Cured Turkey w GI) | 6.3 | 0.96 | 150 | 0 | 1.65 | 0.12 | 0.000 | Inf | 0.004 | 183 |
| Deli Meat | (Uncured Bologna) | 6.3 | 0.93 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.006 | 121 |
| Deli Meat Low Growth | (Cured Bologna) | 6.3 | 0.93 | 150 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Meat No Growth | (Cured Bologna w GI) | 6.3 | 0.93 | 150 | 0 | 1.65 | 0.12 | 0.000 | Inf | 0.000 | Inf |
| Deli Meat No Growth | (Pepperoni) | 4.7 | 0.83 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Meat No Growth | (Salami) | 5.0 | 0.91 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Cheese Low Growth | (Colby) | 5.2 | 0.95 | 0 | 0 | 0 | 0 | 0.002 | 460 | 0.013 | 54 |
| Deli Cheese No Growth | (Monterey Jack) | 5.3 | 0.93 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.001 | 522 |
| Deli Cheese No Growth | (American) | 5.6 | 0.92 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Cheese No Growth | (Provolone) | 5.2 | 0.91 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Cheese Low Growth | (Swiss) | 5.2 | 0.92 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Salad | (Potato) | 4.6 | 0.998 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.000 | Inf |
| Deli Salad Low Growth | (Potato w GI) | 4.6 | 0.998 | 0 | 0 | 1.65 | 0.12 | 0.000 | Inf | 0.000 | Inf |
| Deli Salad | (Protein) | 5.0 | 0.998 | 0 | 0 | 0 | 0 | 0.000 | Inf | 0.003 | 252 |
| Deli Salad Low Growth | (Protein w GI) | 5.0 | 0.998 | 0 | 0 | 1.65 | 0.12 | 0.000 | Inf | 0.000 | Inf |

*Note that the example is provided only as illustration purpose; **: infinite. The generation time is infinite since the growth rate is 0.

### Stochasticity in the $\mu$ parameter

The secondary model mentioned above is deterministic in the sense that one set of environmental parameter leads to one expected value for $\mu$. Augustin *et al.* [84] quantified the variability of growth parameters of *L. monocytogenes* obtained by challenge testing in five food RTE products (vacuum-packed pork pie, vacuum-packed smoked herring, sliced cooked ham packed under modified atmosphere, cooked chicken, and surimi salad). The total variance obtained when adding different sources of variability

(residual, between-batch and between manufacturer) led to a total coefficient of variation[36] for $\mu$ of 45%. In order to consider these source of variability, the $\mu_{ref,i}$ parameter (the specific growth rate at a reference temperature) for a given RTE product *i* (chub, or deli salad bulk) was sampled from a normal distribution with mean $\mu_{ref}$ and standard deviation ($0.45 \times \mu_{ref}$). Negative values were set to 0. The Table 3 illustrates the distribution of the predicted growth during 7 days of storage at 10°C.

**Table 3: Distribution of the predicted growth ($log_{10}$ increase) during a 7 day storage at 10°C (50°F)**

| | Example* | 1st Quantile | Median | Mean | 3rd Quantile |
|---|---|---|---|---|---|
| Deli Meat | (Uncured Ham) | 2.66 | 3.82 | 3.82 | 4.97 |
| Deli Meat Low Growth | (Cured Ham) | 0.87 | 1.25 | 1.25 | 1.63 |
| Deli Meat No Growth | (Cured Ham with GI) | 0.69 | 0.98 | 0.98 | 1.28 |
| Deli Meat | (Uncured Turkey) | 2.08 | 2.98 | 2.98 | 3.87 |
| Deli Meat Low Growth | (Cured Turkey) | 0.68 | 0.97 | 0.97 | 1.27 |
| Deli Meat No Growth | (Cured Turkey with GI) | 0.32 | 0.45 | 0.46 | 0.59 |
| Deli Meat | (Uncured Bologna) | 0.29 | 0.42 | 0.42 | 0.55 |
| Deli Meat Low Growth | (Cured Bologna) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Meat No Growth | (Cured Bologna with GI) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Meat No Growth | (Pepperoni) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Meat No Growth | (Salami) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Cheese Low Growth | (Colby) | 0.65 | 0.93 | 0.94 | 1.22 |
| Deli Cheese No Growth | (Monterey Jack) | 0.07 | 0.10 | 0.10 | 0.13 |
| Deli Cheese No Growth | (American) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Cheese No Growth | (Provolone) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Cheese Low Growth | (Swiss) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Salad | (Potato Salad) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Salad Low Growth | (Potato Salad with GI) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Salad | (RTE Meat Deli Salad) | 0.00 | 0.00 | 0.00 | 0.00 |
| Deli Salad Low Growth | (RTE Meat Deli Salad with GI) | 0.00 | 0.00 | 0.00 | 0.00 |

*Note that the example is provided only as illustration purpose.

## Other parameters

### Lag time

A lag time is observed in the bacterial growth when an abrupt change in the bacterial environment is observed. No abrupt change in the bacterial environment in retail, during transport, and at home is considered in the model. The considered process consists only in slicing or scooping at retail and storage at home. The shifts in temperature are probably not abrupt enough to induce a lag [3]. No consensual model in the literature predicts the lag time following the transfer from a surface to food. As a conservative choice favoring the model that leads to a higher risk [59, 85], ~~no lag is considered in~~ this risk assessment model does not take into account a potential lag phase in bacterial growth that may occur

[36] The coefficient of variation is the ratio of the standard deviation to the mean.

upon transfer of bacteria from one surface to another. A lag after a transfer from FCS or NFCS to food could be considered in future versions of this risk assessment.

#### $y_{max}$ (Maximum Population Density)

The maximal population density is a very important parameter for the prediction of the risk linked to *L. monocytogenes* [86, 87]. Nevertheless, few studies evaluated this parameter. Within the 2003 FDA/FSIS risk assessment for example [3], the maximal population density was related to the temperature. For deli meat, deli-type salads and cheeses, the growth was limited to 5 $\log_{10}$ cfu/g if the temperature was <5°C (41°F), to 6.5 $\log_{10}$ cfu/g if the temperature was 5-7°C (41-44.6°F) and 8 $\log_{10}$ cfu/g if temperature was >7°C (44.6°F). As a safe choice, it will be considered that growth can reach 8 $\log_{10}$ cfu/g in all RTE products, including those with growth inhibitor, whatever the temperature of storage.

*Growth models on sites*

The growth model used on sites is the stochastic derivation of an exponential model without lag, as the one used for food:

$$x(t) \sim x(0) + NegBin\left(x(0), \exp\left(-\frac{egr}{\ln(10)}t\right)\right)$$

with $egr \geq 0$, the exponential growth rate on the considered site. *egr* could be a function of the temperature. Currently, *egr* is set to 0, meaning that no growth is considered on sites. Note that a decrease in the number of bacteria with time may be observed on the various sites [88].

### 6.1.3 Inactivation

In the current risk assessment model, inactivation is limited to the removal and reduction of *L. monocytogenes* on surfaces as the result of cleaning operations, (i.e., wiping, washing, and sanitization). The inactivation process is modeled as following: given $N$ the initial number of bacteria on the site being treated, and $W$ the efficacy of the inactivation process ($0 \leq W_i \leq 1$), $F$ the final number of bacteria on the site is derived stochastically using:

$$F \sim \text{binomial}(N, W)$$

This assumes that the bacteria are inactivated independently. $W$ is currently sampled at each inactivation process from:

$$\log_{10}(W) \sim \text{Pert}(\text{min}, \text{mode}, \text{max})$$

where Pert is the Pert distribution [64], *min, mode* and *max* are specific to *i*) the object and *ii*) the level of inactivation. Currently, three levels of inactivation are implemented: “Wipe,” “Wash,” “Wash and

Sanitize." Note that $W$ is minus the expected $\log_{10}$ reduction of the process. If $\log_{10}(W)$ is -1, then $W$ is 0.1 and the expected $\log_{10}$ reduction is 1; this leads to an expected 10-fold decrease of the number of bacteria on the object. Following a complete literature review [37], (*min*, *mode*, *max*) is set to (-1, -0.5, 0) for all "wiping" processes, to (-1.5, -0.5, 0) for all "washing" processes, and to (-8, -6, -1.5) for all "washing and sanitizing" processes.

#### 6.1.4 Partitioning

The only partitioning processes in the model are:

- partitioning a chub to a slice; and
- partitioning a serving of salad from a bulk container.

The partitioning process has already been described in the subsection dealing with cross contamination during the slicing process and scooping process. Indeed, a homogeneous contamination of the chub and the salad is assumed. As a consequence, given $N_0$ the number of bacteria in the chub (or the salad bulk), $M$ is the mass of the chub (or the salad bulk) and $m$ the mass of the slice (or the salad serving), while the number of bacteria in the slice (or the salad serving) is

$$N_1 \sim \text{binomial}(N_0, m/M)$$

The number of bacteria in the remaining chub (or the salad bulk) will then be $N_1 - N_0$.

### *6.2. Objects in the model*

#### 6.2.1 Food

Three categories of food are considered in the model: deli meat, deli cheese and deli salad. Deli meat and deli cheese will be served following a slicing process. Deli salad will be served by scooping from a bulk container.

Any type of RTE products within these categories may be simulated in the risk assessment model. For example, deli meat could be ham with high potential of *L. monocytogenes*, uncured ham, ham with growth inhibitor, salami, *etc*. The model is flexible enough to support the addition of new RTE products. The following characteristics must be known or estimated for each RTE product:

- "category": "chub" or "salad". When served, a "chub" will imply a process of slicing while a "salad" will imply a process of scooping. "Chubs" are meats and cheeses;
- sale characteristics summarized

  - by the probability to be present in the retail deli (for rare RTE products) or the number of chub/salad bulk in the retail deli (for RTE products that are present in all deli departments), and
  - the relative frequency of sales of this RTE product and the mass of a slice (for "chubs");
- some physical characteristics (i.e., the mean and the standard deviation of the mass of the chub / bulk);
- some chemical characteristics (i.e., pH, water activity, nitrites (ppm), as well as the proportion (w/w) of sodium lactate, potassium lactate and sodium diacetate). Those factors are used to estimate the growth rate in the RTE product (see section 6.1);
- mean and standard deviation of the initial $\log_{10}$ concentration in *L. monocytogenes*;
- number of days the RTE product can be held in the retail deli after opening or preparation;
- mean and standard deviation of the $\log_{10}$ of the transfer coefficients (see p. 30) of bacteria from these food category to other food or sites;
- probability to have this food item presliced in the morning, with a mean and standard deviation of the weight of RTE product that would be presliced.

### 6.2.2 Sites

Sites are potentially contaminated objects that are present in a deli department. Those sites were chosen following the observational study specifically developed for this model [28]. Currently, the following objects are considered: "floor", "sink", "handle", "case", generic "Non Food Contact Surface" (NFCS), "utensil" (and its "handle"), "slicer," generic "Food Contact Surface" (FCS), and "scale." Two additional "sites" are associated with food workers: "hands" and "gloves".

The sites are characterized by:

- their initial contamination at the beginning of the simulation;
- the probability to have a niche compartment/to be contaminated from the environment and, in this case, the number of bacteria transferred to the considered site during a release of bacteria from the niche/environment and the average time of operation between two releases (see p. 35);
- the mean and the standard deviation of the $\log_{10}$ reduction of *L. monocytogenes* when they are wiped, washed, sanitized, or washed and sanitized (see p. 43);
- the mean and standard deviation of the $\log_{10}$ of the transfer coefficients (see p. 30) of bacteria from these sites to other sites or food;
- the exponential growth rate (*egr*) of *L. monocytogenes* on this object, currently *egr* = 0.

More than one site of each category may be present in the retail deli. Additional objects could easily be implemented, as soon as they are associated with specific events (potential cross contamination from/to this object).

*Structure of the deli departments*

In the model, the user can build a variety of deli-department layouts or, using an associated relative probability, may run simulations using a set of specific deli-department layouts. A layout is characterized by:

- its hours of operation;
- its number (≥1) of various sites present in the deli-department (floor, sink, handle, scale, utensil, slicer, FCS, NFCS),
- the probability ($0 \leq p \leq 1$) that gloves are worn by an employee handling unpackaged foods when serving customers,
- the probability ($0 \leq p \leq 1$) the niche / environmental contamination occurs in the department,
- the time in hours between cleaning the food contact surfaces,
- the number of objects that are cleaned during a sporadic cleaning event.

Moreover, a matrix of contact has to be specified for a given retail deli. This matrix of contact allows one to specifiy which objects or food worker can be in contact with which category of food. For example, in a complex retail deli including three slicers, it is possible to specify that the slicer #1 is used only for cheese, the slicer #2 for meat with no growth, the slicer #3 for all kind of RTE products. This matrix of contact allows one to study various deli department patterns.

## *6.3. Events in the model*

Importantly, the model tracks only the actions made by and the transfers resulting from the action of a single food worker. More complex models could be derived for multiple food workers.

### 6.3.1 Main events

The main events simulated within the model are “Opening the deli,” “Closing the deli,” and “Operating the deli”. Each is described below.

*Opening the deli*

The virtual deli is opened 7 days a week, during a given number of hours. This number of hours is specified at the retail deli level.

When the retail deli opens, the food items that were opened or prepared more than a specified number of days prior (e.g., 7 days for refrigerated RTE foods) [27]) are discarded. This mimics a date marking system [27]. Additionally, when the retail deli opens, some food items may be "presliced" in large quantity. Afterwards, presliced items will be sold throughout the day. A food item is presliced or not according to a probability of preslicing defined by the user (if 1: some amount of RTE product will be presliced each morning; if 0: this food item will never be presliced; if > 0 and <1: a random value will be drawn each morning to decide whether or not the RTE product will be sliced). The amount of RTE product (>0 g) that will be presliced will be randomly sampled from a normal distribution with mean and standard deviation defined by the user. Then the RTE product will be presliced using the same process as if a serving of this RTE product of that size was requested by a customer.

*Closing the deli*

When the retail deli closes (or every 24 hours of operation if the deli is opened 24/7), all hard surfaces and equipment in the deli are washed and sanitized. The remaining presliced RTE products are discarded. Bacterial growth on all sites and food is considered during the time the deli is closed.

*Operating the deli*

Within the operating hours, three main events are considered: i.e., "Non Deli Time," "Sporadic Clean," and "Serve Customer." Additionally, *i*) the FCSs are washed and sanitized regularly, according to a planned schedule; *ii*) some transfer of bacteria from the niches may occur, according to a random schedule.

During the "Non Deli Time" event, nothing happens cocerning our considered process (except bacterial growth, see below).

During the "Sporadic Clean" event, some sites are cleaned within the deli. The number *n* of objects cleaned during a sporadic clean event is characteristic of the retail deli (defined by the user). The algorithm selects the *n* sites that have not been cleaned since the longest time, with a random selection in case of ties. Those objects are then "washed" (i.e., not "washed and sanitized").

Before all major events, the algorithm checks if one transfer from one niche to its corresponding site occurred or not (see p.35).

At the end of a main event, the algorithm checks the "FCS clock". This clock is set to 0 at the opening time. Regularly, as specified by the user (in the baseline, every 4 hours according to the 2009 FDA Food Code), the FCSs (in the baseline: the slicer(s), the generic FCS(s), the scale(s), and the utensil(s)), are washed and sanitized. The FCS clock is then reset.

At the end of each main event, the bacterial growth that occurred during that period is evaluated and bacterial population numbers are updated, according to the growth models.

*Serve a customer*

When this main event is chosen by the algorithm, the first action is the choice of the RTE product to be sold. The choice of a RTE product is proportional to the global sale of this RTE product compared to the other ones that are present in the retail deli. The mass sold is selected. Then the process varies if the RTE product needs to be sliced (meat or cheese) or needs to be served (deli salad).

## Serving meat or cheese

In Lubran *et al.*'s study of deli employee behavior [28], a regular baseline behavior sequence was commonly observed in employees serving customers in a deli departments [28]. The food employee would change gloves, open the deli case, pick up the chub, close the case, unwrap the chub, slice the RTE product onto his gloves, put the RTE product on a deli tissue, put the deli tissue on the scale, touch the scale, put the deli tissue in a plastic bag, put the label on the plastic bag, give the plastic bag to the consumer, rewrap the chub, open the case, put the chub in the case, close the case. Of course, some deviations from this baseline were observed. The frequencies of these alternatives were evaluated from the observational study and incorporated into the risk assessment model (Table 4).

**Table 4: Sequence of events when serving deli meat or deli cheese (derived from [28]).**

| Event | Number of times observed / total observations |
|---|---|
| Wipe the Slicer | 7/83 |
| Wash Hands and Change Gloves<br>OR Do not Wash Hands and Change Gloves<br>OR Do not Wash Hands and Do not Change Gloves | 33/83<br>22/83<br>28/83 |
| Touch a NFCS | 4/83 |
| Open the Case | 68/83 |
| Close the Case | if had opened it |
| Touch the Refrigerator Handle | 2/66 |
| Open a New Chub | if the mass of the chub < mass to be sold |
| | If open a new Chub |
| No contact<br>OR Contact New Chub - Sink<br>OR Contact New Chub – FCS<br>OR Contact New Chub - Slicer | 6/17<br>4/17<br>1/17<br>1/17 |
| Pick up a Chub | 83/83 |
| Change Gloves | 1/83 |
| Touch the Knob of the Slicer | 18/83 |
| Slice on Gloves<br>or Slice on Deli Tissue | 82/83<br>1/83 |
| Touch the Scale | 83/83 |
| Contact Chub –- FCS | 1/83 |
| Open Case | If had opened/closed it previously |
| Put Chub in Case | 83/83 |
| Close Case | If had opened it previously |
| Wipe the Slicer | if had not done it at the beginning<br>15/68 |

## Serving salad

A similar baseline sequence was used for the main event “serve a deli salad.” The baseline sequence, as observed in retail delis [28], consists of change gloves, open the case, take salad bulk, close the case, pick up utensils, serve salad, put the RTE product on the scale, open the case, put salad bulk in case, close the case, touch the scale, wash utensils. Alternatives are provided Table 5.

**Table 5: Sequence of events when serving deli salad (derived from [28].)**

| Event | Frequency / Condition |
|---|---|
| Wash Hands and Change Gloves | 1/11 |
| or Do Not Wash Hands and Change Gloves | 6/11 |
| or Do Not Wash Hands and Do Not Change Gloves | 4/11 |
| Touch a NFCS | 1/11 |
| Open the Case | 9/11 |
| or Open the Case Twice | 1/11 |
| or Open the Refrigerator | 1/11 |
| Open a New Bulk of Salad | if the remaining mass < mass to be sold |
| Pick up Salad Bulk | 11/11 |
| Pick up Utensils | 11/11 |
| Serve Salad | 11/11 |
| Close the Case | If it had been opened |
| Touch the Scale | 11/11 |
| Wash and Sanitize the Utensil | 6/11 |
| or Sanitize the Utensil | 2/11 |
| or Do not Wash nor Sanitize the Utensil | 2/11 |

## Customer Serving Times

The duration of a serving (h) is assumed proportional to the serving size. Serving times were measured through buying individual sales of various deli RTE products at different retail delis across different times of the day. Weights and times are shown in Table 6. Times represent the time from when the order was placed until the chub was returned to the case.

**Table 6. Observed Data for Calculation of Customer Serving Time.**

| RTE product | Ordered weight | | Serving time | |
|---|---|---|---|---|
| | Pounds | Grams | minutes | hours |
| American cheese | 0.5 | 227 | 1.2 | 0.0200 |
| Turkey | 0.5 | 227 | 1.22 | 0.0203 |
| Ham | 0.5 | 227 | 3.03 | 0.0506 |
| American cheese | 1 | 454 | 2.33 | 0.0389 |
| Turkey | 1 | 454 | 2.67 | 0.0444 |
| American cheese | 1 | 454 | 4.27 | 0.0711 |
| Turkey | 1 | 454 | 3.02 | 0.0503 |
| Ham | 0.25 | 113 | 2.45 | 0.0408 |
| American cheese | 0.5 | 227 | 1.17 | 0.0194 |

A regression to predict time based on ordered weight was generated. Times were quite variable depending on whether a new chub needed to be opened, the deli worker could easily find the chub ordered, *etc*. Consequently the regression fit is rather poor. This high variability is captured by including a residual standard error from the regression in the time generation within the risk assessment model.

Time (hr) = 0.00007017 weight (g) + 0.01745

$R^2 = 0.30$

Residual standard error: 0.0155

A minimum time of 0.02 hours (1.2 minutes) was assumed for any size serving. An example random draw of this approach is shown in the red symbols in Figure 9. The solid black circles represent the observed data.

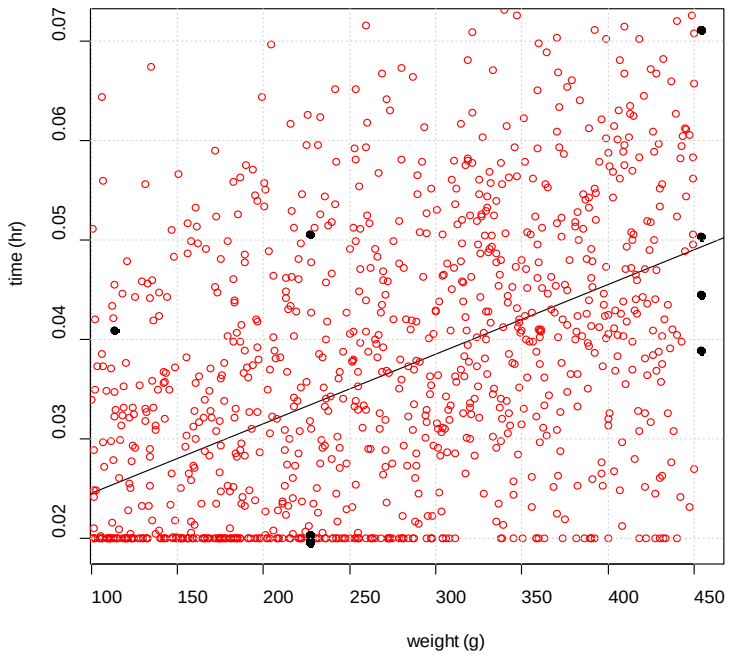



**Figure 9: Simulation of customer serving times**

Thus, the customer serving time is modeled as

duration = max(0.02, 0.01745 + 0.00007017 × *SS* + Normal(0, 0.0155)).

where *SS* is the serving size (g).

The duration of a deli-salad serving is also assumed proportional to the serving size. It is assumed that it takes a time following a normal(4, 0.4) minutes per pound with a minimum of 30 s, that is, for a duration expressed in hours and a serving size in grams,

duration = max(0.0083, SS × Normal(0.0001468, 0.00001468)).

### 6.3.1 Sites

In the baseline and all alternatives, no bacterial growth is considered on the sites. It is considered that the sites are not contaminated at the beginning of the simulation. However, the first 1% or 10,000 in 1,000,000 servings are removed from the simulation prior to analysis (burn-in period).

### 6.3.2 Basic processes

The main events are a single or a succession of basic processes. Table 7 provides the correspondence between the main events used in the current model and the basic processes.

**Table 7: Translation of the basic events in terms of basic processes.**

| ***Basic event*** | ***Basic process*** | ***Objects involved*** |
|---|---|---|
| Remove Glove | Remove all Bacteria | Glove |
| Change Glove | Cross contamination[a] | Glove - Hand |
| Put on Glove | Changes Site for Hand/Glove Cross Contamination with Other Sites. | Glove |
| Close Case | Cross Contamination | Case – Hand or Glove[b] |
| Open Case | Cross Contamination | Case – Hand or Glove |
| Open Chub with Contact Chub FCS | Cross Contamination | Chub - FCS |
| Open Chub with Contact Chub Sink | Cross Contamination | Chub - Sink |
| Open Chub with Contact Chub Slicer | Cross Contamination | Chub - Slicer |
| Pick-up Utensil | Cross Contamination | Utensil Handle – Hand or Glove |
| Put Chub on FCS | Cross Contamination | Chub - FCS |
| Serve Salad | Cross Contamination<br>Partitioning | RTE Product – Utensil<br>RTE Product – RTE Product Sold |
| Slice | Slice | Chub - RTE Product Sold– Slicer |
| Slice on Glove | Cross Contamination | First Slice – Hand or Glove |
| Touch Knob | Cross Contamination | Slicer – Hand or Glove |
| Touch NFCS | Cross Contamination | NFCS – Hand or Glove |
| Touch Refrigerator Handle | Cross Contamination | Handle – Hand or Glove |
| Touch Scale | Cross Contamination | Scale – Hand Or Glove |
| Touch Scale | Cross Contamination | Scale – Hand or Glove |
| Wash Hands | Inactivation/Removal (Wash) | Hands |
| Wash Utensil | Inactivation/Removal (Wash) | Utensil and Utensil Handle |
| Wash and Sanitize Utensil | Inactivation/Removal (Wash and Sanitize) | Utensil and Utensil Handle |
| Wipe Slicer | Inactivation/Removal (Wipe) | Slicer |

[a]: "Cross contamination":[a]: Possible cross contamination if one object carries some bacteria. [b]: "Hand or Glove": Hand or glove according to the current hand status of the food employee.

### 6.3.3 Temperature in display cases

Temperature of a RTE product is assumed equal to the temperature in the cases in which it is displayed.

*Data*

Temperature of the RTE products in the display cases were inferred from a study conducted by Ecosure [19]. The display case temperatures of a variety of RTE products were recorded in this study as following: "when reaching a desired display case within their normal shopping pattern, some participants removed the RTE product to be purchased and inserted a thermometer directly into the RTE product. Participants left the thermometer in the RTE product until the temperature stabilized and then recorded the RTE product temperature and time of day" [19]. Amongst the tested RTE products, the data obtained for "Sliced meat" (Bologna) were used to derive a temperature distribution for deli cases in the model. Recorded temperatures ranged from -3.33°C (26°F) to 18.33°C (65°F). The raw data are reported Table 8.

**Table 8: Raw storage temperature data for "Sliced Meat" (°F and °C.)**

| **°F** | **26** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** | **40** | **41** | **42** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **°C** | **-3.33** | **-1.11** | **-0.56** | **0.00** | **0.56** | **1.11** | **1.67** | **2.22** | **2.78** | **3.33** | **3.89** | **4.44** | **5.00** | **5.56** |
| *n* | 1 | 2 | 1 | 9 | 8 | 11 | 11 | 23 | 23 | 68 | 45 | 120 | 51 | 61 |

| **°F** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** | **53** | **54** | **55** | **56** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **°C** | **6.11** | **6.67** | **7.22** | **7.78** | **8.33** | **8.89** | **9.44** | **10.00** | **10.56** | **11.11** | **11.67** | **12.22** | **12.78** | **13.33** |
| *n* | 25 | 64 | 54 | 47 | 30 | 73 | 22 | 63 | 10 | 20 | 7 | 9 | 6 | 7 |

| **°F** | **57** | **58** | **60** | **62** | **65** |
|---|---|---|---|---|---|
| **°C** | **13.89** | **14.44** | **15.56** | **16.67** | **18.33** |
| *n* | 1 | 5 | 10 | 2 | 2 |

(Source [19])

An analysis of the data leads to the conclusion that the collected data should be used directly, as an empirical distribution, rather than as a parametric one.

*Model*

In the risk assessment model, every morning, the temperature of each display case is randomly sampled as being -1°F, +0°F, or +1°F as the day before, using an algorithm preserving the empirical distribution issued from the Ecosure dataset. For that purpose, a Metropolis-Hastings like algorithm was used. Given $T_n$ the current temperature (e.g., 40°F), $T_{n+1}$ the temperature of the following day, the algorithm is as following:

- draw a proposed new temperature $T_{prop}$ that is equal to the next higher temperature observed in the dataset (e.g., 41°F) or equal to the next lower temperature observed in the dataset (e.g., 39°F) with equal probabilities; Say that the draw is 41°F;

- The number of observations of the temperature $T_n$ in the dataset is $E_n$ (e.g., 120), the number of observed temperature $T_{prop}$ in the data set is $E_{prop}$ (e.g., 51). Calculate the ratio: $r = E_{prop} / E_n$; here: $r = 51/120 = 0.425$.
- Accept the proposed move to $T_{prop}$ with probability min(1, $r$). Here, draw a value uniformly between 0 and 1 and accept the proposal if this value is lower than 0.425. If the proposal is not accepted, then $T_{n+1} = T_n = 40$; else $T_{n+1} = T_{prop} = 41$.

It is possible to slow down the shift of temperature by moving only occasionally, using either a regular shift (example: one shift every week) or using a probability of proposal of shift that is independent of the current temperature. In the baseline model, a shift is proposed every day.

Figure 10 illustrates the use of this method for the Ecosure data [19] as well as the concordance between the Ecosure empirical distribution and the simulated distribution.

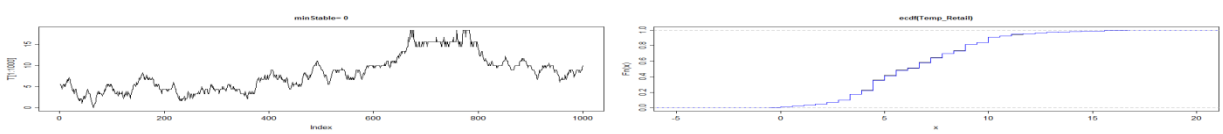



**Figure 10: Illustration of the Monte Carlo Markov Chain used to simulate the temperature changes in retail deli cases.**

Left panel: time series for 1,000 days, Right Panel: empirical cumulative density function from Ecosure [19] and simulated empirical cumulative density function.

### *6.4. From the retail deli to foodborne illness*

The output of the risk assessment model is a distribution of number of *L. monocytogenes* per serving of RTE products. *L. monocytogenes* growth may occur during the transport from the retail deli to the home and during the storage in the refrigerator at home. This growth will be a function of the RTE product characteristics, the time, and the temperature of storage. No cross contamination will be considered at home.

The final output is then the risk per serving of RTE food. This output is evaluated considering the consumption data and, eventually, the dose response model.

### 6.4.1 Transport

*Time, temperature and model*

The most pertinent datasets for time-temperature of transport is the Ecosure 2007 dataset [19]. The protocol within this study was as following: when reaching a desired display case, participants recorded the temperature of the RTE food and the time of day. "Immediately before placing products in the home refrigerator or freezer, the temperature of each product was taken and the time recorded. The change in temperature from the retail case to home is considered to be short term high temperature abuse resulting from shopping, excessive ambient temperatures and delays between removal of product from its display and re-refrigeration at home." See details in [19] and corresponding data on www.FoodRisk.org.

## Time to reach home

The best parametric distribution fitting the Ecosure data [19] on the duration between refrigerated storage at the retail deli and refrigerated storage at home $\Delta t$ (h) is a ln-normal distribution (Table 9), as compared to a normal, a Weibull, a gamma, a logistic, and a log-logistic distribution on the basis of the Anderson-Darling statistic (results not shown).

**Table 9: Parameter of the fitted ln-normal distributions**

| Delay to get home (h) | mean (s.e. Wald) [95% CI Bootstrap] | sd (s.e. Wald) [95% CI Bootstrap] | $\rho$ spearman ($p$ = 0) |
|---|---|---|---|
| Deli-meat | 0.132 (.0143) [.104, .159] | .403 (.0101) [.384, .422] | -.06 ($p$ = .03) |

## Increase in the temperature: Deli-Meat

A linear model was developed using Ecosure data. The explained variables was the increase of temperature ($\Delta T$, °F) of the deli meat product and the duration of the transport ($\Delta t$, h), the weight of the product ($w$, oz.), and the initial temperature ($T_0$, °F) were explaining. The residuals are important and the adjusted $R^2$ is only 0.09. Given these variables, the variation of temperature is eventually modeled as:

$$\Delta T = \max(0, 13.27 - .1276 \times T_0 + 2.131 \times \Delta t - .2961 \times w + \varepsilon) \text{ with}$$
$$\varepsilon \sim Normal(0, 5.19)$$

## Increase in the temperature: Deli-Salad

A similar linear model using the variation in temperature as the explained variable and the temperature at $t_0$, the transport duration and the weight of the product show that the weight is not a significant parameter for deli salad. This model leads to the following model for deli salad:

$$\Delta T = \max(0, 10.52 - .1482 \times T_0 + 1.748 \times \Delta t + \varepsilon) \text{ with}$$
$$\varepsilon \sim Normal(0, 4.70)$$

No data are available for deli cheese: the model developed to predict the increase in the temperature for deli meat will be used for these cheeses.

*Growth during the transport*

The growth during the transport of duration $\Delta t$, starting at a temperature of $T_0$ and ending at a temperature of $T_f = T_0 + \Delta T$, may be approximated by the growth that would occur during the same duration at a fixed temperature of $T_0 + \Delta T/2$. The growth models used are the same as those used in the deli-department.

Nevertheless, the growth occurs only when the temperature is higher than the minimal temperature of growth $T_{\min}$. A linear increase of the temperature during the transportation is assumed from $T_0$, the temperature at retail to $T_f$, the temperature when the product arrive at home ($\geq T_0$). $T_0$ and $T_f$ are possibly lower than $T_{\min}$. The mean temperature during which the growth occurs is then

$$m = \frac{\max(T_{\min}, T_0) + \max(T_{\min}, T_f)}{2}.$$

The effective time of growth (time when $T > T_{\min}$) is

$$\Delta t_{eff} = \Delta t \times \frac{(\max(T_f, T_{\min}) - \max(T_0, T_{\min}))}{(T_f - T_0)}.$$

### 6.4.2 Home

The time-temperature characteristics of the home storage have been studied extensively by Kosa et al, [89]. Classical parametric survival modeling was used to derive parametric distributions from the RTI International storage practices data set [90]. The time-temperature during home storage will be modeled using the distributions proposed in Table 10 and Table 11. As an example for Deli Meat, the algorithm to draw a storage time at home is as follows (from Table 11):

- draw a sample $x \sim$ Uniform(0, 1) distribution
- if $x < 0.04$ (i.e., 4%): the serving is eaten at the opening of the package. The time to consumption (days) is drawn from an exponential(1/0.457) distribution;

- else, the serving is eaten at the last occasion. The time to consumption (days) is drawn from a Weibull(2.08, 8.33) distribution.

Note that no data on hard cheese sliced to order are available. Soft cheese data were used instead. All simulated temperature <0°C (32°F) were set to 0°C.The bacterial growth is modeled as developed pages 36-43.

**Table 10: Fitted Laplace distribution of the refrigerator temperature data in Fahrenheit and Celsius.**

| | Location | Scale |
|---|---|---|
| Fahrenheit | 39.3 | 4.23 |
| Celsius | 4.06 | 2.31 |

From [90]

**Table 11: Fitted distribution of time to first consumption of RTE food using RTI International data.**

| | Time to first consumption (day) | Ate package at one time: weighted % | Time to last consumption (day) |
|---|---|---|---|
| | Fitted Distribution | | Fitted Distribution |
| Deli Meat – Sliced to Order | Exponential(.457) | 4% | Weibull(2.08, 8.33) |
| Soft Cheese | Weibull(.873, 5.34) | 8% | Weibull(1.34, 18.7) |
| Deli Salad | Exponential(.475) | 14% | Weibull(1.34, 7.49) |

From [90]. Exponential($x$) is the exponential distribution with mean $x$.

### 6.4.3 Consumption

Specific consumption data were extracted from the 1999-2006 National Health and Nutrition Examination Survey (NHANES, a USDA/DHHS survey) using the FARE™ Program (Food Analysis and Residue Evaluation Program, v. 8.63) developed by Exponent®. Details are given in the Appendix 2. Figure 11 is the empirical cumulative distribution function of the serving size per eating occasion obtained from this analysis for deli salad, deli meat, and deli cheese. Table 12 provides some basic statistics from this distribution.

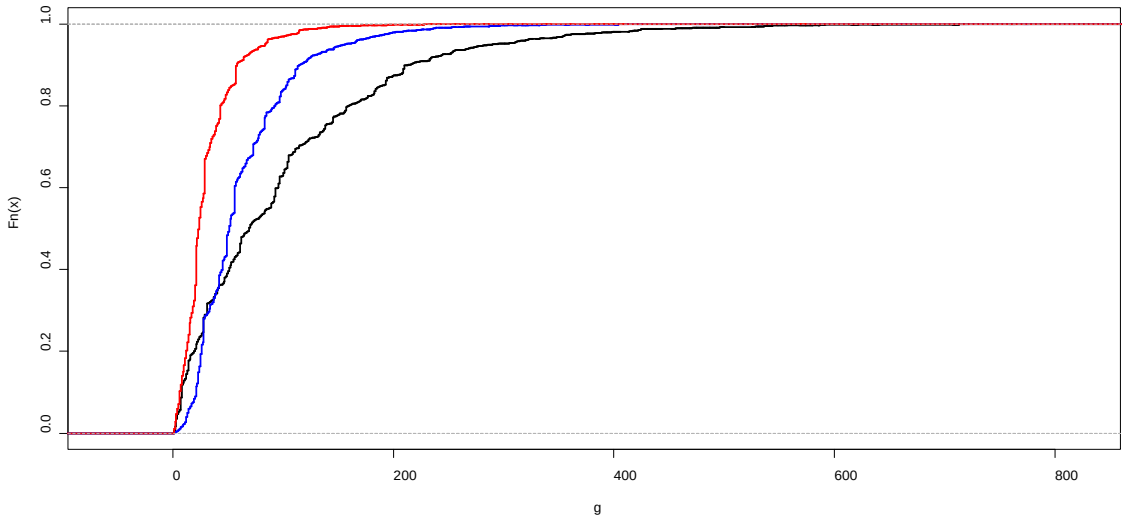



**Figure 11: Distribution of serving size for deli salad (black), deli meat (blue) and deli cheese (red) for the total population**

**Table 12: Summary statistics of the empirical distribution of serving sizes, as simulated in the *L. monocytogenes* retail model (g/eating occasions).**

| | Deli Meat | Deli Salad | Deli Cheese |
|---|---|---|---|
| Minimum | 1 | 1 | 1 |
| 1st Quartile | 28 | 28 | 15 |
| Median | 51 | 69 | 24 |
| Mean | 63 | 99 | 31 |
| 3rd Quartile | 83 | 138 | 39 |
| Maximum | 775 | 763 | 982 |

### 6.4.4 Dose-response model

The number of bacteria in the serving sold after transport and growth in the refrigerator is converted into a concentration using the mass of the serving sold. This concentration is then multiplied by the serving size (gram per serving) to obtain the ingested dose. Note that, at this level, the dose not a discrete number but a continuous one, representing the mean of a Poisson distribution of the number of ingested cfus for the exponential dose-response [91].

The dose response model is a function that links the ingested dose to the probability of a given specified endpoint. A general review of the hazard characterization process may be obtained in FAO/WHO [92]. A specific review for the characterization of *L. monocytogenes* (i.e., characterization of severity and the selection of appropriate biological end points to be modeled, factors that affect dose-response relations for

*L. monocytogenes*, approaches to modeling dose-response) may be obtained in the FAO/WHO risk assessment of *L. monocytogenes* in RTE foods [59].

Relative to a "general" population, an increased susceptibility is commonly associated with:

- pregnant women and neonates, resulting in stillbirth or neonatal infection;
- the older adults; and
- persons with particular conditions, including cancer and immunosuppressive therapy, AIDS, cardiovascular disease, congestive heart failure, diabetes, cirrhosis and alcoholism [93, 94].

To date, two major dose-response models for humans scaled on epidemiological data are available: one developed within the 2003 FDA/FSIS quantitative assessment of relative risk to public health from foodborne *L. monocytogenes* among selected categories of RTE foods [3] and one developed within the FAO/WHO risk assessment of *L. monocytogenes* in RTE foods [59]. The second model uses the latter dose-response relationship. All details on this dose-response can then be obtained in the FAO/WHO risk assessment [59].

The FAO/WHO risk assessment considers invasive listeriosis as endpoint. It considers two subpopulations: the population with "increased susceptibility" [59] (including neonates, older adults and immunocompromised), and the population with "decreased susceptibility" [59] (all others). The model is an exponential dose-response model [91] that might be written as

$$\Pr(\text{inf}|D)=1-\exp(-r\,D)$$

where $\Pr(\text{inf}|D)$ is the marginal probability of invasive listeriosis in a population that ingests a food where the serving-to-serving variability of contamination follows a Poisson distribution of mean $D$. The exponential dose response model is a single-hit model; it considers that pathogens act independently and that ≥1 pathogen is enough within the host to evoke the endpoint [91]. Parameter $r$, the unique parameter of this model, is the probability that 1 cell evokes the endpoint in a consumer at random from the reference population. It is considered in the exponential dose-response model that $r$ is a constant for the specific population on which the model is applied. Note that the marginal dose-response relationships in the FAO/WHO [59] and the 2003 FDA/FSIS [3] risk assessment models closely compare, because they rely mostly on the same data. These models are almost linear at low to medium dose.

Indeed, the unique $r$ parameter per subpopulation of the FAO/WHO [59] model is estimated from exposure data issued from a draft FDA/FSIS report [95] and from the annual number of cases of listeriosis estimated in the United States [96]. The point estimates for $r$ used in this model are $1.06 \times 10^{-12}$

for the susceptible population and $2.37 \times 10^{-14}$ for the other population [see Table 2.17, p. 56 and Table 2.20, p.58, 59].

Uncertainty for the *r* parameters was derived based on four parameters that influence the dose-response relations, namely the percentage of the population with increased susceptibility to *L. monocytogenes* in the United States, the percentage of cases of total severe listeriosis cases associated with the increased susceptibility population in the United States, the total number of cases in the United States and the maximum achievable dose of *L. monocytogenes* per serving [59]. Using the FAO/WHO [59] assumptions, a Monte-Carlo simulation was built to derive an empirical distribution of uncertainty for each of the two *r* parameters. A median *r* estimates is $7.76 \times 10^{-13}$ [$1.32 \times 10^{-13}$; $6.98 \times 10^{-12}$] for the susceptible population and $1.76 \times 10^{-14}$ for a 95% CI of [$2.07 \times 10^{-15}$; $2.10 \times 10^{-13}$] for the other population. Note the scale of the uncertainty. The fraction of the population in the two subpopulations is also uncertain. No uncertainty is included for any dose-response parameter for this risk assessment because the emphasis is on comparing outputs for different deli operating rules. Because this confounding uncertainty is not the purpose of this study, it was chosen to use the point estimates for *r*.

## *6.5. Additional baseline inputs*

### 6.5.1 Retail deli characteristics

Two categories of retail deli are currently considered: a retail deli A type (20% of simulated retail delis) and retail deli B type (80% of simulated retail delis). Retail deli A type includes one of each considered category of object, (i.e., one Floor, one Sink, one Refrigerator [handle], one Scale, one Case, one Utensil (and its handle), one Slicer, one Food Contact Surface, and one Non Food Contact Surface). The retail deli B type includes two of each considered category of object. Each retail deli is opened 14 hours per day.

In the baseline risk assessment model, the “food contact surfaces” (FCSs) are washed and sanitized once every 4 hours of operation. When food workers engage in sporadic cleaning, it is assumed that they wash four objects. Also, it is considered that food workers wear gloves while serving customers 100% of time (as observed by Lubran *et al.* [28] in States with the glove policy).

In the baseline, it is assumed that one slicer is used only for deli meat and that the other slicer is used for deli cheese in larger retail delis with two slicers. There is no separation of deli cases or any other type of

objects according to the type of RTE food (e.g., cheese, deli salad, deli meat). When multiple sites can be used in the retail deli, the specific sites (e.g., slicer, utensil) used for that serving are randomly picked.

### 6.5.1 General operation

In all baselines and scenarios, the probability of occurrence of a Non Deli Time event amongst the main events ("Non Deli Time," "Sporadic Clean," and "Serve Customer") is 30%. Its duration follows a Normal distribution with mean 3 minutes, and standard deviation 0.3 minute. The probability of occurrence of a Sporadic Clean event among the main events is 5%. Its duration follow a Normal distribution with mean 10 minutes and standard deviation 1 minute. The main event "Serve a Customer" occurs with a probability of 65%.

### 6.5.2 RTE products

A retail deli from the baseline model includes 20 different RTE products. The sales characteristics are presented Table 14. The relative frequency of sales for most of the RTE products are from "What's in store 2010" [97]. The sizes of the servings that are sold are sampled from the empirical distribution observed by Ecosure [19] from the sales of 787 various deli meats. The empirical cumulative distribution is provided Figure 12.

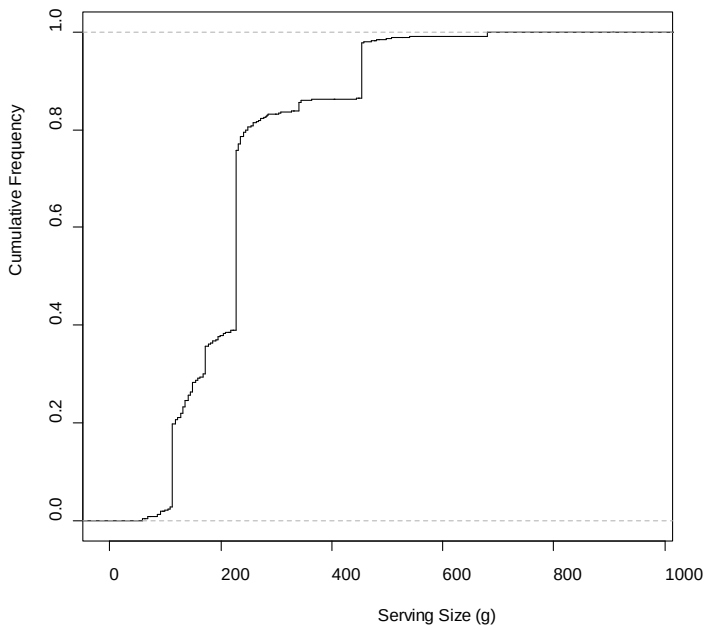



**Figure 12: Empirical cumulative distribution of the size of RTE food serving in a retail deli** (Source: [19]).

Importantly, the initial concentration distribution (cfu/gram) for all RTE products is assumed to be a $\log_{10}$ normal distribution. The mean and standard deviation of this $\log_{10}$ normal distribution are assumed to be issued from a multinormal distribution with mean (-9.228, 2.923) and covariance matrix $C = \begin{pmatrix} 0.232 & -0.085 \\ -0.085 & 0.032 \end{pmatrix}$. These parameters are maximum likelihood estimates from the FSIS *L. monocytogenes* verification sampling program data [8, 98]. Data from 2006–2010 were used to estimate this distribution [99]. The dataset consisted of 56,985 samples with an observed prevalence of 0.42% (239 positives). Twenty-two of the samples had quantifiable concentrations above the detection limit. The highest observed concentration was 230 MPN/g. A maximum likelihood estimation algorithm, which accounted for the censoring of the data due to the multiple detection limits [16], was used to fit the lognormal model to the data. In order to avoid any unrealistic concentration using this unbounded, heavily tailed, $\log_{10}$ normal distribution, this distribution was truncated to 500 cfu per gram

For a 2,270 gram chub, and assuming a Poisson-lognormal(-9.228, 2.923) distribution of the bacteria, this distribution leads to a prevalence (percentage of chubs containing >0 bacteria) of 2.97%. Table 13 presents some characteristics of this distribution and of distributions that will be used in some of the alternatives.

**Table 13: Characteristics of the distribution of bacteria in contaminated chubs (2270 grams) according to the mean of the $\log_{10}$ normal-Poisson distribution.**

| | Mean | sd | prevalence (prob > 0 cfu) | prob > 2270 cfu (1 cfu/g) | prob > 22,700 cfu (100 cfu/g) |
|---|---|---|---|---|---|
| Baseline | -9.228 | 2.923 | 2.97% | 0.08% | 0.01% |
| Alternatives | -9.529 | 2.923 | 2.35% | 0.06% | 0.00% |
| | -8.928 | 2.923 | 3.71% | 0.11% | 0.01% |
| | -7.000 | 2.923 | 12.71% | 0.83% | 0.10% |
| | -5.000 | 2.923 | 31.94% | 4.36% | 0.83% |
| | -3.000 | 2.923 | 58.04% | 15.24% | 4.36% |

The characteristics of the various RTE products are reported Table 15. These characteristics are extracted from the chemical analysis results provided in the predictive microbiology literature [72, 77, 79, 80, 82, 100-120].

**Table 14: Sales and characteristics of the RTE products.**

| RTE Product Type | (Example*) | Number of Chub/Bulk in each Retail Deli | Sales quantity (Relative Quantity) | Mass of a Chub/Bulk in g. | (Sd) |
|---|---|---|---|---|---|
| Deli Meat | (Uncured Ham) | 2 | 4.7 | 2724 | (227) |
| Deli Meat Low Growth | (Cured Ham) | 2 | 4.7 | 2724 | (227) |
| Deli Meat No Growth | (Cured Ham w GI) | 1 | 4.7 | 2724 | (227) |
| Deli Meat | (Uncured Turkey) | 2 | 5 | 2724 | (227) |
| Deli Meat Low Growth | (Cured Turkey) | 2 | 5 | 2724 | (227) |
| Deli Meat No Growth | (Cured Turkey w GI) | 1 | 5 | 2724 | (227) |
| Deli Meat | (Uncured Bologna) | 1 | 1 | 2724 | (227) |
| Deli Meat Low Growth | (Cured Bologna) | 1 | 1 | 2724 | (227) |
| Deli Meat No Growth | (Cured Bologna w GI) | 1 | 1 | 2724 | (227) |
| Deli Meat No Growth | (Pepperoni) | 1 | 1 | 2724 | (227) |
| Deli Meat No Growth | (Salami) | 1 | 3 | 2724 | (227) |
| Deli Cheese Low Growth | (Colby) | 1 | 1 | 3178 | (227) |
| Deli Cheese No Growth | (Monterey Jack) | 1 | 1.4 | 3632 | (227) |
| Deli Cheese No Growth | (American) | 1 | 7.6 | 3632 | (227) |
| Deli Cheese No Growth | (Provolone) | 1 | 1.4 | 3632 | (227) |
| Deli Cheese Low Growth | (Swiss) | 1 | 1.4 | 3632 | (227) |
| Deli Salad | (Potato) | 1 | 5 | 4540 | (227) |
| Deli Salad Low Growth | (Potato w GI) | 1 | 5 | 4540 | (227) |
| Deli Salad | (Protein) | 1 | 2 | 4540 | (227) |
| Deli Salad Low Growth | (Protein w GI) | 1 | 3 | 4540 | (227) |

* Examples are proposed as illustrative purposes

**Table 15: Characteristics of the RTE products.**

| RTE Product Type | (Example*) | pH | aw | Nitrites (ppm) | Potassium Lactate (w/w %) | Sodium Diacetate (w/w %) |
|---|---|---|---|---|---|---|
| Deli Meat | (Uncured Ham) | 6.4 | 0.97 | 0 | 0 | 0 |
| Deli Meat Low Growth | (Cured Ham) | 6.4 | 0.97 | 150 | 0 | 0 |
| Deli Meat No Growth | (Cured Ham w GI) | 6.4 | 0.97 | 150 | 1.65 | 0.12 |
| Deli Meat | (Uncured Turkey) | 6.3 | 0.96 | 0 | 0 | 0 |
| Deli Meat Low Growth | (Cured Turkey) | 6.3 | 0.96 | 150 | 0 | 0 |
| Deli Meat No Growth | (Cured Turkey w GI) | 6.3 | 0.96 | 150 | 1.65 | 0.12 |
| Deli Meat | (Uncured Bologna) | 6.3 | 0.93 | 0 | 0 | 0 |
| Deli Meat Low Growth | (Cured Bologna) | 6.3 | 0.93 | 150 | 0 | 0 |
| Deli Meat No Growth | (Cured Bologna w GI) | 6.3 | 0.93 | 150 | 1.65 | 0.12 |
| Deli Meat No Growth | (Pepperoni) | 4.67 | 0.83 | 0 | 0 | 0 |
| Deli Meat No Growth | (Salami) | 5 | 0.91 | 0 | 0 | 0 |
| Deli Cheese Low Growth | (Colby) | 5.2 | 0.95 | 0 | 0 | 0 |
| Deli Cheese No Growth | (Monterey Jack) | 5.25 | 0.93 | 0 | 0 | 0 |
| Deli Cheese No Growth | (American) | 5.6 | 0.92 | 0 | 0 | 0 |
| Deli Cheese No Growth | (Provolone) | 5.2 | 0.91 | 0 | 0 | 0 |
| Deli Cheese Low Growth | (Swiss) | 5.2 | 0.92 | 0 | 0 | 0 |
| Deli Salad | (Potato) | 4.6 | 0.998 | 0 | 0 | 0 |
| Deli Salad Low Growth | (Potato w GI) | 4.6 | 0.998 | 0 | 1.65 | 0.12 |
| Deli Salad | (Protein) | 5 | 0.988 | 0 | 0 | 0 |
| Deli Salad Low Growth | (Protein w GI) | 5 | 0.988 | 0 | 1.65 | 0.12 |

* Examples are proposed as illustrative purposes

The FDA Food Code [27] specifies that RTE, potentially hazardous food (time/temperature control for safety food) prepared and held refrigerated for more than 24 hours in a food establishment must be marked at the time the original container or package is opened in a food establishment to indicate the date

by which the food shall be consumed or discarded. In the baseline model, chubs of ham, turkey, bologna and salads are discarded if they are not used 7 days after the date they are opened. Foods that do not require a 7-day limit after opening according to the FDA Food Code [27] (e.g., pepperoni, salami, and cheese (Colby, Monterey Jack, American, Provolone, Swiss)) are discarded after 30 days if they are not used.

In the baseline model, RTE products are not presliced; they are sliced and served at the consumer request.

### 6.5.3 Transfer coefficients

The current values of the parameters defining the transfer coefficient distributions ($M_{Tij}$ and $S_{Tij}$ see section 6.1.1), following the analysis described in Hoelzer *et al*. [37], are reported in Table 16. The parameters are shown only for the transfers that are currently simulated in the model. See Hoelzer *et al*. [37] for details.

**Table 16: Mean (standard deviation) of the $\log_{10}$ of the transfer coefficients for *L. monocytogenes* at retail.**

| | To Meat | Cheese | Salad | Floor | Sink | Handle | Case | Utensil | Utensil Handle | Slicer | Scale | FCS | NFCS | Glove | Hand |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From Meat | | | | | -0.28 (0.2) | | | -0.28 (0.2) | | -0.28 (0.2) | | -0.28 (0.2) | -0.28 (0.2) | -1.69 (0.81) | -1.69 (0.81) |
| Deli Cheese | | | | | -0.28 (0.2) | | | -0.28 (0.2) | | -0.28 (0.2) | | -0.28 (0.2) | -0.28 (0.2) | -1.69 (0.81) | -4.96 (0.37) |
| Salad | | | | | | | | -0.28 (0.2) | | -0.28 (0.2) | | -0.28 (0.2) | -0.28 (0.2) | -1.69 (0.81) | -4.96 (0.37) |
| Floor | | | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Sink | -0.28 (0.2) | -0.28 (0.2) | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Handle | | | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Case | | | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Utensil | -0.28 (0.2) | -0.28 (0.2) | -0.28 (0.2) | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Utensil Handle | | | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Slicer | -0.28 (0.2) | -0.28 (0.2) | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Scale | | | | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| FCS | -0.28 (0.2) | -0.28 (0.2) | -0.28 (0.2) | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| NFCS | -0.28 (0.2) | -0.28 (0.2) | -0.28 (0.2) | | | | | | | | | | | -1.84 (0.87) | -1.84 (0.87) |
| Glove | -4.96 (0.37) | -4.96 (0.37) | -4.96 (0.37) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -3.43 (0.79) | -3.43 (0.79) |
| Hand | -1.69 (0.81) | -4.96 (0.37) | -4.96 (0.37) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -1.84 (0.87) | -3.43 (0.79) | -3.43 (0.79) |

## *6.6. Implementation*

The model is written in the open source language R version > 2.11.1 [121], which is freely available for download at http://www.r-project.org/. The parameters are specified in a Microsoft® Excel workbook read by R through an ODBC (Open Database Connectivity)(RODBC package).

The major disadvantage of discrete event models is that their computing times are long. Any state being dependent on the preceding one, this prevents vectorization and requires loops in R, which run much slower. A lot of effort has been made while writing the code in order *i*) to be able to launch the code on parallelized processors, using the R SNOW package ; ii) to profile the time of computing.

The Interagency Retail *L. monocytogenes* Risk Assessment Workgroup has access to High Performance Computing (HPC) tools brought by the Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, FDA. This allowed the group to run the model on up to 2,016 cores (Figure 13). Running the code in parallel greatly reduced run time and was used to provide results.

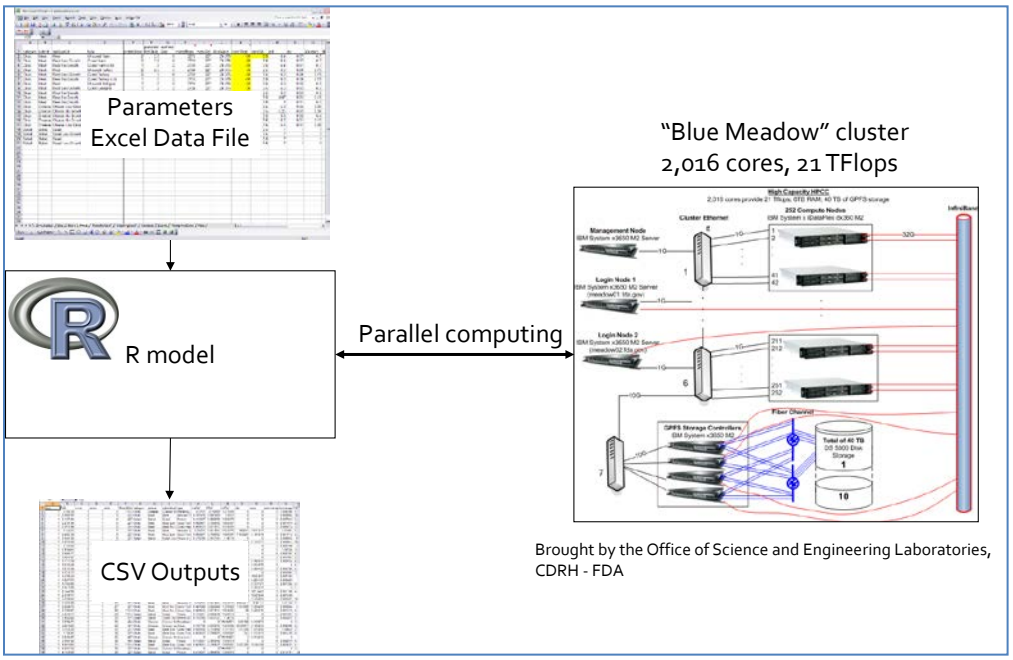



**Figure 13: General scheme of simulations**

The current general algorithm is as provided Figure 13. On 101 cores, it takes about 0.45 hour to run 100 retail delis in parallel, 1,100,000 sales for each retail deli.

## *6.7. Studying the model*

### 6.7.1 RTE products

Given that each simulation is run for periods measured in years (1,000,000 servings) for 100 retail delis, a resulting output file size that would record each sale would be too large to be handled. Thus, the risk assessment model outputs include summary statistics of the servings and of the events for each simulation. The summary for the serving includes for each retail deli and food sub category:

- the number of servings;
- the number of contaminated serving;
- the mean number of *L. monocytogenes* cfus amongst positive RTE product servings;
- the mean number of *L. monocytogenes* cfus per gram of RTE product amongst positive servings;
- the mean *L. monocytogenes* concentration amongst positive RTE product servings when sold and when eaten;
- the mean ingested dose of *L. monocytogenes*;
- the mean risk of invasive listeriosis in the two subpopulations;
- the mean of the $\log_{10}$ of these outputs;
- the sum of square of these outputs.

These few statistics are sufficient to build various other statistics, such as the mean for all servings (negative and positive), the variance, the standard error, within sub-category of RTE food, within uncertainty loop, within repetition, *etc*. It also is sufficient to build an analysis of variance.

Moreover, in order to better characterize the cumulative density function of these outputs, another summary provides the number of contaminated serving that falls in some contamination level bins. These statistics count the number of deli sales that fall in the (-∞; 0.001), [0.001; 0.01), [0.01; 0.1),... [1E6, 1E7), [1E7, ∞) bin of contamination (in cfu/g of RTE products). Knowing these counts, it is easy to rebuild the interval based cumulative density function within sub-category of food, within repetition, *etc*.

If needed, a file containing a record for each of the simulated servings may be built. It includes all characteristics of the product sold (e.g., growth characteristics, final size, associated risk). This file is usually too large to be handled, but may be built and studied for shorter runs to study a very specific situation.

### 6.7.2 Sites

A file is provided to track the contamination of the sites: the summary reports for each retail deli and for each site, the kind of retail deli (e.g., “A” or “ B”), the fraction of time a site is contaminated, and the mean number of events during which the given site stays contaminated.

The model also can output the time series of *L. monocytogenes* counts at each site each time an event occurs or for one selected type of event. This file is usually too large to be handled for a complete run.

### 6.7.3 Transfer matrix

Within the risk assessment model, a matrix was developed to track each transfer of *L. monocytogenes* during a simulation. The structure of the matrix is depicted in Figure 14.

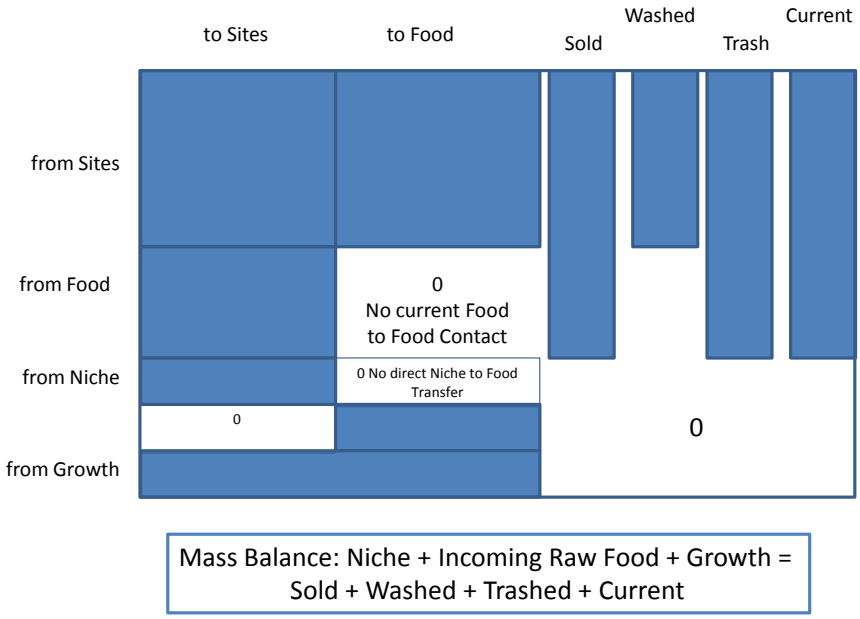



**Figure 14: Structure of the *L. monocytogenes* transfer matrix in the model of the Interagency Risk Assessment - *L. monocytogenes* in Retail Delicatessens.**

The risk assessment model summarizes the information from a run by proving *i*) the number of contacts between objects; *ii*) the number of effective contacts (i.e., number of contacts with at least one cfu involved); *iii*) the average number of *L. monocytogenes* cfu transferred per contact, and; *iv*) the overall number of transferred cfu of *L. monocytogenes*.

The intensity of the transfers occurring in a model may be graphically illustrated as in Figure 20 to study the dynamics of the transfer of *L. monocytogenes* in the risk assessment model as well as the impact of mitigations on each *L. monocytogenes* transfer.

# 7. Risk Assessment Results and Discussion

## *7.1. Risk management questions and model approaches*

### 7.1.1 Baseline retail deli and RTE product conditions

The model requires the input of bacterial loadings and frequencies of bacterial transfer from the niches and the mean bacterial concentration in the contaminated product type. Baseline conditions needed to be established to evaluate the public health impact of changes in retail deli practices and the effectiveness of the various retail deli food safety mitigations. The conditions in different retail stores and within a single retail deli at different times may vary a great deal in terms of *L. monocytogenes* levels of environmental and product contamination. A sensitivity analysis of the levels and frequencies of *L. monocytogenes* contamination from niches and the mean levels of *L. monocytogenes* on RTE products entering the retail deli for further preparation (e.g., slicing) before being sold to the consumer was conducted in section 7.2.1.

The approach used in this risk assessment was to evaluate the public health effect of various food safety mitigations under six different baseline conditions that may characterize a retail deli and the RTE product its serves at different times over the course of operations. These six baseline conditions are:

- A retail deli with multiple niches that releases *L. monocytogenes* to food contact surfaces. This approach would also represent retail delis where general environmental contamination of non-food contact surfaces is transferred to surfaces that may be in contact with food. This baseline assumes that on average 100 *L. monocytogenes* are released to food contact surfaces periodically, with an average period between two releases of one week (**W**). The level selected for this specific baseline was selected amongst other levels (see section 7.2.1). This baseline will be denoted: **Multiple Niche 100W** (1$^{st}$ baseline model condition).
- A retail deli with no niches or environmental *L. monocytogenes* transfer. This baseline will be denoted: **No niche** (2$^{nd}$ baseline model condition).
- A retail deli with no niche with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average federally inspected plant data indicate [99]. Theses baselines assume (see section 7.2.1) a mean concentration in that incoming RTE product of $10^{-5}$ cfu/g, increased from the monitored $10^{-9.2}$ cfu/g. The level selected for these specific baselines were selected to generate a readily observable increase in the predicted risk and were further evaluated by a sensitivity analysis (see section 7.2.1). Two types of retail deli situations are examined, including:

- The incoming contaminated RTE product supports growth. (Sales volume and other RTE product specific data based on available data on RTE food that support *L. monocytogenes* growth). This baseline will be denoted: **Incoming Growth Chub** (3rd baseline model condition).
- The incoming RTE product does not support growth. (Sales and other RTE product specific data were based on available data on RTE food that does not support *L. monocytogenes* growth). This baseline will be denoted: **Incoming Non-Growth Chub** (4th baseline model condition).

- A retail deli compliant with the 2009 FDA Food Code guidance to maintain deli cases at ≤41°F (≤5 °C).
  - A retail deli with multiple niches and compliant temperature control. This baseline will be denoted: **Niche & Temperature Control** (5th baseline model condition).
  - A retail deli without any niches with compliant temperature control. This baseline will be denoted: **Temperature Control** (6th baseline model condition).

When evaluating the impact of incoming contaminated product, sales and product composition were taken from typical high sale deli meat and cheese food products. The incoming concentrations were selected as a range to be higher than actually observed so that the potential public health impact of these higher levels could be evaluated.

In the absence of *ad-hoc* data, the specific values defining each baseline type are merely representative. For example, the **Multiple Niche 100W** baseline considers that niches transfer 100 cfu on an average weekly frequency. The baseline values are thus representative of a type of retail delis. A range of values for niche characteristics and levels of contamination of incoming products are evaluated in a sensitivity analysis in Section 7.2.1.

### 7.1.2 Retail deli food safety mitigation scenarios

Various retail deli food safety mitigation scenarios were evaluated to inform the specific risk management questions posed for this risk assessment (see Section 3). The food safety intervention scenarios that were run for each of the baseline conditions are given below. The abbreviations used on the graphs are shown first in bold, followed by a brief explanation. The reader can refer to a list of these abbreviations in the Table page vii. These scenarios are grouped according to the risk management question the scenario illustrates.

Because of the large number of retail deli food safety mitigations considered in this risk assessment, the scenarios were divided into two categories:

- Category 1: those mitigations primarily based on improving sanitation; and
- Category 2: worker/industry behavior and those mitigations primarily directed at restricting growth through time and temperature control.

Risk assessment model scenario analyses were conducted to inform specific risk management questions as follows:

1) What would be the potential public health impact of practicing more frequent or more extensive cleaning procedures for food contact surfaces and/or NFCS on the prevalence of *L. monocytogenes* in RTE products sold in retail delis and on the corresponding mean risk of invasive listeriosis than is currently specified in the 2009 FDA Food Code? The corresponding tested scenarios were:

- **Wash & Sanitize**: Increase the effectiveness of retail deli cleaning from simply washing to washing and sanitizing (i.e., from an average $\log_{10}$ reduction obtained from a Pert(-1.5, -0.5, 0) to a Pert(-8, -6, -1.5)).
- **Clean 8 Sporadic**: doubling the number of retail deli sites sporadically cleaned from 4 to 8;
- **No Sanitation**: do not conduct any wiping, washing, or sanitizing of retail deli FCSs;
- **No Sporadic Cleaning**: retail deli workers clean FCSs as required by the 2009 FDA Food Code, but do not conduct any additional sporadic cleanings as observed by Lubran *et al.* [28].

2) What is the potential public health impact of increasing the use of single-service gloves in the retail delis?

- **No Glove**: retail deli workers do not use gloves when serving customers;
- **Gloves Every Serving**: retail deli workers change gloves for every sale of RTE products.

3) What if scale touch pads, refrigerator and deli case handles, and other frequently touched non-food contact surfaces were considered food contact surfaces and were therefore cleaned and sanitized at a minimum frequency as per FDA Food Code [27] requirements?

- **NFCS as FCS**: retail deli workers clean deli NFCSs as if they were FCSs (i.e., every 4 hours in accordance with the 2009 FDA Food Code).

4) What if practices were in place so that no cross contamination occurred in delis (i.e., no additional *L. monocytogenes* added to incoming RTE products)?

- **Transfers to 0**: scenario where *L. monocytogenes* cross contamination in the retail deli would only result from the deli slicer (i.e., set cross contamination transfer coefficients to 0 for all sites except the slicer);
- **Transfers and Slicer to 0**: scenario where there is no *L. monocytogenes* cross contamination in the retail deli (i.e., set cross contamination transfer coefficients to 0, meaning no cross contamination occurs for all sites, including the slicer).

5) What if display cases were not touched with gloved or bare hands (i.e., used tissues or had automatic door open/shut)?

- **No Contact Glove Case**: retail deli workers do not use their hands (gloved or ungloved) to open the deli case (e.g., if a floor switch is used).

6) What would be the potential public health impact if the level of *L. monocytogenes* contamination is reduced in RTE foods coming into the retail deli?

- **Reduce Level**: lower the mean incoming *L. monocytogenes* concentration on all RTE products from a mean of the $\log_{10}$ of -9.228 to a mean of the $\log_{10}$ of -9.529 (see Section 7.2.1). This leads to an average prevalence for a 2,270 g chub of 2.35% *vs*. 2.97% in the baseline.

7) What would be the potential public health impact of "preslicing" all RTE products vs. "slicing to order" (hypothesis: less cross contamination occurring in morning prior to other cross contamination events).

- **Preslice**: retail deli workers pre-slice all chubs of RTE product (deli meat and deli cheese) in the morning after cleaning. A quantity equal to the median of the daily sales is presliced every morning. When a consumer orders a RTE product, the food worker serves the presliced RTE product, until the presliced quantity is all sold. If needed, additional RTE product is sliced to order. At the end of the day, the remaining presliced RTE product is discarded.

8) What would be the potential public health impact of using separate slicers and/or separate counters for RTE products that permit growth of *L. monocytogenes* and for RTE products that do not?

- **Separate Slicer**: retail deli workers use a separate slicer for RTE products that support growth of *L. monocytogenes* versus those RTE products that do not;
- **Separate Slicer Case**: retail deli workers use a separate slicer and a separate deli case for RTE products that support the growth of *L. monocytogenes* versus those RTE products that do not.

9) What would be the potential public health impact of lowering the level of environmental contamination of food contact surfaces?

- **Lower Env Contam**: reduce transfer of *L. monocytogenes* among RTE products, FCSs, and NFCs (i.e., reduced transfer coefficients by 50%) in the retail deli.

10) What if food workers do not slice RTE products directly on their gloved hands?

- **Do Not Slice Onto Gloves**: during the observational study, it was observed that the food worker usually gets the slices on their gloves before putting them on the deli tissue (rather than slicing it directly on the deli tissue). In this alternative, retail deli workers collect the slices RTE products directly on tissue paper rather than on his or her gloves.

11) What is the potential public health impact of bacterial growth in retail delis?

- **Temp = 5°C:** set the retail deli case temperature for all retail delis to 5°C (41°F) (i.e., in compliance with the 2009 FDA Food Code) rather than utilizing real-world deli case temperatures reported by Ecosure [19];
- **No Growth (T = -5°C)**: set all retail deli case temperatures to -5°C (23°F). At this temperature, no *L. monocytogenes* growth will occur.

12) What would be the potential public health impact of a complete compliance to the cold holding requirements for certain RTE foods in deli cases (hold at ≤41°F i.e., ≤5 °C)?

- **Temp ≤ 5°:** use the retail deli case temperatures observed in the Ecosure dataset [19] at or below 5°C (41°F). This implies that all retail delis with deli case temperatures exceeding the 2009 FDA Food Code recommendation come into compliance.

13) What would be the impact of shortening the time a RTE product can be used in a deli department?

- Shorten time in retail deli: retail delis reduce the length of time RTE products are held before they are sold or disposed from 7 to 4 days..

14) What would be the impact if all (or no) RTE products (e.g., RTE meat and poultry products, RTE deli salads) coming into the deli were formulated with growth inhibitors?

- **All GI**: reformulate all RTE products sold at the retail deli that would otherwise support *L monocytogenes* growth to include growth inhibitors to restrict the growth (same growth inhibitor (GI) formulation as cured ham with GI);
- **No GI:** reformulate all RTE products that support *L. monocytogenes* growth that are sold at the retail deli and do not include GI to restrict *L. monocytogenes* growth.

## *7.2. Baseline analysis*

This section provides the results of the various baselines and compares the various risk mitigation scenarios within each baseline. The following section (7.3) compares the risk mitigation scenarios across the various baselines.

The actual levels selected for specific baselines ("Retail deli with Multiple Niches" and "Retail delis with contaminated incoming RTE products") were selected to be large enough to show an increased predicted risk relative to the "no niche" baseline. Before providing the results of the various baselines, Section 7.2.1 provides a sensitivity analysis of the levels of specific baselines.

### 7.2.1 Sensitivity analysis

Figure 15 shows a sensitivity analysis of the mean predicted risk of listeriosis per serving of RTE food for a susceptible population [59] as these choices change. The blue bars to the left are for different niche loadings. "W" and "D" respectively stand for mean weekly or mean daily transfers. The number represents the mean number of cfu transferred to the site when transfer occurs. For contaminated RTE product, the number in parentheses represents the mean $\log_{10}$ concentration (e.g., the baselines scenarios "Retail delis with contaminated incoming RTE product" are from the (-5) bars).

Importantly, unlike the results presented for incoming contaminated RTE products baselines (see respective Sections page 89 and page 93), the estimated risk presented here specifically exclude sales of

the contaminated RTE product itself. Thus, any increase in predicted risk is due to a cross contamination to some other RTE product.

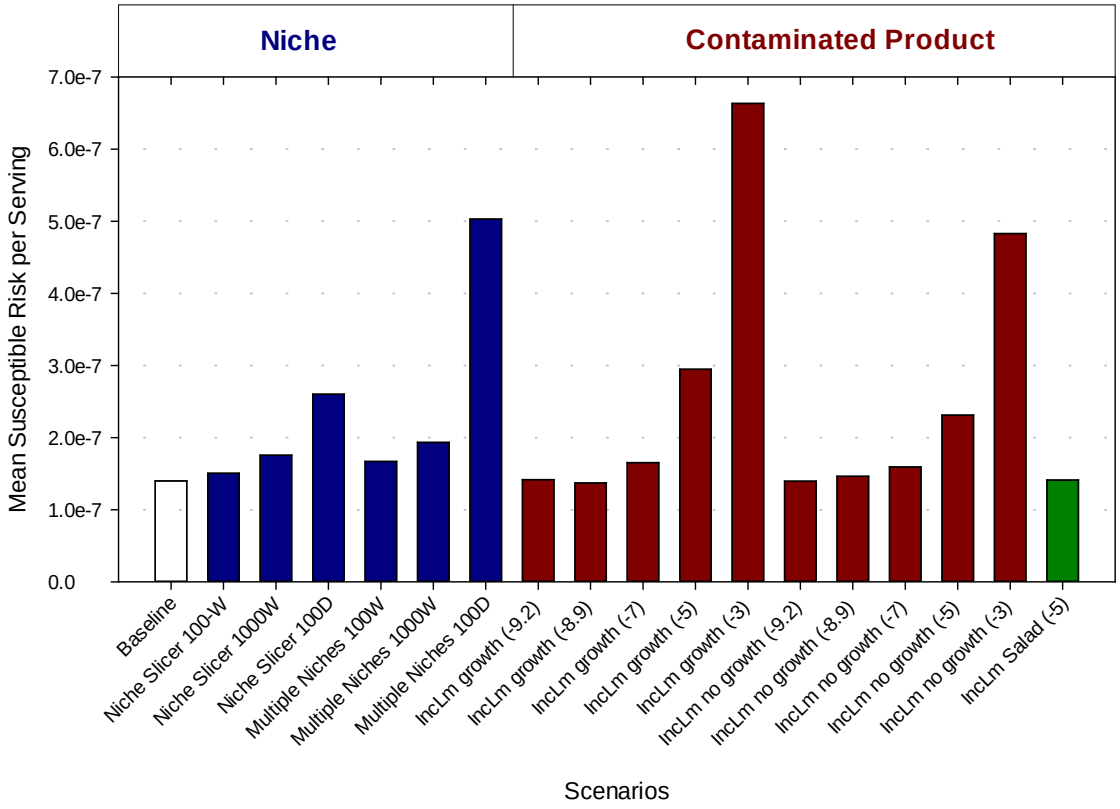



**Figure 15. Sensitivity analysis for niches and contaminated RTE product.**

**Baseline:** Retail deli with no niche or environmental bacteria transfer on food contact surfaces.

**Niche Slicer 100-W:** Retail deli with transfers of 100 *L. monocytogenes* cfu on the food contact surface of the slicer, with an average frequency of one transfer per week.

**Niche Slicer 1000-W:** Retail deli with transfers of 1,000 cfu *L. monocytogenes* on the food contact surface of the slicer, with an average frequency of one transfer to RTE product per week.

**Niche Slicer 100-D:** Retail deli with transfers of 100 cfu *L. monocytogenes* on the food contact surface of the slicer, with an average frequency of one transfer to RTE product per day.

**Multiple Niche 100-W:** Retail deli with transfers of 100 cfu *L. monocytogenes* on multiple food contact surfaces, with an average frequency of one transfer to RTE product per week.

**Multiple Niche 1000-W:** Retail deli with transfers of 1,000 cfu *L. monocytogenes* on multiple food contact surfaces, with an average frequency of one transfer to RTE product per week.

**Multiple Niche 100-D:** Retail deli with transfers of 100 cfu *L. monocytogenes* on [redacted] food contact surfaces, with an average frequency of one transfer to RTE product per day.

**IncLm growth (-9.2)**: Retail deli with no niche or environmental bacteria transfer on food contact surfaces with *L. monocytogenes* average contamination of incoming RTE products equal to the current estimate of federally inspected plant (-9.2 $\log_{10}$)

**IncLm growth (-8.9)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that support growth of *L. monocytogenes* equal to -8.9 $\log_{10}$, other RTE products having an average contamination equal to -9.2 $\log_{10}$

**IncLm growth (-5)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that support growth of *L. monocytogenes* equal to -5 $\log_{10}$, other RTE products having an average contamination equal to -9.2 $\log_{10}$

**IncLm growth (-3)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that support growth of *L. monocytogenes* equal to -8.9 $\log_{10}$, other RTE products having an average contamination equal to -3 $\log_{10}$

**IncLm no growth (-9.2)**: Retail deli with no niche or environmental bacteria transfer on food contact surfaces with *L. monocytogenes* average contamination of incoming RTE products equal to the current estimate of federally inspected plant (-9.2 $\log_{10}$). Same situation as in S-IncLm growth (-9.2).

**IncLm no growth (-8.9)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that do not support growth of *L. monocytogenes* equal to -8.9 $\log_{10}$, other RTE products having an average contamination equal to -9.2 $\log_{10}$

**IncLm no growth (-5)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that do not support growth of *L. monocytogenes* equal to -5 $\log_{10}$, other RTE products having an average contamination equal to -9.2 $\log_{10}$

**IncLm no growth (-3)**: Retail deli with *L. monocytogenes* average contamination of incoming RTE products that do not support growth of *L. monocytogenes* equal to -8.9 $\log_{10}$, other RTE products having an average contamination equal to -3 $\log_{10}$

**Note:** For the specific objective of this sensitivity analysis, the estimated risks for the simulations that incorporated a contaminated RTE product exclude the sales of the contaminated product itself. These results should not be compared to those presented in the later sections. For example, if the mean incoming level is increased to -5 $\log_{10}$, the mean risk per serving for the susceptible population with an incoming product that supports growth is estimated to be $16.6 \times 10^{-7}$ when the sales of the contaminated RTE product are considered. If the contaminated product sales are excluded, the mean risk is $2.9 \times 10^{-7}$ as shown in the graph. These figures are $2.8 \times 10^{-7}$ vs. $2.3 \times 10^{-7}$ when the incoming contaminated product does not support growth, respectively.

The main conclusions of the sensitivity analysis are that:

- allowing more *L. monocytogenes* into the retail deli environment increases the predicted risk, regardless of whether these bacteria come from a niche(s) in the retail deli environment or from *L. monocytogenes* on RTE product from the processor;
- highly contaminated RTE product cross contaminates other RTE products, leading to an increase predicted risk per serving from consumption of these cross contaminated RTE products. This is especially true for highly contaminated RTE products that permit growth, but it is also true for those that do not permit growth.
- allowing more frequent environmental cross contamination (daily *vs*. weekly) has proportionally more impact than allowing more bacteria per cross contamination event (100 *vs*. 1,000 cfus per contamination event);

Based on this sensitivity analysis, the following baselines were chosen:

- Retail deli with Multiple Niches/Transfers from the Environment : multiple niches/transfers, 100 cfu, with an average frequency of one transfer per week;
- Highly contaminated RTE products: mean level of *L. monocytogenes* contamination of -5 $\log_{10}$ cfu/g (that is 17,000 times the baseline).

### 7.2.2 Baseline conditions

*Baseline Condition: Multiple Niches / Transfers from the Environment*

Note that the scales are not held constant across each graph in the following sections, notably for different baselines. The baselines and mitigations are identified using an abbreviation, as specified above. The reader can refer to the table page vii for an extended description of these abbreviations.

For this baseline, a retail deli with multiple niches is used. Each niche contaminates its associated site with *L. monocytogenes* at a mean frequency of once per week and at a mean transfer of 100 cfu for each contamination event. This baseline would also mimic retail delis with frequent transfers from the retail deli environment.

The change in RTE products contaminated with *L. monocytogenes* and corresponding change in predicted public health risk (estimated mean risk per serving to the susceptible population) as a result of changes in sanitation and retail deli worker/industry behavior are shown in Figure 16 and Figure 17. The bottom graphs show the prevalence of *L. monocytogenes* in RTE products and the estimated risk of listeriosis. The top graphs present the relative change (%) in estimated prevalence per serving and in the estimated risk of listeriosis per serving relative to the baseline.

For each baseline, 30 simulations of 100 retail delis × 1,000,000 servings are computed with the model without mitigation. The $2.5^{th}$ and $97.5^{th}$ percentiles of the mean prevalence and the $2.5^{th}$ and $97.5^{th}$ percentiles of the mean risk per serving obtained from these 30 simulations provides 95% confidence intervals for this baseline. Other mitigations are evaluated from the results of 1 simulation of 100 retail delis × 1,000,000 servings. Results of any mitigation falling within the 95% confidence interval should be considered as not significantly different from the results obtained without mitigation. The 95% confidence intervals about the baseline are shown as horizontal lines on the bottom graphs.

As can be seen in Figure 16 and Figure 17, the absence of sanitation greatly increases the estimated prevalence of *L. monocytogenes* in the sold RTE product and, therefore, the predicted public health risk

resulting from these RTE products. Not conducting any sanitation increase the estimated risk by 41% (x-axis label: No Sanitation). Risk reductions can be predicted by reducing the incoming level of *L. monocytogenes* on RTE products (Reduce Level). A reduction in incoming level of *L. monocytogenes* on RTE products yields a 22% decrease in the predicted per-serving risk from RTE products. Conceptually, preventing cross contamination by setting all the transfer coefficients to 0 (Transfers and Slicer to 0) also significantly reduces the predicted risk (34%). When the slicer transfer coefficients were not included (Transfers to 0), the predicted risk was not significantly different from the baseline, emphasizing the importance of the slicer in RTE product cross contamination. Any improvement in the design of the slicer that would reduce the transfer coefficients could have a potential beneficial impact in mitigating the predicted risk of listeriosis.

Figure 18 and Figure 19 display the effect that the growth mitigation scenarios on the mean predicted risk per serving and the prevalence of *L. monocytogenes* in RTE product sold to the consumer when multiple niches are present. While the effects of most scenarios on prevalence are insignificant, the effects on relative risk are profound. Including a growth inhibitor in all RTE products (All GI) almost does away with any predicted risk (96% reduction). Conversely, removing growth inhibitors (No GI) increases the predicted risk by almost a factor of two (184%). These results emphasize the importance of mitigations that control for the growth of *L. monocytogenes* in RTE product in the retail deli and in the home. The inclusion of growth inhibitors in RTE product that supports *L. monocytogenes* growth is a mitigation scenario that will continue to have an effect once the RTE product is sold and leaves the retail deli. While they have little impact on prevalence, they have a significant impact on *L. monocytogenes* concentrations at the time of consumption, and thus on the predicted risk. Proper holding temperatures and reduced holding times at home also would reduce the predicted risk, but this is out of the scope of this study and improvement of cold holding at home was not tested here. As previously observed in *L. monocytogenes* risk assessment [3, 59], time and temperature abuse during home storage is considered a major contributor to the predicted risk of contracting listeriosis from RTE foods.

While difficult to tell because of the scales, Figure 19 also shows that improved temperature control is an effective risk reduction mitigation. Maintaining all display case temperatures at 5°C (41°F) or less resulted in a 9% reduction in the predicted risk when compared to the current estimated industry practice .

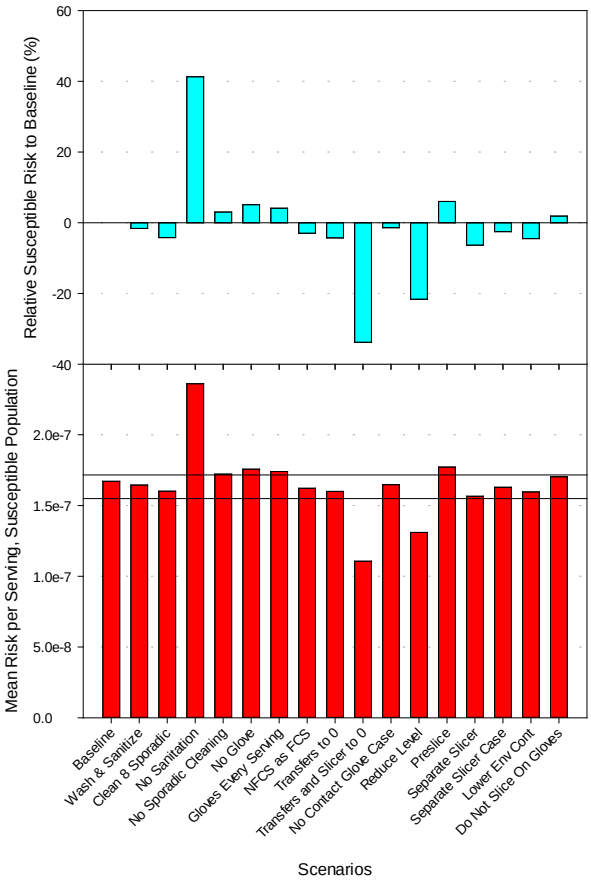



**Figure 16: Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population in a retail deli with multiple niches**

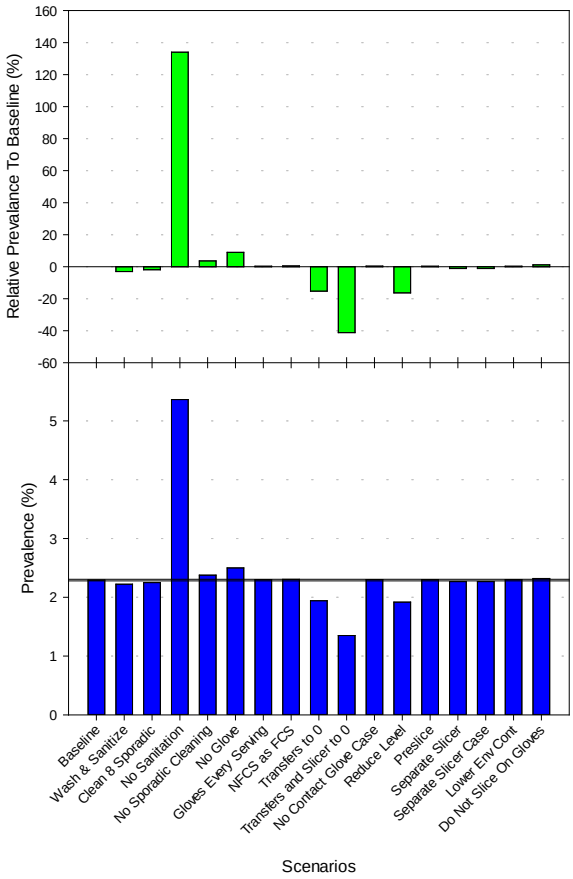



**Figure 17: Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products in a retail deli with multiple niches**

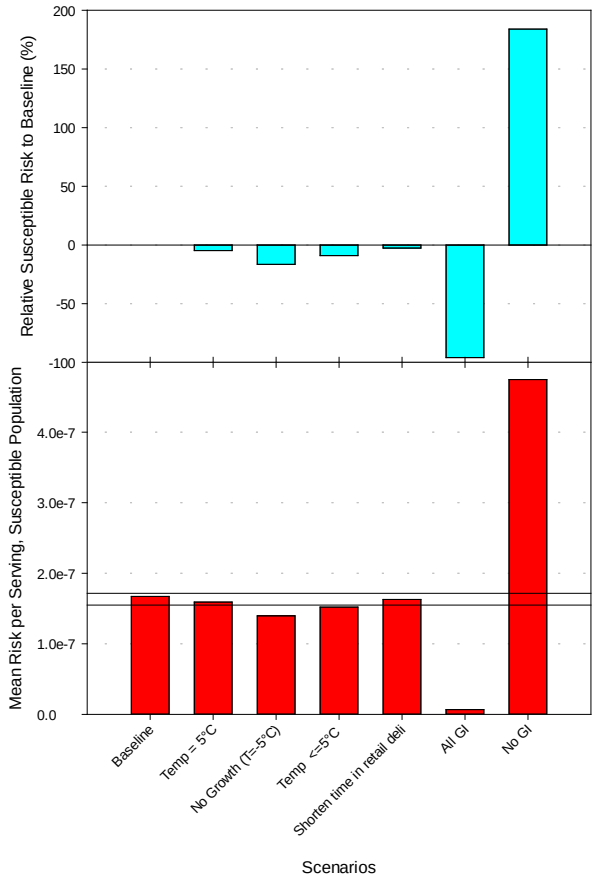



**Figure 18: Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population in a retail deli with multiple niches**

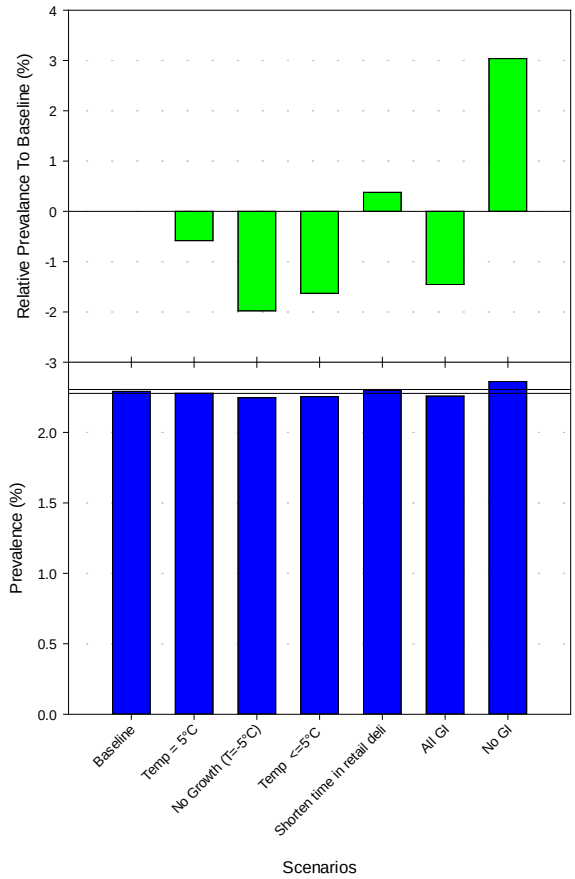



**Figure 19: Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products in a retail deli with multiple niches**

Analyses of the growth, transfers, and inactivation for a typical baseline run are shown in Figure 20 and Figure 21.

Figure 20 illustrates the total number of bacteria transferred between each pair of sites as well as the total number of new bacteria from growth and the total number of bacteria that are discarded from inactivation/removal. Note that the overall number of bacteria transferred from/to RTE products (meat, cheese, and salad) is influenced by their relative sales for this figure: a RTE product rarely sold would lead to a lower total number of transferred bacteria. Significant growth is observed, particularly in deli meats. A significant number of bacteria end in the “washed” or “trashed” compartment (i.e., the compartments that count the number of bacteria that are eliminated from sanitation practices). This reinforces the importance of sanitation. A large number of colored cells, both in the “From” and “To”

category, are associated with gloves. This illustrates the importance that actual handling/touching by the worker has on cross contamination.

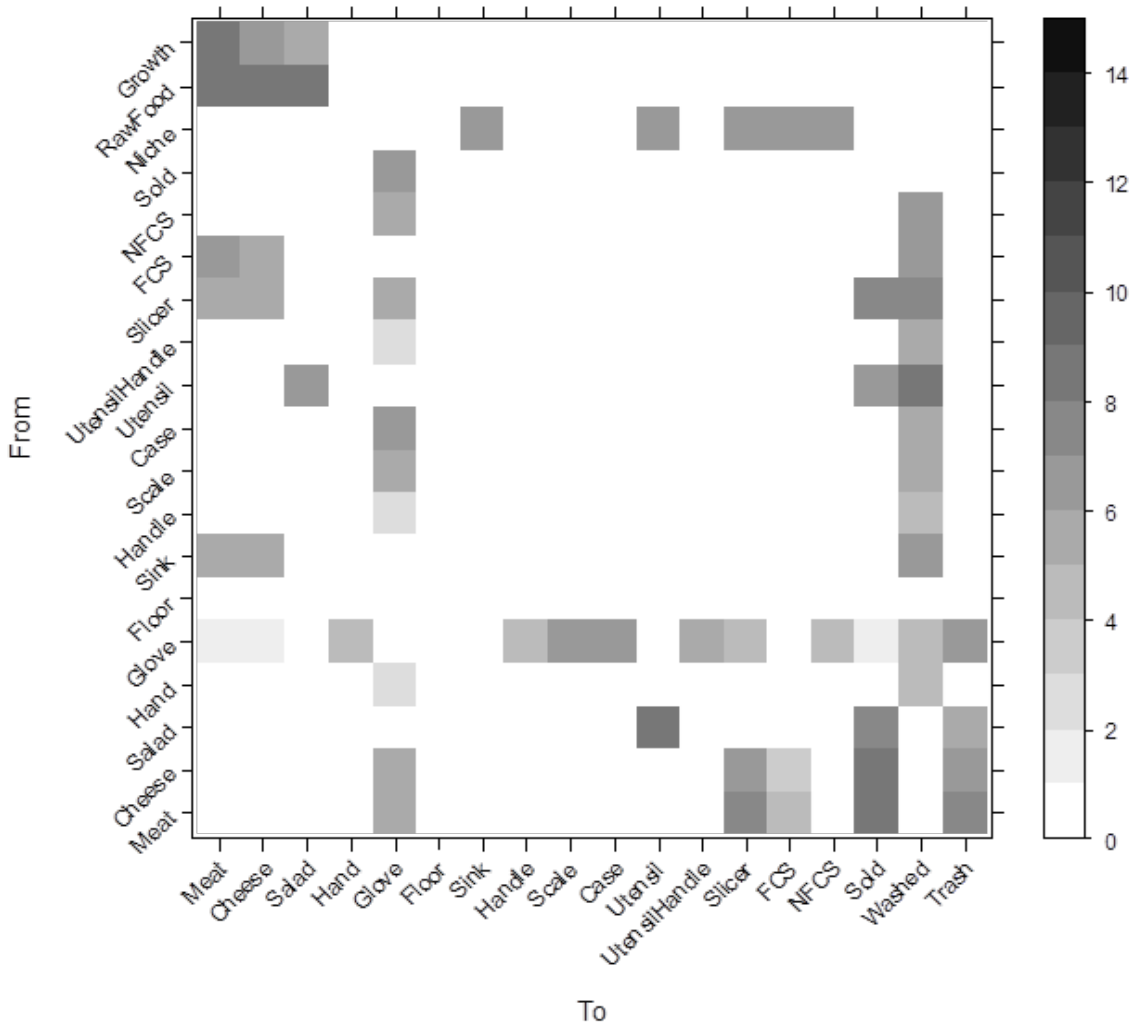



**Figure 20: Total *L. monocytogenes* cfu grown, inactivated, and transferred between pairs of sites for a baseline retail deli with multiple niches ($log_{10}$ scale). White squares indicate transfers that are not considered in the model or that are not meaningful.**

Figure 21 illustrates similar matrix limited to transfers where the bacteria transferred have been normalized by the actual number of contacts. Higher cfu transfers per contact are noted between deli meat and slicer, and to a lesser degree between deli cheese and slicer.

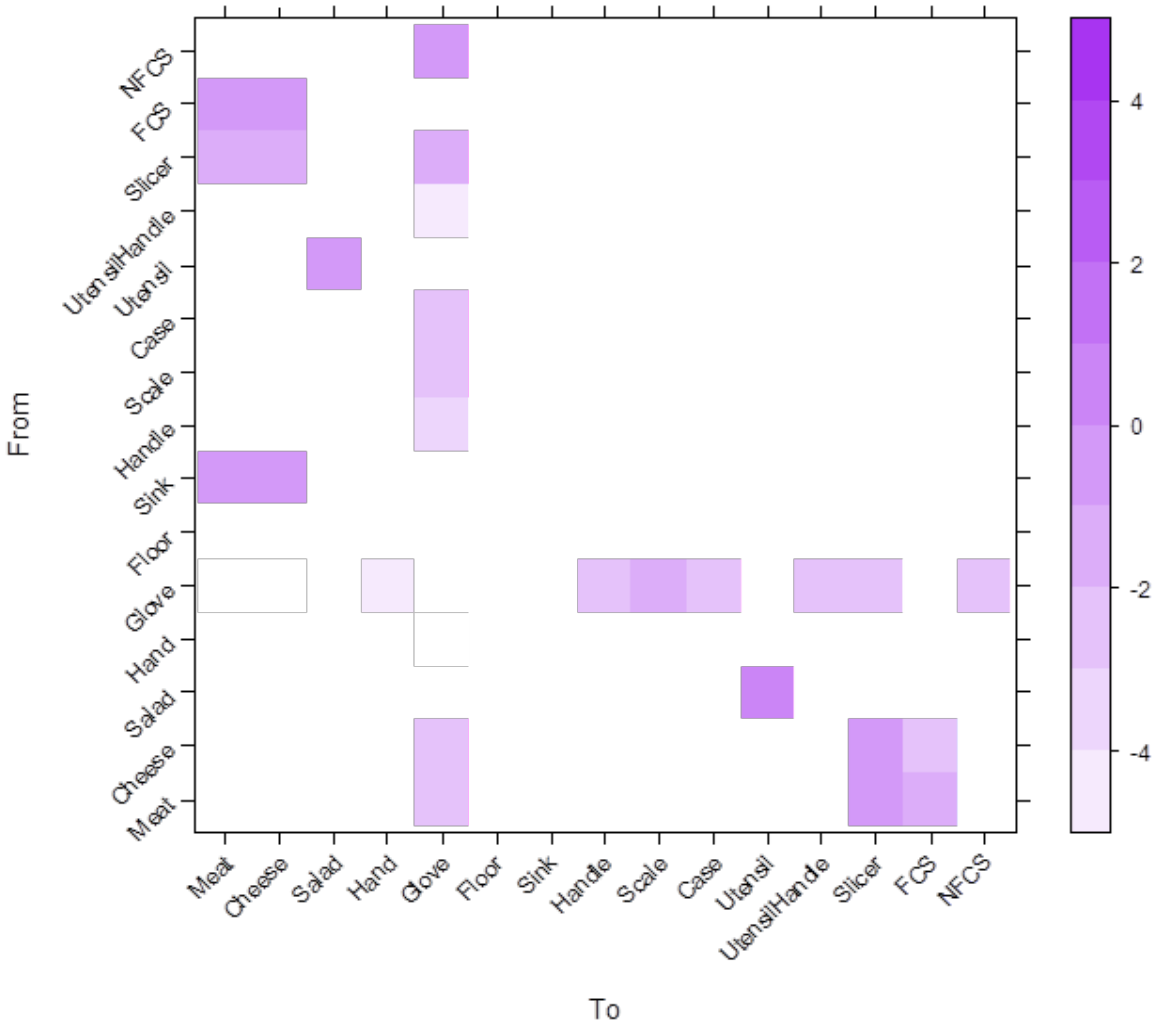



**Figure 21: *L. monocytogenes* cfu transferred per actual contact between each pair of sites for a baseline retail deli with multiple niches ($\log_{10}$ scale). White squares indicate transfers that are not considered in the model or that are not meaningful.**

Figure 22 evaluates the duration of site contamination. The upper graph indicates that for a retail deli with multiple niches/transfer from the environment, the NFCS are contaminated most often (upper graph). When contaminated, the contamination persist the longest (lower graph). Nevertheless, this graph shows that the contamination remains transient on sites even in case of regular transfer from the niche/environment.

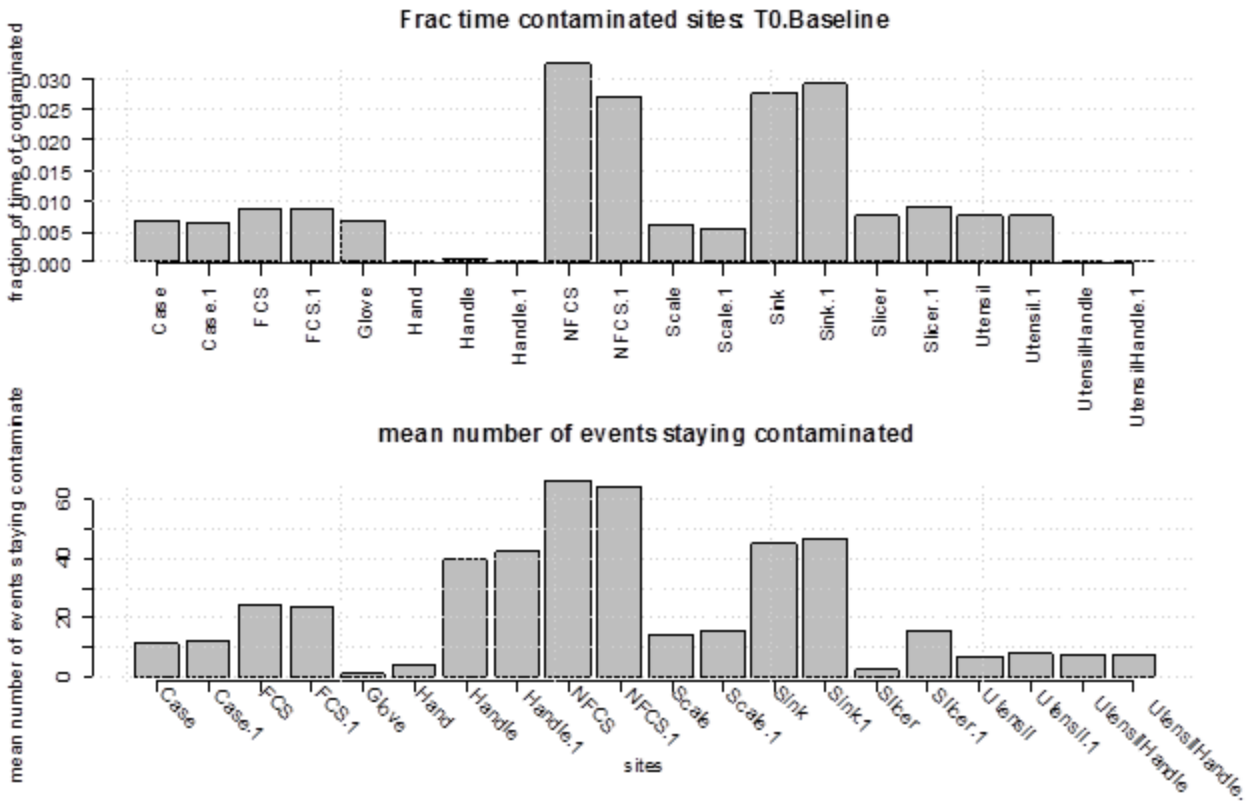



**Figure 22: Contamination time analysis for sites in baseline retail deli with multiple contaminated niches. Upper graph: fraction of time each site is contaminated during a baseline simulation. Bottom graph: mean number of events a site stay contaminated.**

For a listeriosis case to occur through a retail deli sale, several events must occur. Contamination must be present in or enter the retail environment. Within this model, contamination can enter the retail deli by means of a contaminated chub or be present in the retail deli in a niche or other environmental source. Figure 23 illustrates the process leading from a contaminated chub to a high risk of listeriosis from consumption of a RTE product sold from the deli-department. Thirty sales are shown from a baseline retail deli with transfer from the environment, although the environment contamination itself does not factor into this analysis. The sales and actual RTE products are shown in Figure 23a (bottom). A chub of cured ham with a high *L. monocytogenes* concentration is used for two sales: #84903 and #84909. All other RTE products sold are at much lower concentrations. When the RTE products are sliced, the total number of bacteria leaving with each sale is shown in Figure 23b. (These values are total cfus, not adjusted for weight of the sale. As expected, the two sales from the contaminated chub have very high cfu counts, over 2,000 and over 6,000 cfus, respectively. The pattern after the contaminated chub is sliced changes. Sale #84904 is a deli cheese RTE product, so a different slicer was used and cross contamination

does not occur. The two subsequent sales (#84905 and #84906) are for salami and uncured turkey respectively. Bacterial transfers from the contaminated slicer contaminate these sales, in a typical exponentially decreasing amount until the slicer is either sanitized or all of the available bacteria are transferred from the slicer to sales. Subsequent sales (#84907 and #84908) are thus not contaminated. Therefore, this first cross contamination event contaminates two additional sales. The second contamination event (#84909) contaminates three additional sales. Sale #84912 is potato salad, and so does not contact the slicer and is not involved in the cross contamination.

The dose at consumption for each of these sales is shown in Figure 23c. For listeriosis to occur, the FAO/WHO dose-response model [59] indicates that very large numbers of bacteria must be consumed – more than is almost ever present in the retail sale itself. Therefore the next process that must occur prior to a listeriosis case is significant growth during consumer handling (i.e., from the time of the sale to the time of consumption). This implies that the RTE product itself must support growth and typically consumer mishandling (i.e., the RTE product is retail deli for an extended period and/or at an elevated temperature). Only one of the sales in this example has both these features: sale #84906. On the cross contaminated uncured turkey, *L. monocytogenes* grew to its maximum concentration of $10^8$ cfu/g and was consumed in an approximate 100 g serving. The other contaminated sales are either in low/non-growth RTE products or are not mishandled.

Finally, a listeriosis case usually results when a susceptible person consumes a high dose of *L. monocytogenes*. Figure 23d shows the resulting risks of invasive listeriosis following the consumption of one serving from these sales. For this run, the one high dose was consumed by an individual from the general population, so the resulting risk of illness, evaluated using the corresponding dose response model, was less than 0.03%.

Given this required chain of events for each listeriosis case, it is much more likely that retail contamination results in very sporadic cases of listeriosis, unlike the major outbreaks where large numbers of illnesses are traced back to insanitary conditions or loss of process control. Currently, cases known to be outbreak-associated are <1% of reported cases to the Foodborne Diseases Active Surveillance Network (FoodNet) [10]

The model also illustrates the difficulty of tracing back sporadic illnesses to a specific food. Assuming RTE product was still available to be tested at the home and at the retail deli, testing the uncured turkey at the home would indicate a high concentration. However, testing at retail the exact chub the serving was

taken from would find *L. monocytogenes* absent. Even without consideration of the long incubation period for listeriosis [122], identifying contaminated RTE food and linking this to retail deli cross contamination would be very difficult.

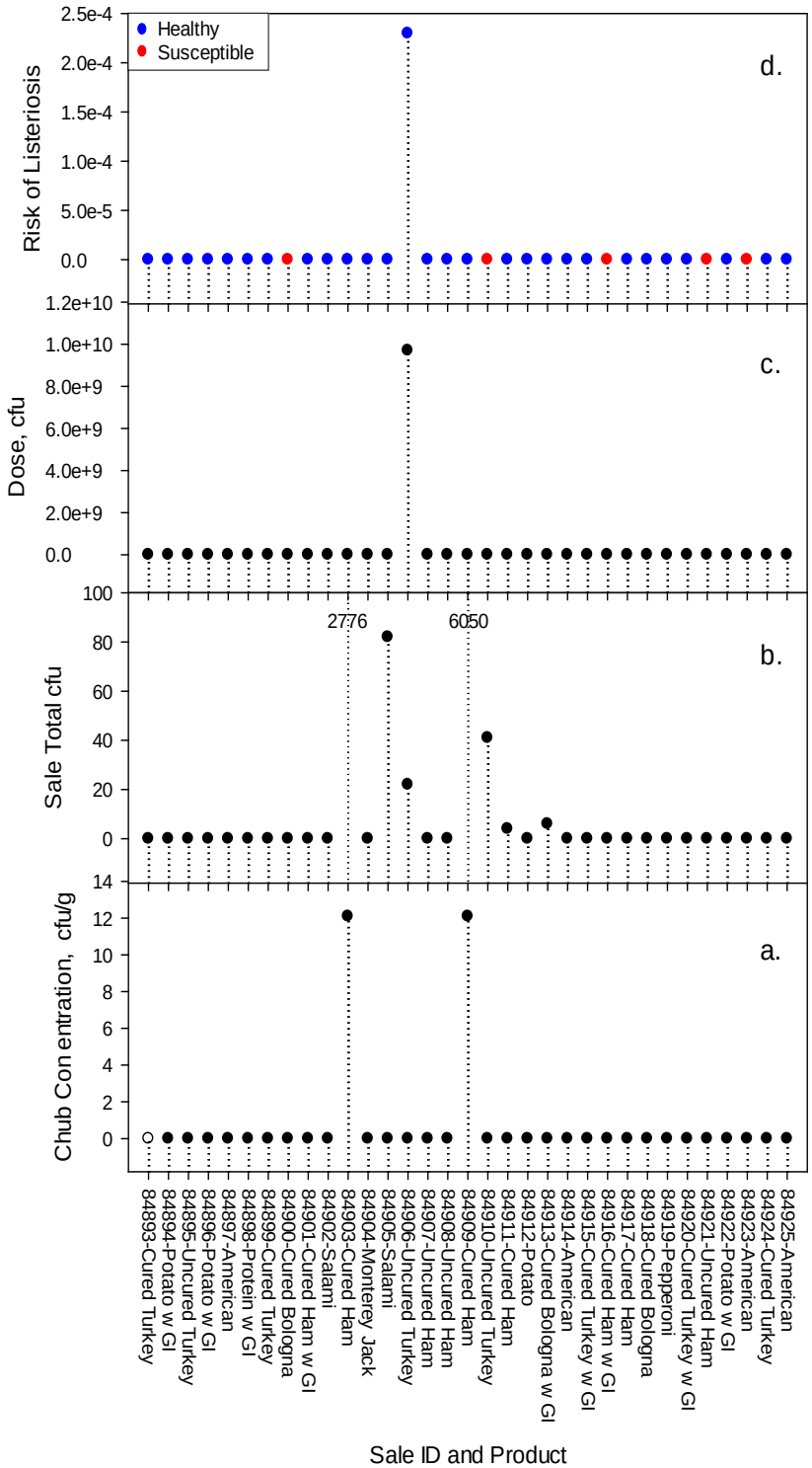



**Figure 23. Timeline illustration of sales, cross contamination, and subsequent risk of listeriosis**

*Baseline Condition: No niche*

For this baseline, a retail deli without any niches or highly contaminated RTE product was evaluated. The sanitation mitigations are shown in Figure 24 and Figure 25 and the growth mitigations in Figure 26 and Figure 27. Here, sanitation has a much lower impact because there are fewer bacteria to remove. Preslicing increases the predicted risk by 25%. As with the niches-contaminated retail deli, reducing incoming *L. monocytogenes* levels reduces the predicted risk (24% reduction) and preventing any cross contamination does as well (19% reduction). Only no sanitation had a noticeable impact on the prevalence.

The growth mitigations are shown in Figure 26 and Figure 27. As with a niche retail deli, growth inhibitor impact was overwhelming. Temperature control was even more effective for retail delis without any niches than for niche retail delis. Simply maintaining case temperatures at less than 5°C (41°F) resulted in a 16% reduction in the predicted risk. For a retail deli without any niches, the only way for external bacteria to enter the deli area is through the incoming RTE product at low concentrations. Preventing *L. monocytogenes* from growing becomes more important. In the niche retail deli, even when growth was completely controlled, new *L. monocytogenes* regularly entered because of the niches.

A comparison of the relative effectiveness of the mitigation strategies for a retail deli without any niches and a retail deli with multiple niches is shown in Figure 28. The growth inhibitor options have been removed for scaling reasons. A 1:1 line (dashed) and a regression line (solid) have been added for reference. A linear regression is not expected. The predicted risks from a retail deli with multiple niches are logically higher; all the points but one fall below the 1:1 line. The degree to which they fall below this line is based on the arbitrary assumption of a frequency of contamination from a niche at 1 week with a mean transfer of 100 cfu. Different niche loadings would have moved the points closer or farther from the 1:1 line, as evaluated in the sensitivity analysis of Section 7.2.1. What this graph illustrates is which mitigations perform significantly better or worse for the different retail deli types.

For example, preslicing falls far above the regression line. Pre-slicing in a retail deli without any niches is a relatively worse mitigation than in a niche-contaminated retail deli. Conversely, the three temperature control options all fall far below the regression line. Temperature control is a relatively better mitigation for retail delis without any niches than for niche-contaminated retail delis. The lack of sanitation impacts a niche contaminated retail deli more than a retail deli without any niches.

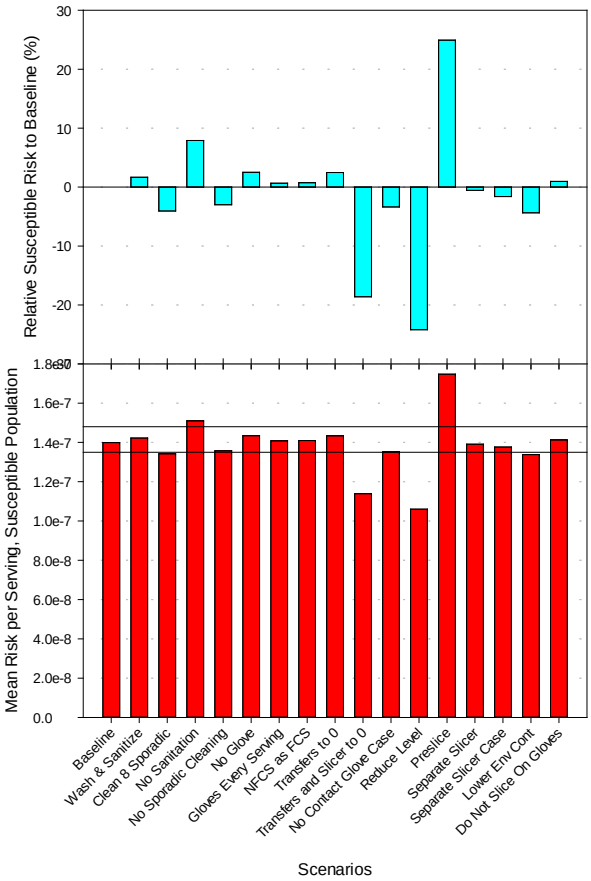



**Figure 24: Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for sanitation mitigations in a retail deli without any niches**

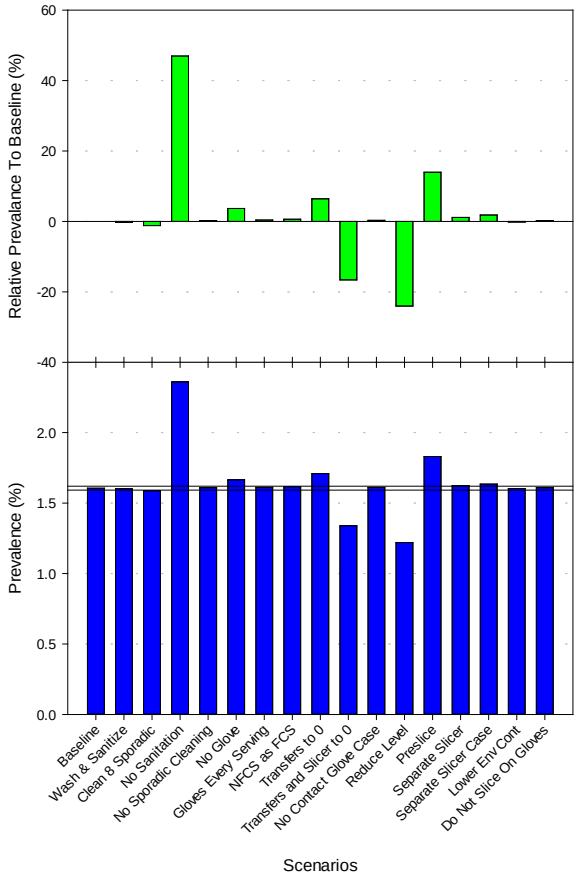



**Figure 25: Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for sanitation mitigations in a retail deli without any niches**

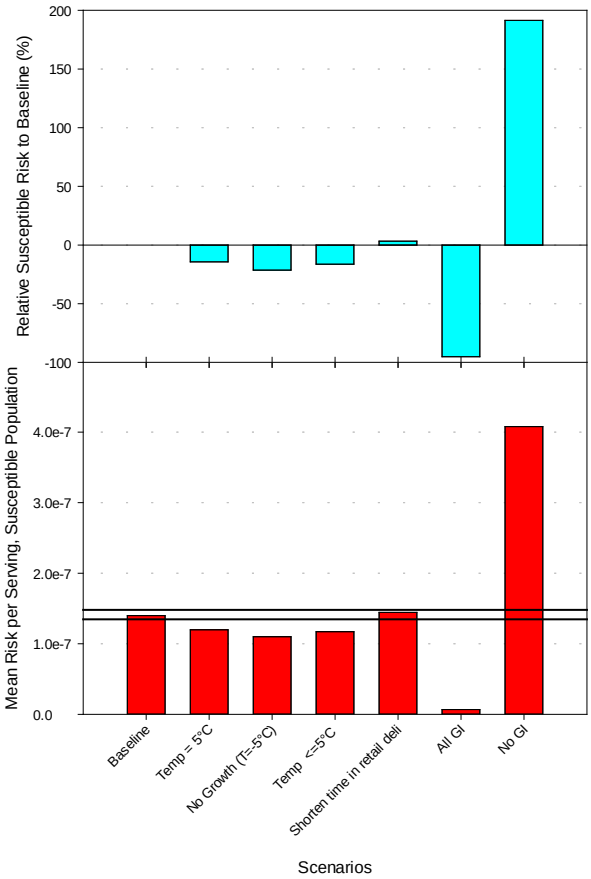



**Figure 26: Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for growth mitigations in a retail deli without any niches**

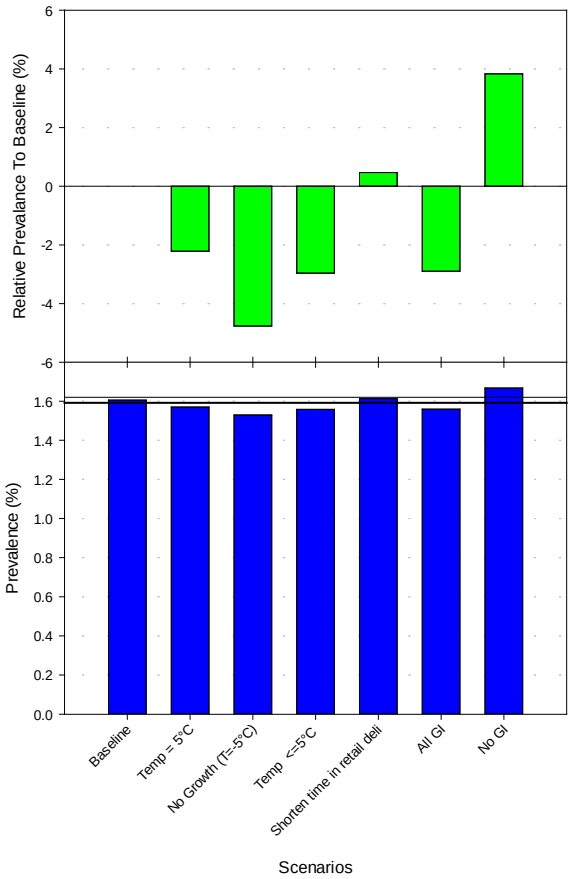



**Figure 27: Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products in a retail deli without any niches**

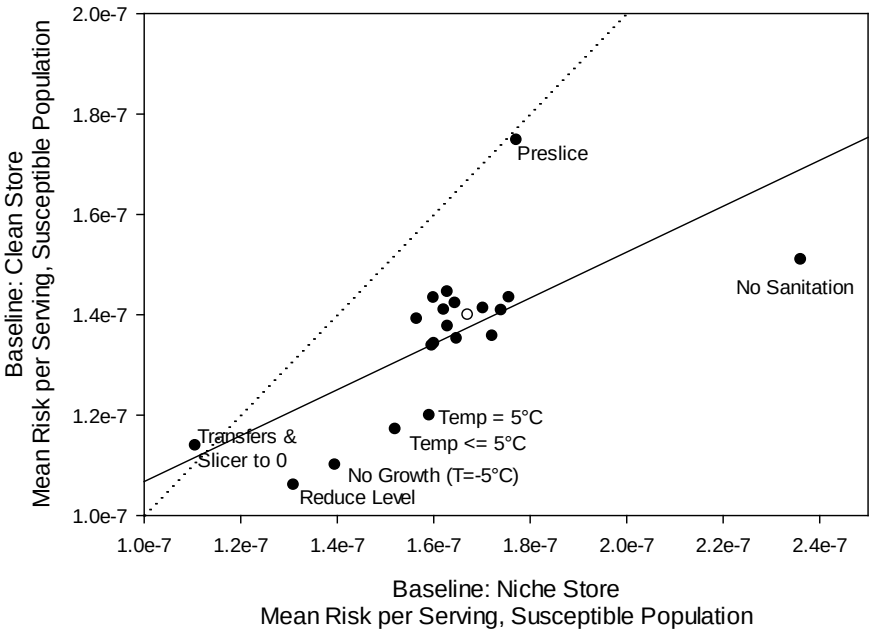



**Figure 28: Risk comparisons between niche retail deli and retail deli without any niches**

*Baseline Condition: highly contaminated incoming RTE product that supports growth*

For these scenarios, the incoming growth-supporting RTE product had the mean incoming *L. monocytogenes* concentration increased from -9.2 $\log_{10}$ cfu/g to -5 $\log_{10}$ cfu/g (i.e., over a four order of magnitude increase). This level of contamination is fairly high. It leads to a probability for a 2,270 g chub to be positive (≥1 cfu in the chub) of 32%, and a probability for this chub to have an average concentration ≥100 cfu/g of 0.83% (Table 13). The predicted risks include the risk linked to the incoming contaminated RTE product, (i.e., the contaminated RTE product was sold and consumed) and these sales were included in the risk calculation. A different approach to contaminated RTE product was taken during the sensitivity analysis of Section 7.2.1, where sales from the contaminated RTE product were not recorded.

Sanitation mitigations are shown in Figure 29 and Figure 30, while growth mitigations are shown in Figure 31 and Figure 32. In this baseline, only preslicing significantly increased the predicted risk (50%). Removing all cross contamination had a slight beneficial effect (10% reduction). None of the other mitigations were notably different from the baseline.

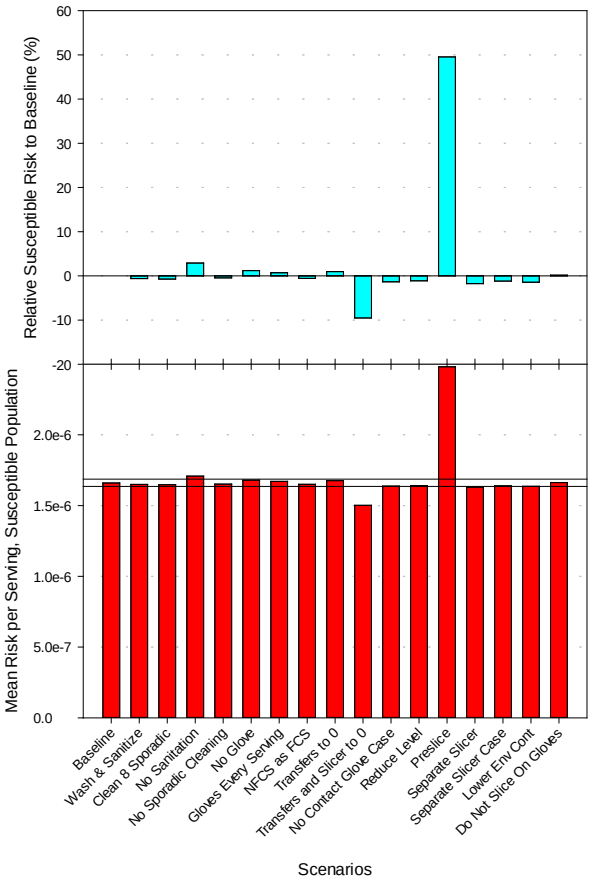



**Figure 29: Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for sanitation mitigations for retail delis with an incoming contaminated RTE product that supports growth**

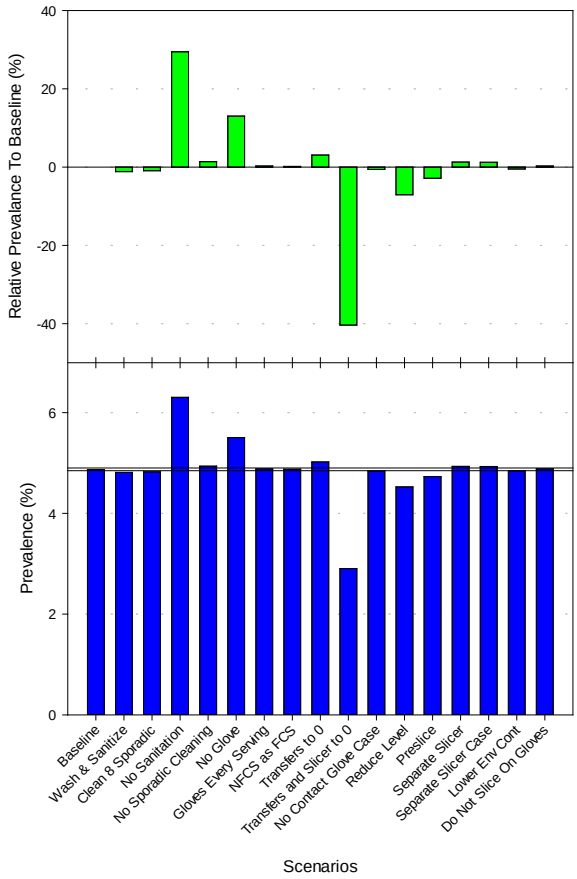



**Figure 30: Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for retail delis with an incoming contaminated RTE product that supports growth**

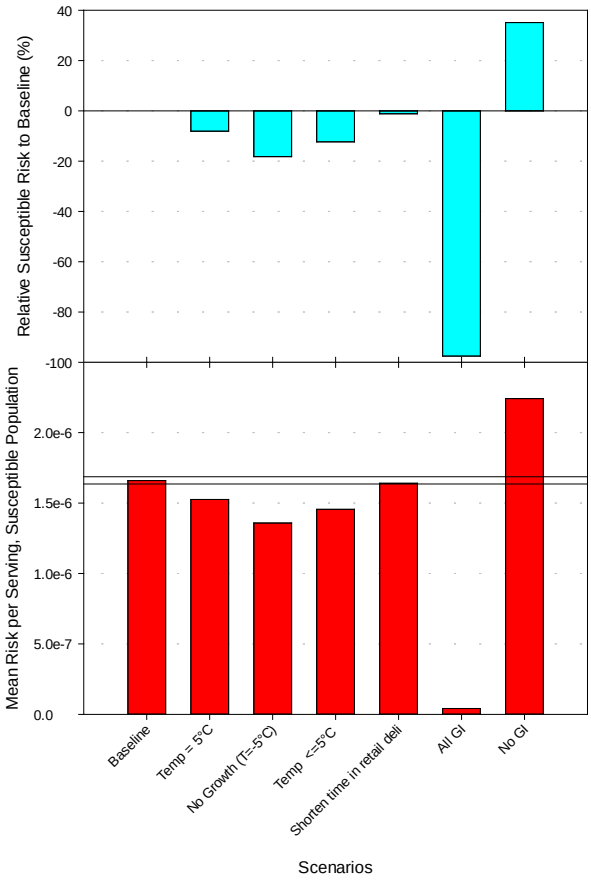



**Figure 31: Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for retail delis with an incoming contaminated RTE product that supports growth**

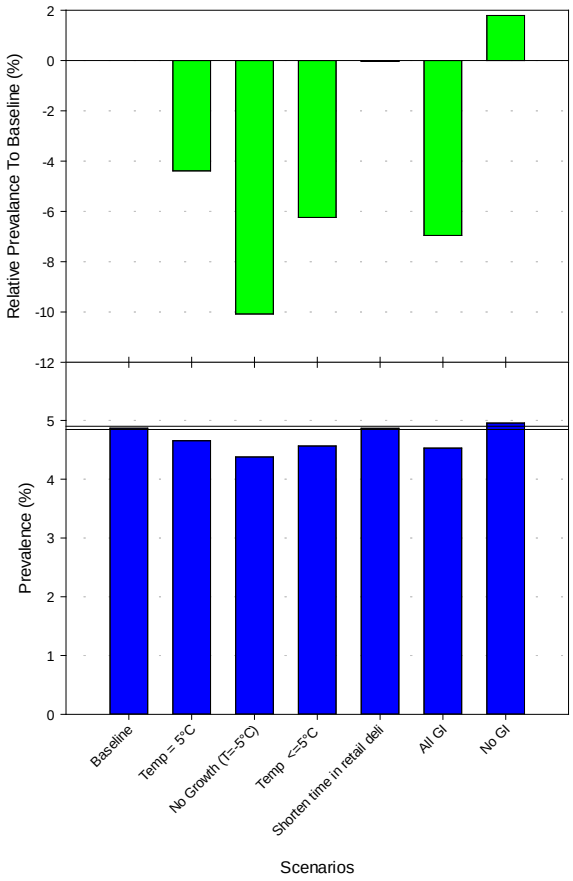



**Figure 32: Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for retail delis with an incoming contaminated RTE product that supports growth**

In this situation, the prevalences increase with no sanitation, even though there is little corresponding change in the predicted risk.

Growth mitigations showed more promise. As with all of the other retail deli types, use of growth inhibitors dominated the responses, and growth inhibitors for all RTE products virtually removed any risk. Controlling the case temperature to ≤5°C (41°F) resulted in a 12% reduction.

The risk comparison to a niche retail deli for different mitigations is shown in Figure 33. The growth inhibitor scenarios were not included on the graph to allow the risk scale to focus on the remaining

scenarios. The 1:1 line is not included because the scales are so different. Temperature controls are more effective in the retail delis which have an incoming RTE food that support growth than for retail delis with multiple niches. Preslicing is correspondingly worse for retail delis that have an incoming RTE food that support growth.

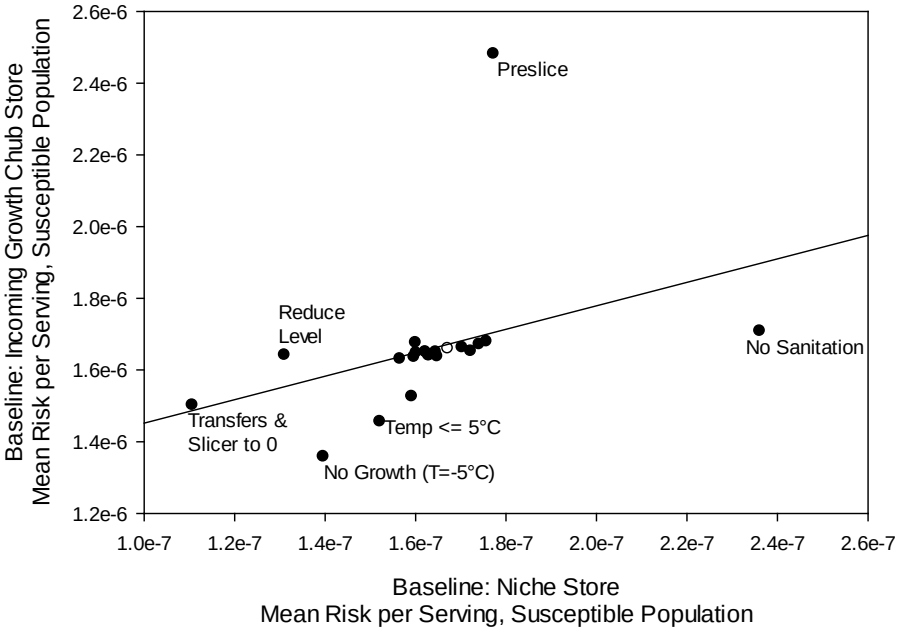



**Figure 33: Risk comparison for niche retail deli versus retail deli with incoming RTE product that supports growth**

It appears that the incoming levels of *L. monocytogenes* in the contaminated RTE product for this baseline are relatively high and represent a higher overall loading than the niche retail deli. In this case, preslicing of the contaminated RTE product actually makes the situation worse. Controlling the growth in the relatively highly contaminated RTE product is effective, because the model does not include growth at FCS or NFCS. Therefore, while a niche contaminates an associated site, growth does not occur at the site.

*Baseline Condition: highly contaminated incoming RTE product that does not support growth*

As with the previous scenario, a retail deli with a highly contaminated incoming RTE product is modeled. In this case, the product does not support growth. As before, the mean *L. monocytogenes* in the incoming RTE product is increased by more than four orders of magnitude from -9.2 $\log_{10}$ cfu/g to -5 $\log_{10}$ cfu/g.

Sanitation mitigations are presented in Figure 34 and Figure 35; growth mitigations are shown in Figure 36 and Figure 37. The theoretical "no cross contamination" scenario (Transfers and Slicer to 0) in the deli is quite effective (61 % reduction). If cross contamination is completely prevented, the high bacteria concentrations in the contaminated RTE product cannot spread to other RTE products, notably to RTE products that support growth. For this situation, preslicing also reduces the predicted risk (34 % reduction). As expected, the theoretical "no sanitation" scenario increases the predicted risk (24% increase). In our setting, the "Separate Slicer" scenario implies that deli meat products that support growth are sliced on a specific slicer and all other products are sliced on the other slicer. In this baseline, this scenario leads to a higher number of potentially cross contaminated RTE products. As a consequence, separate slicers for deli meat that support growth (with or without separate cases) increase the predicted risk by 23% in this baseline. More specific settings could be tested in future runs of this model.

Growth inhibitors are still critically important. For an incoming contaminated RTE product that does not support growth, temperature control is significantly different from the baseline, although slightly. Controlling the case temperature to ≤5°C (41°F) resulted in an 8% reduction. Because the contaminated RTE product does not support growth at any temperature, temperature control only affects the other RTE products.

The risk comparisons between retail delis with multiple niches and retail delis with incoming contaminated non-growth RTE product is shown in Figure 38. The points are above the 1:1 reference line indicating higher predicted risk for the incoming contaminated chubs baseline compared to the baseline with multiple niches. "No cross contamination," "preslicing," and "no sanitation" scenarios lead to lower risks relatively to the niche retail deli. Separate slicers lead to relatively higher risks.

A comparison between the conditions with increased contamination in a growth versus non-growth RTE product is shown in Figure 39. Both incoming contaminated RTE products have the same mean *L. monocytogenes* levels (increased from -9.2 to -5 $\log_{10}$ cfu/g). The non-growth RTE product actually has

higher sales level, but the predicted risks from the growth-permitting RTE product are always substantially higher. The 1:1 line cannot be shown because of the difference in scale. Having “no cross contamination” while instituting effective temperature controls appears to reduce risk more for RTE product that supports growth than for RTE products that do not support growth. Growth, especially when the RTE product is heavily contaminated, is a major source of new bacteria within the retail environment. Temperature control to reduce or prevent growth reduces the predicted risk when the contaminated RTE product supports growth. Similarly preventing cross contamination from the growth chubs, particularly as growth increases the concentrations further, also reduces the risk well. On the other hand, preslicing RTE foods increases the predicted risk significantly more when foods support the growth of *L. monocytogenes*.

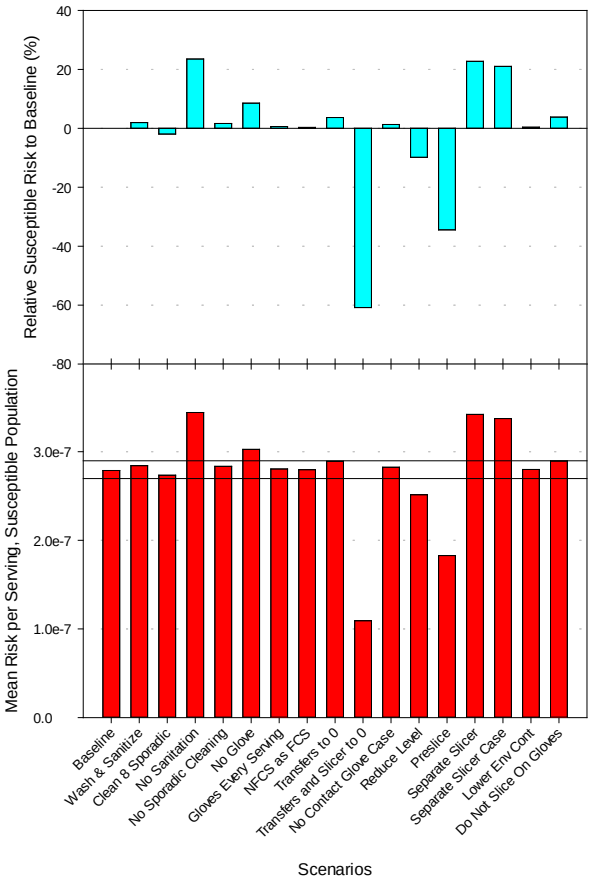



**Figure 34: Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for sanitation mitigations for retail delis with an incoming contaminated RTE product that does not support growth**

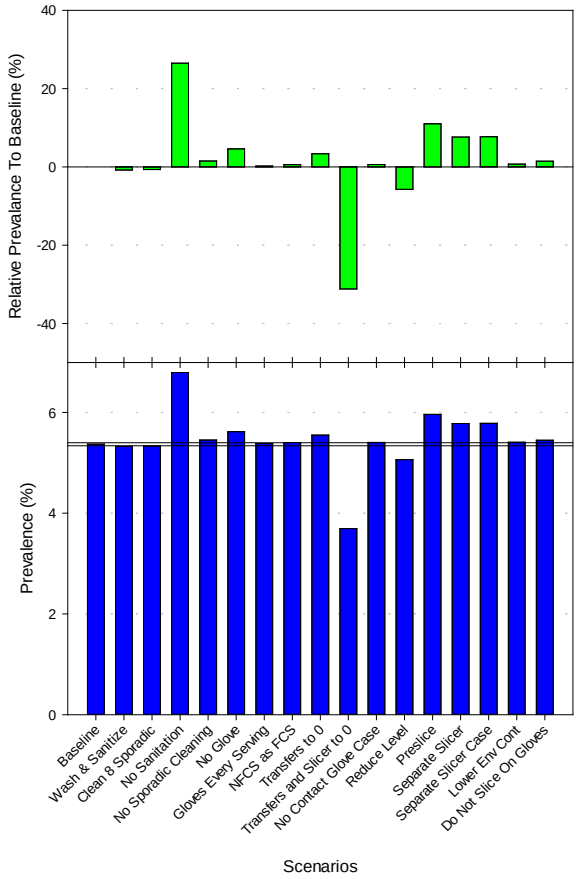



**Figure 35: Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for sanitation mitigations for retail delis with an incoming contaminated RTE product that does not support growth**

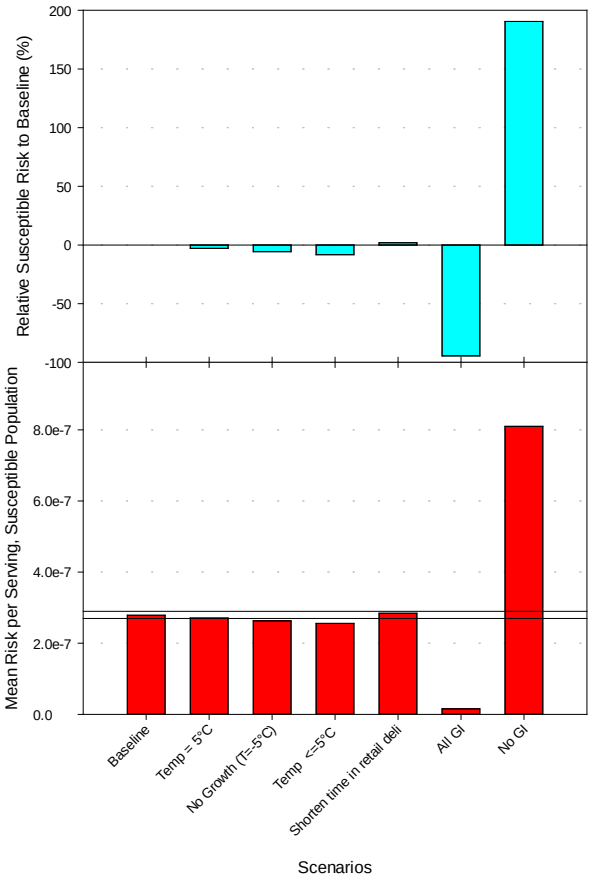



**Figure 36: Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for retail delis with an incoming contaminated RTE product that does not support growth**

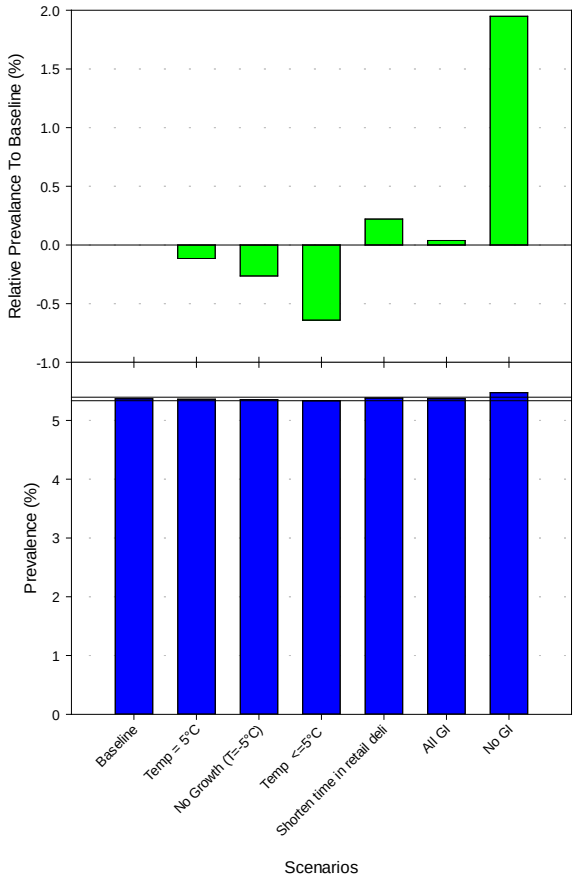



**Figure 37: Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for retail delis with an incoming contaminated RTE product that does not support growth**

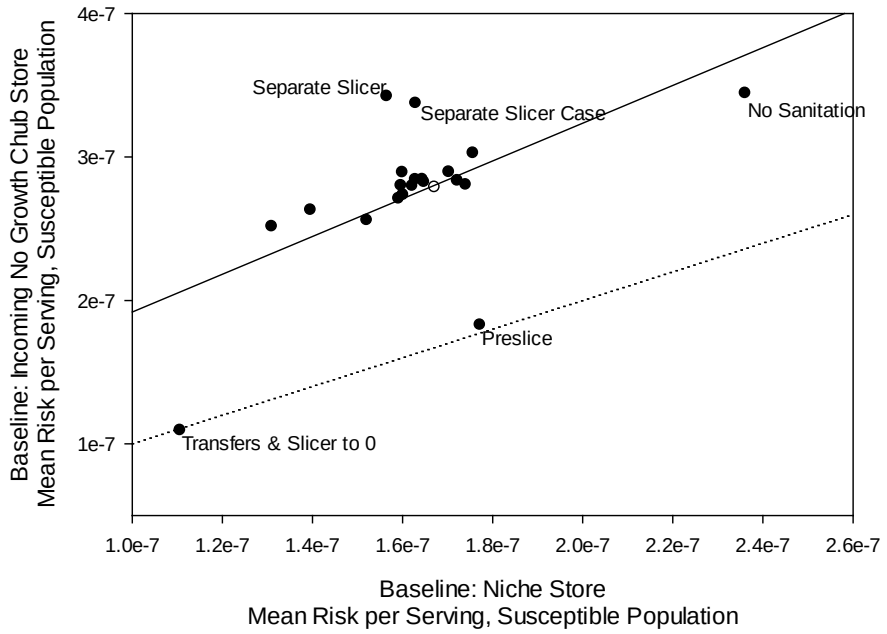



**Figure 38: Risk comparison for niche retail deli versus a retail deli with incoming product that does not support growth**

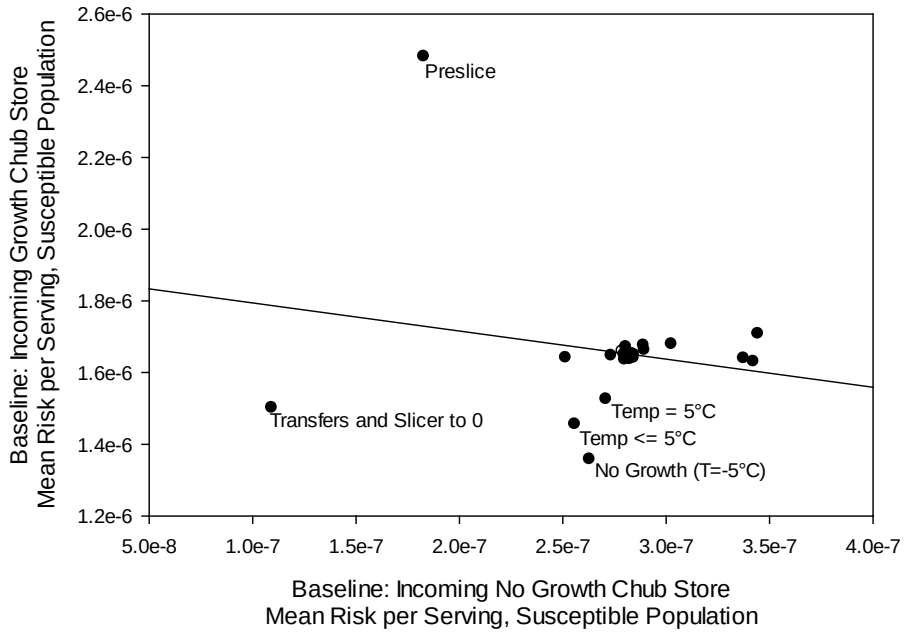



**Figure 39: Risk comparison for niche retail deli versus retail deli with incoming RTE product that does not support growth versus one that does support growth**

*Baseline Condition: No niche with required temperature control*

The mitigations for a retail deli without any niches that maintains its deli case at ≤5°C (41°F) are shown in Figure 40 through Figure 43. As expected, the absolute magnitudes of the predicted risks are lower than even a retail deli without any niches baseline. "No sanitation" and "preslicing" increase the predicted risk by 12% and 19% respectively. Preventing all retail cross contamination and reducing the incoming *L. monocytogenes* level reduce the estimated risk by 19% and 22% respectively. Growth inhibitors are still extremely effective.

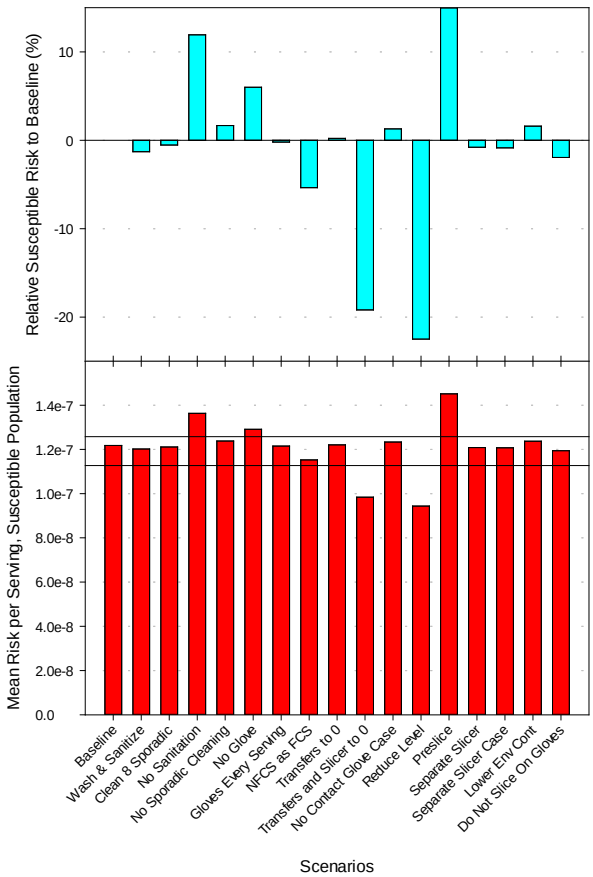



**Figure 40. Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for sanitation mitigations for retail deli with temperature control.**

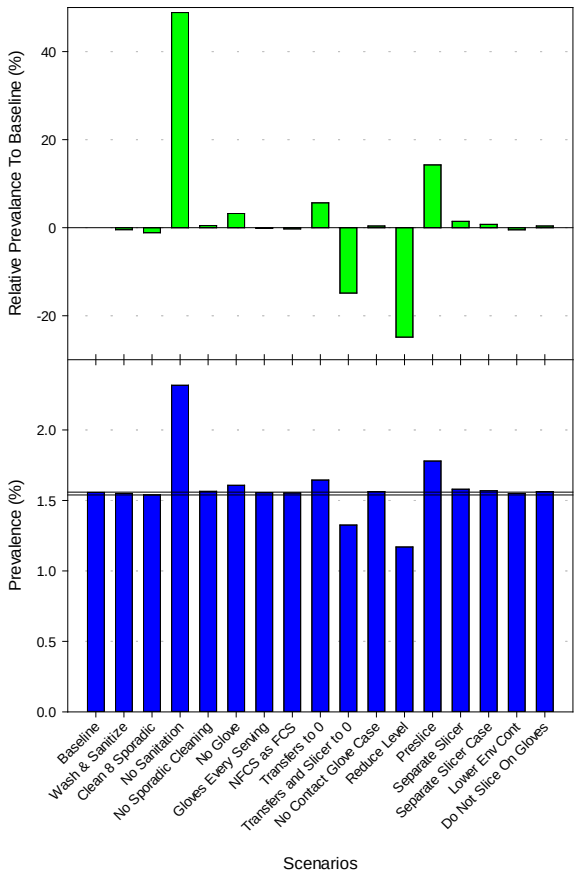



**Figure 41. Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for sanitation mitigations for retail deli with temperature control.**

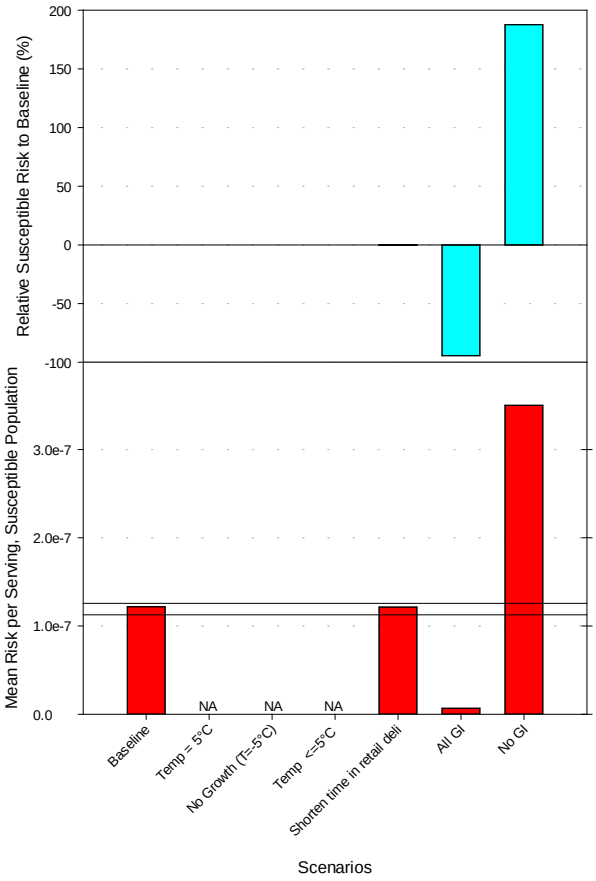



**Figure 42. Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for retail deli with temperature control.**

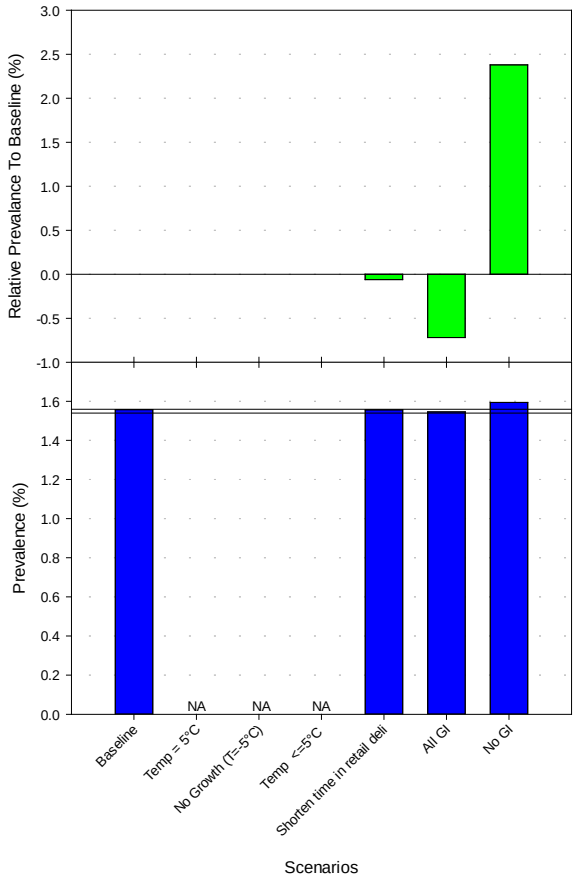



**Figure 43. Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for retail deli with temperature control.**

*Baseline retail deli with multiple niches and temperature control*

Results for retail delis with multiple niches but temperature control of the deli case at ≤5°C (41°F) are provided in Figure 44 to Figure 47. Lack of any sanitation increases the predicted risk by 50%; eliminating cross contamination and reducing incoming *L. monocytogenes* levels reduces the predicted risk by 30% and 16% respectively. Growth inhibitors remain extremely effective.

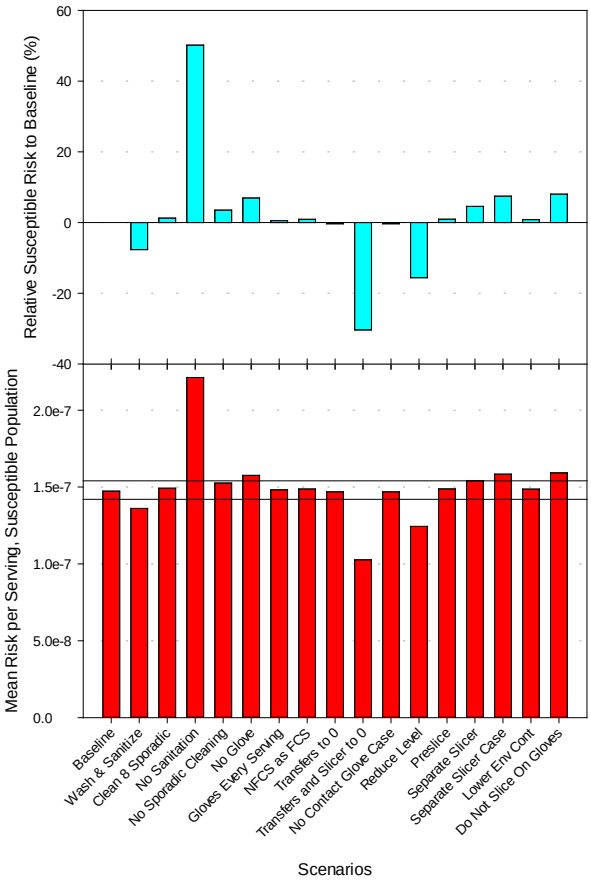



**Figure 44. Effect of various sanitation mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for sanitation mitigations for retail deli with multiple niches and with temperature control.**

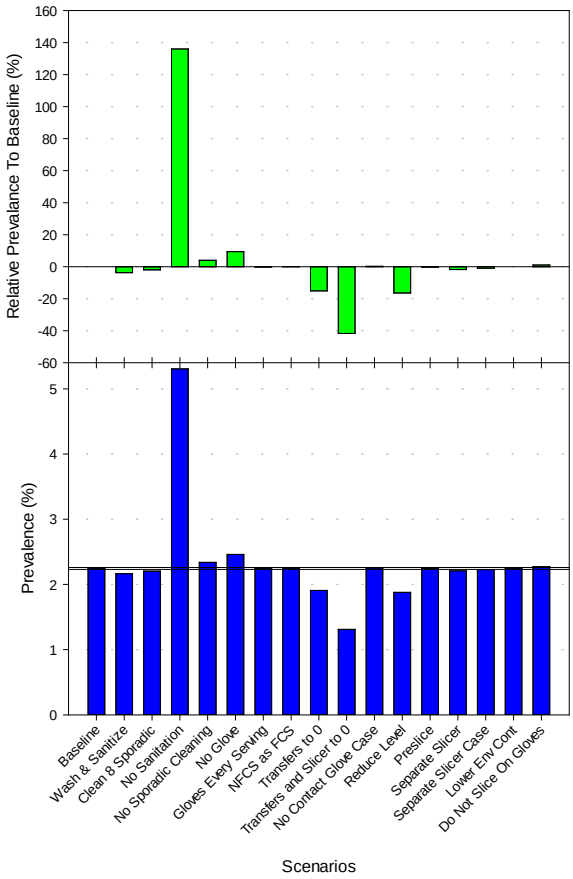



**Figure 45. Effect of various sanitation mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for sanitation mitigations for retail deli with multiple niches and with temperature control.**

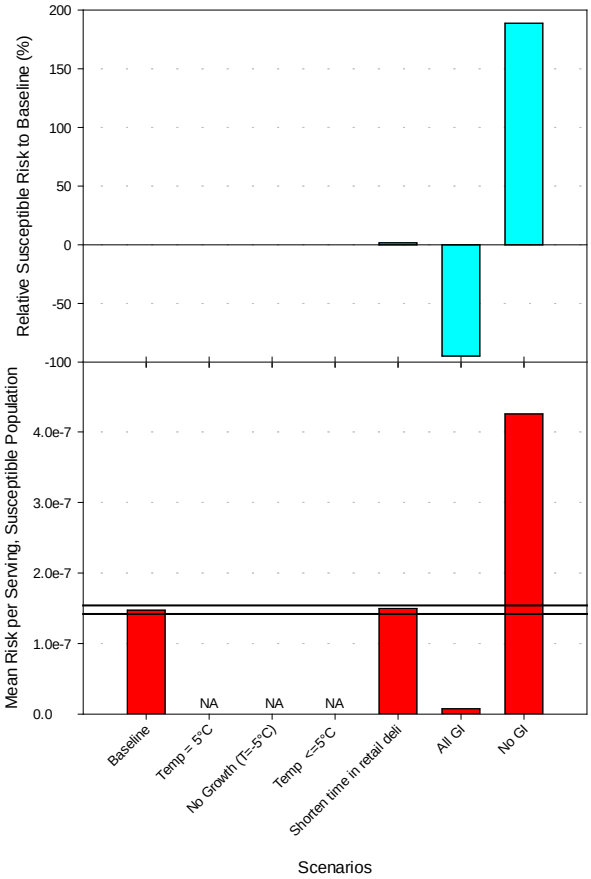



**Figure 46. Effect of various growth mitigation scenarios on the mean risk per serving and relative risk in the susceptible population for retail deli with temperature control.**

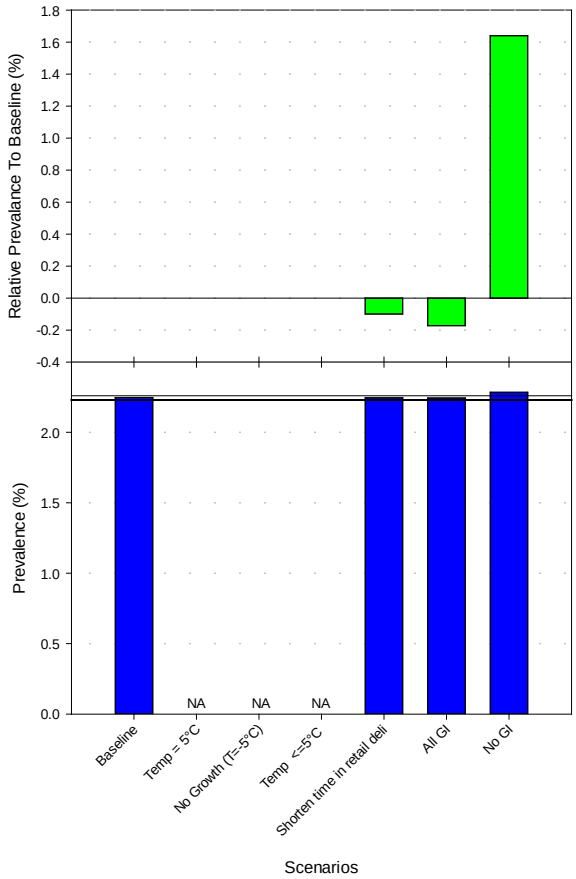



**Figure 47. Effect of various growth mitigation scenarios on the prevalence and relative prevalence of *L. monocytogenes* contaminated RTE products for retail deli with temperature control.**

## *7.3. Responses to risk management questions*

The relative risk to the susceptible population associated with an alternative scenario as compared to the risk calculated for a baseline condition was evaluated within each baseline. The scenarios were developed according to risk management questions as provided in Section 3. Figure 48 through Figure 60 illustrates the results for the various alternative practices across baselines. Remember, the absolute values for the predicted risk change drastically for each baseline. With the exception of the growth inhibitor analysis, all the relative risks in the graphs are scaled the same to make comparison between the predicted risks associated with different risk management scenarios more apparent. The baseline conditions and the mitigation scenarios are described in 7.1.1 and 7.2.2 respectively.

### 7.3.1 What would be the impact on the prevalence of *L. monocytogenes* in RTE products sold in retail delis and on the corresponding mean risk of invasive listeriosis per serving of practicing more frequent or more extensive cleaning procedures for food contact surfaces and/or non-food contact surfaces than is currently specified in the 2009 FDA Food Code 2009?

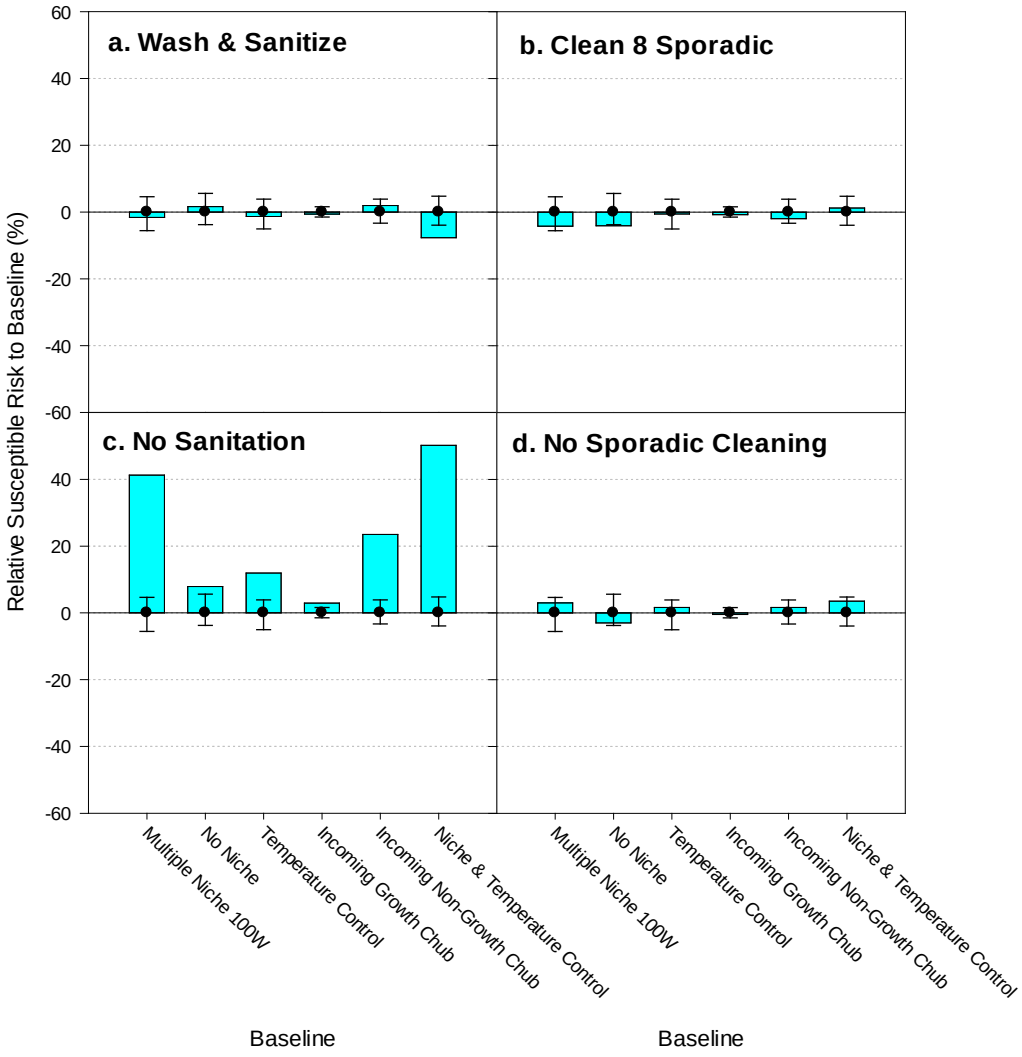



**Figure 48: Relative risk comparison for sanitation options**

**Wash & Sanitize**: increase the effectiveness of cleaning from simply washing to washing and sanitizing (i.e., from an average $\log_{10}$ reduction issued from a Pert(-1.5, -0.5, 0) to a Pert(-8, -6, -1.5)); **Clean 8 Sporadic**: increase the number of sites sporadically cleaned from 4 to 8; **No Sanitation**: do not conduct any wiping, washing, or sanitizing; **No Sporadic Cleaning**: only clean FCS to the minimum required by the 2009 FDA Food Code, but do not conduct the additional sporadic cleanings (as was observed by Lubran *et al.* [28]).

The relative risks for changes in sanitation are shown in Figure 48. Figure 48c clearly indicates that failing to clean and sanitize all together results in a significant increase in the predicted risk of listeriosis. Nevertheless, it seems that modifying any of the single sanitation-related practices individually (i.e., cleaning more effectively (Figure 48a). Increasing the number of sporadic cleaning sites (Figure 48b) and not conducting any sporadic cleaning (Figure 48d) had little impact on the relative risk in each retail deli condition studied. Specific scenario for the cleaning frequency and disinfection of the slicer could be developed in future version of this model.

### 7.3.2 What is the impact of increasing the use of single-service gloves in the retail environment?

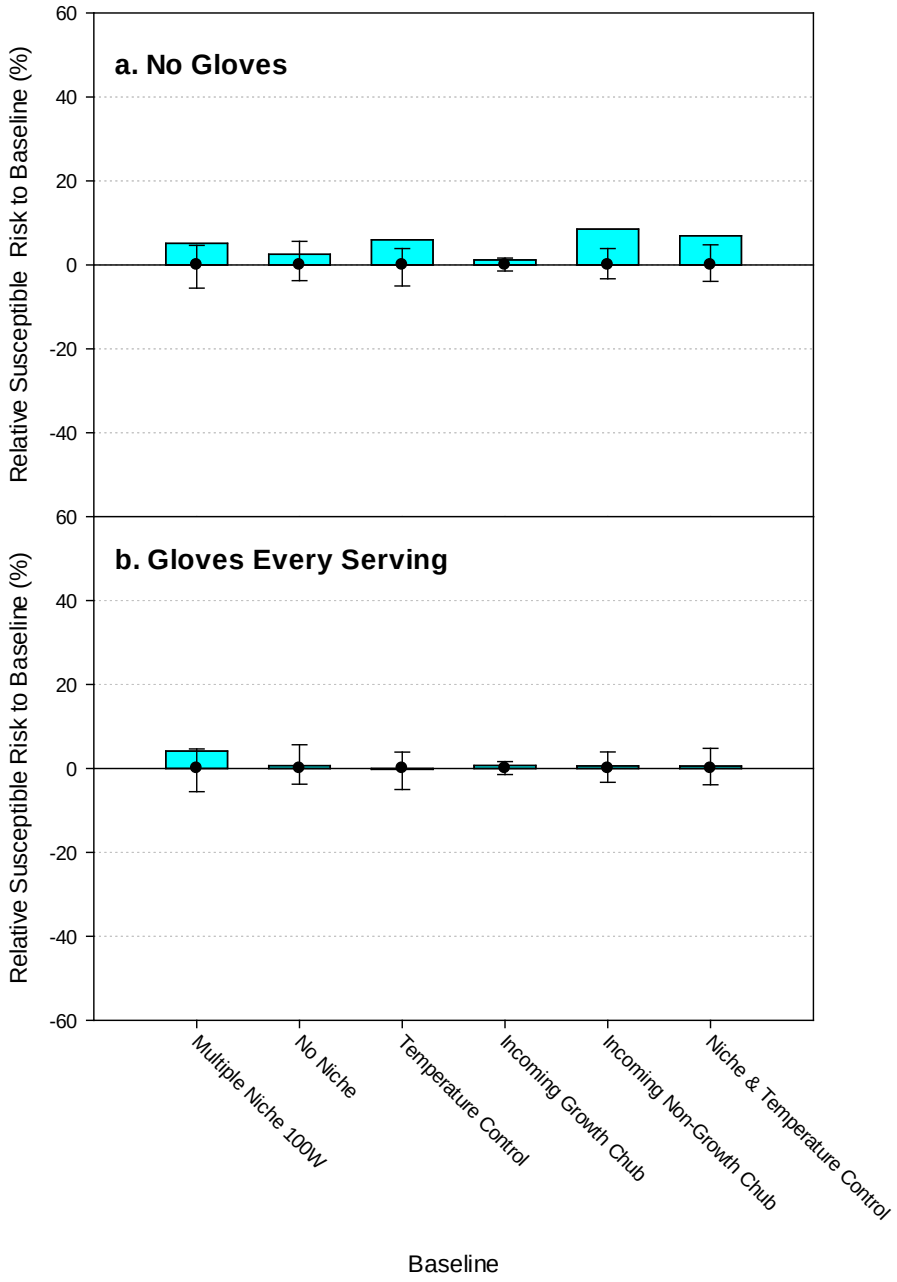



**Figure 49: Relative risk comparison for glove use.**

**No Glove**: do not use gloves when serving customers; **Gloves Every Serving**: change gloves for every serving.

The lack of glove use consistently increases the predicted risk across all retail deli types (Figure 49a) often at statistically significant levels. Thus glove use is recommended to aid in *L. monocytogenes* control

and would be expected to be critical for other foodborne pathogens such as norovirus or *Shigella* [123]. Changing gloves for every serving did not result in a significant change (Figure 49b), but recall that gloves are changed for approximately 65% of servings in baselines already.

### 7.3.3 What if scale touch pads, refrigerator and deli case handles and other frequently touched non-food contact surfaces were considered food contact surfaces and were therefore required to be cleaned and sanitized at a minimum frequency?

these items were required to be cleaned and sanitized every four hours and, as a result could then be touched by gloved hands without requiring a decontamination action afterwards.

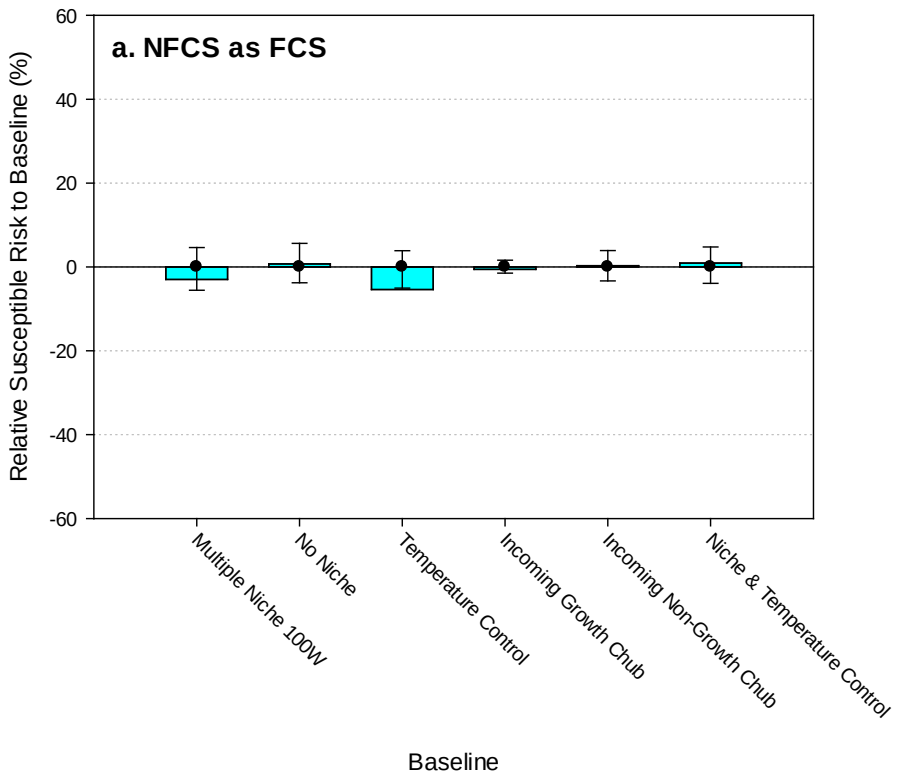



**Figure 50: Relative risk comparison for treating NFCS as FCS**

**NFCS as FCS**: treat NFCS as if they were FCS that must be cleaned every 4 hours according to the FDA Food Code.

Treating NFCS as FCS for cleaning purposes had little impact on the predicted risk. The only retail deli type where the risk reduction was statistically significant was for a retail deli without any niches that

implemented temperature control. In this case, where *L. monocytogenes* levels are low and growth is limited, the additional cleaning might be beneficial relatively to the baseline low risk.

### 7.3.4 What if practices were in place so that no cross contamination occurred in delis?

No additional *L. monocytogenes* added to incoming RTE product.

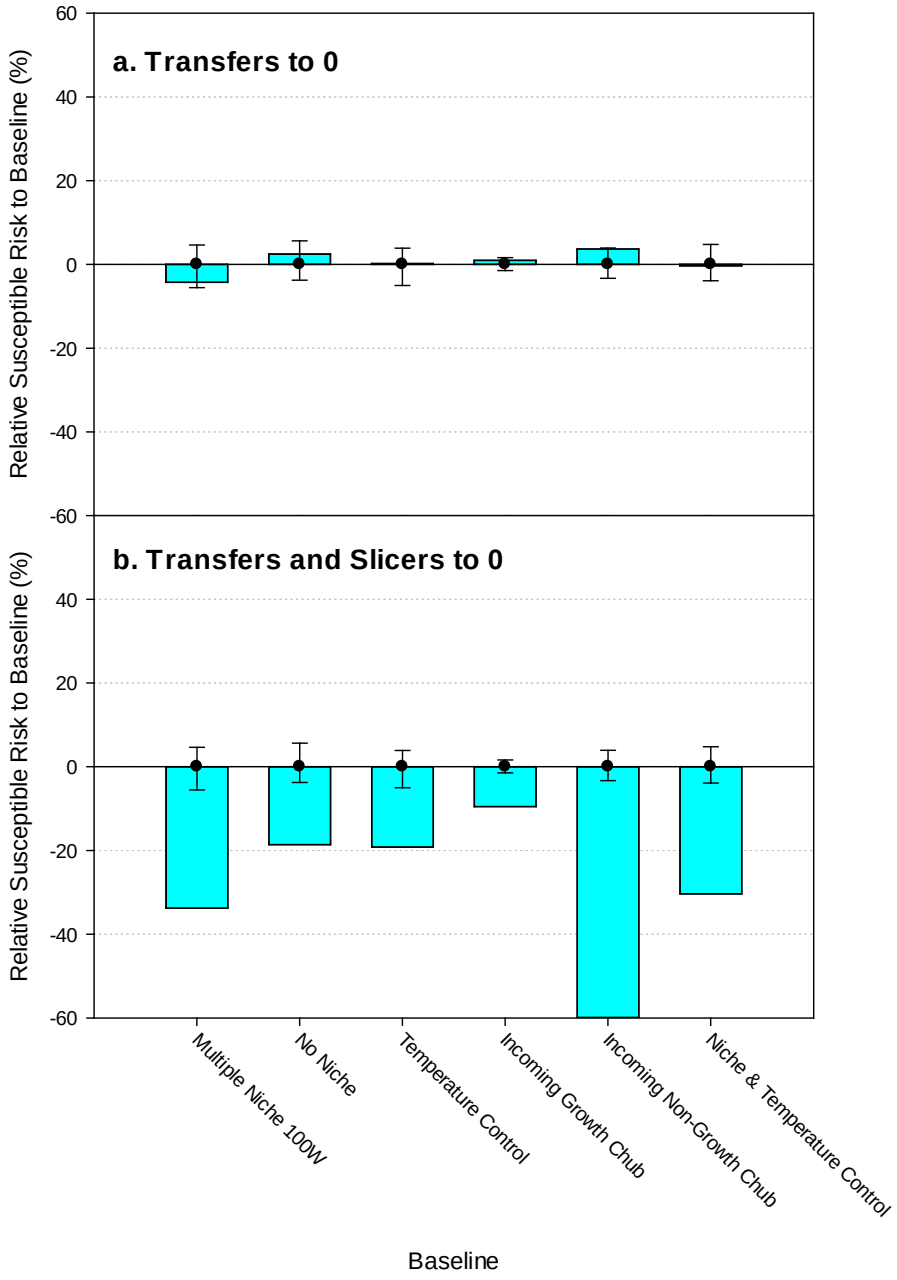



**Figure 51: Relative risk comparison for transfer coefficients**

**Transfers to 0**: set cross contamination transfer coefficients to 0 (i.e., no cross contamination occurs). This setting does not affect the slicer, (i.e., cross contamination can still occur from one sale to the next through the slicer). See the next mitigation; **Transfers and Slicer to 0**: set cross contamination transfer coefficients to 0 (i.e., no cross contamination occurs, for all sites including the slicer).

Setting the transfer coefficients to 0 prevents cross contamination for all sites except the slicer. This approach had no significant impact on the relative risk (Figure 51a). Including the slicer in the sites, however, greatly reduced the predicted risk (Figure 51b) across all retail deli types evaluated. This highlights the importance of the slicer in cross contamination. The importance of the slicer in potential cross contamination has been demonstrated experimentally [see for example 23, 37, 54, 58, 124]. Our results confirm that this element may be of major importance when all cross contamination events are considered in a deli department setting.

### 7.3.5 What if display cases were not touched with gloved or bare hands?

Used tissues or automatic door to open/shut display case to reduce cross contamination.

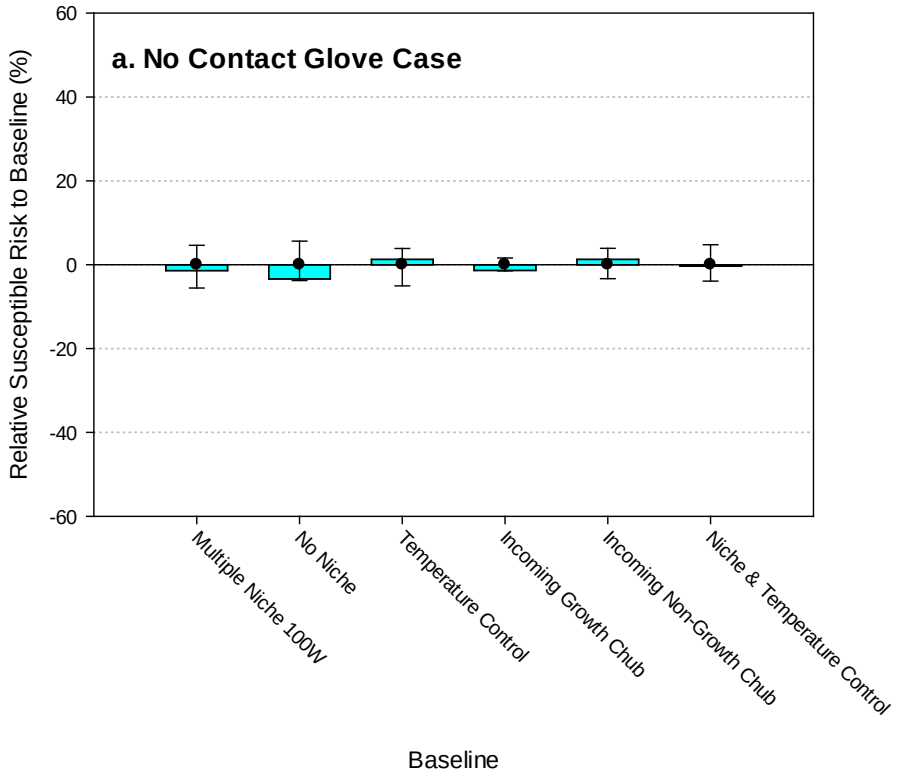



**Figure 52: Relative risk comparison for contact between gloves and case handle**

**No Contact Glove Case**: glove/hands are not used to open the deli case (e.g., if a floor switch is used.)

Preventing contact between the case handle and hand/gloves had no significant impact in any of the baselines studied. Actually, this scenario is a subset of the scenario **Transfers to 0** (cross contamination transfer coefficients to 0 (i.e., no cross contamination occurs)), with one transfer set to 0. This result confirms that, within a baseline, no single cross contamination event has a major impact on the predicted risk, with the exception of the cross contamination within the slicer.

### 7.3.6 What would be the impact if the level/frequency of *L. monocytogenes* contamination is reduced in RTE foods coming into the retail deli?

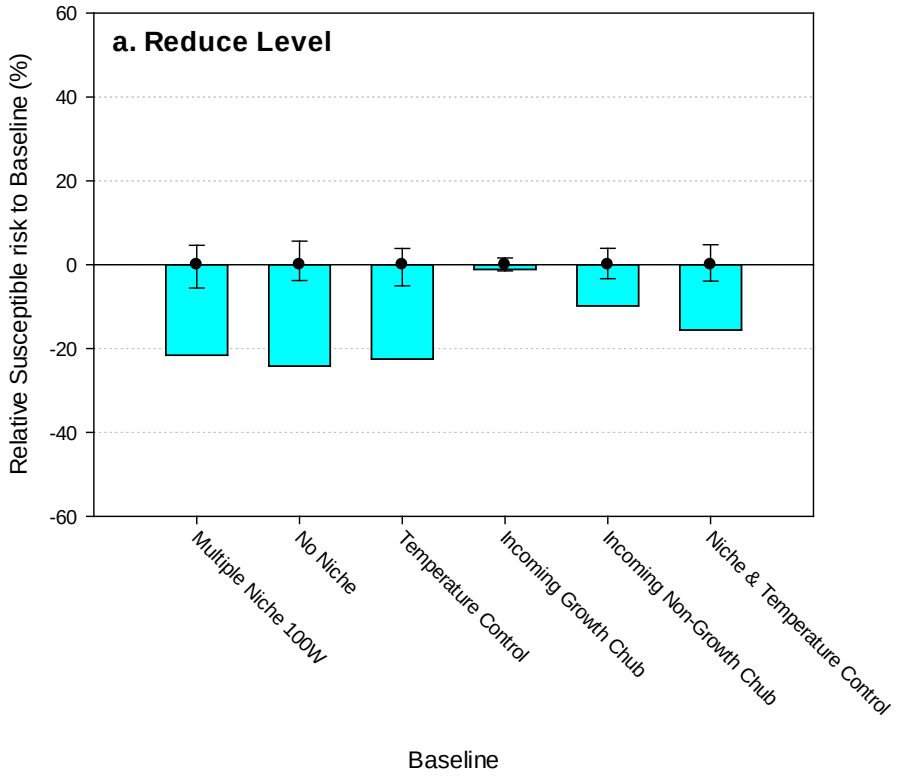



**Figure 53: Relative risk comparison for reducing incoming level**

**Reduce Level**: lower the mean incoming *L. monocytogenes* concentration on all RTE products from a mean of the $\log_{10}$ of -9.228 to a mean of the $\log_{10}$ of -9.529. This leads to an average prevalence for a 2,270 g chub of 2.35% *vs*. 2.97% in the baseline (Section 6.5.2).

Reducing the incoming *L. monocytogenes* concentration significantly reduced the predicted risk. Incoming *L. monocytogenes* represents one of the major routes that the bacteria can come in contact with FCS and cross contaminate in this model. Even in situations where *L. monocytogenes* from the environment are regularly introduced in the deli department, the level of bacteria in incoming RTE product does have an impact on the final relative risk of listeriosis from the consumption of RTE products from the deli department.

### 7.3.7 What would be the impact of "preslicing" all RTE products *vs.* "slicing to order"?

Following the hypothesis that less cross contamination occurs in the morning prior to other cross contamination events.

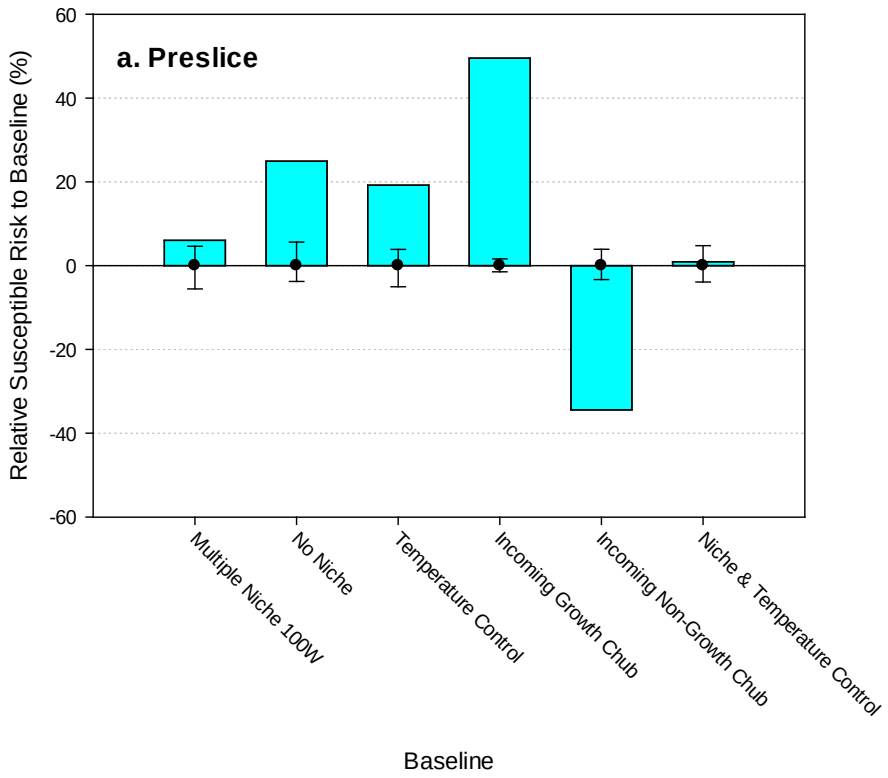



**Figure 54: Relative risk comparison for preslicing**

**Preslice**: preslice all chubs of RTE product in the morning after cleaning. For each RTE product, a quantity of food equals to the median of the daily sales is presliced every morning. When a consumer orders a RTE product, the food worker serves the presliced RTE product, until the presliced quantity is all sold. If needed, additional RTE product is sliced to order. At the end of the day, the remaining presliced RTE product is discarded from consumption.

Preslicing generally increased the predicted risk, often substantially and especially if a contaminated growth supporting chub was present. Based on a deeper study of the model outputs (analysis per serving on a short run, rather than overall statistics - results not shown), it was determined that this is due to a relatively important contamination of the slicer during the preslicing process following one single contaminated chub. A high number of RTE product servings are then cross contaminated, leading to a

higher predicted risk. A retail deli with an incoming contaminated non-growth chub was the only baseline situation where preslicing lead to a significantly lower predicted risk. In this situation, preslicing leads to a distribution of the bacteria to the same category of (non-growth) RTE products rather than to various (growth and non-growth) RTE product if sliced throughout the day. This limits the contamination of the RTE product that supports growth that leads the predicted risk.

### 7.3.8 What would be the potential public health impact of using separate slicers and/or separate counters for RTE products that permit growth of *L. monocytogenes* and for RTE products that do not?

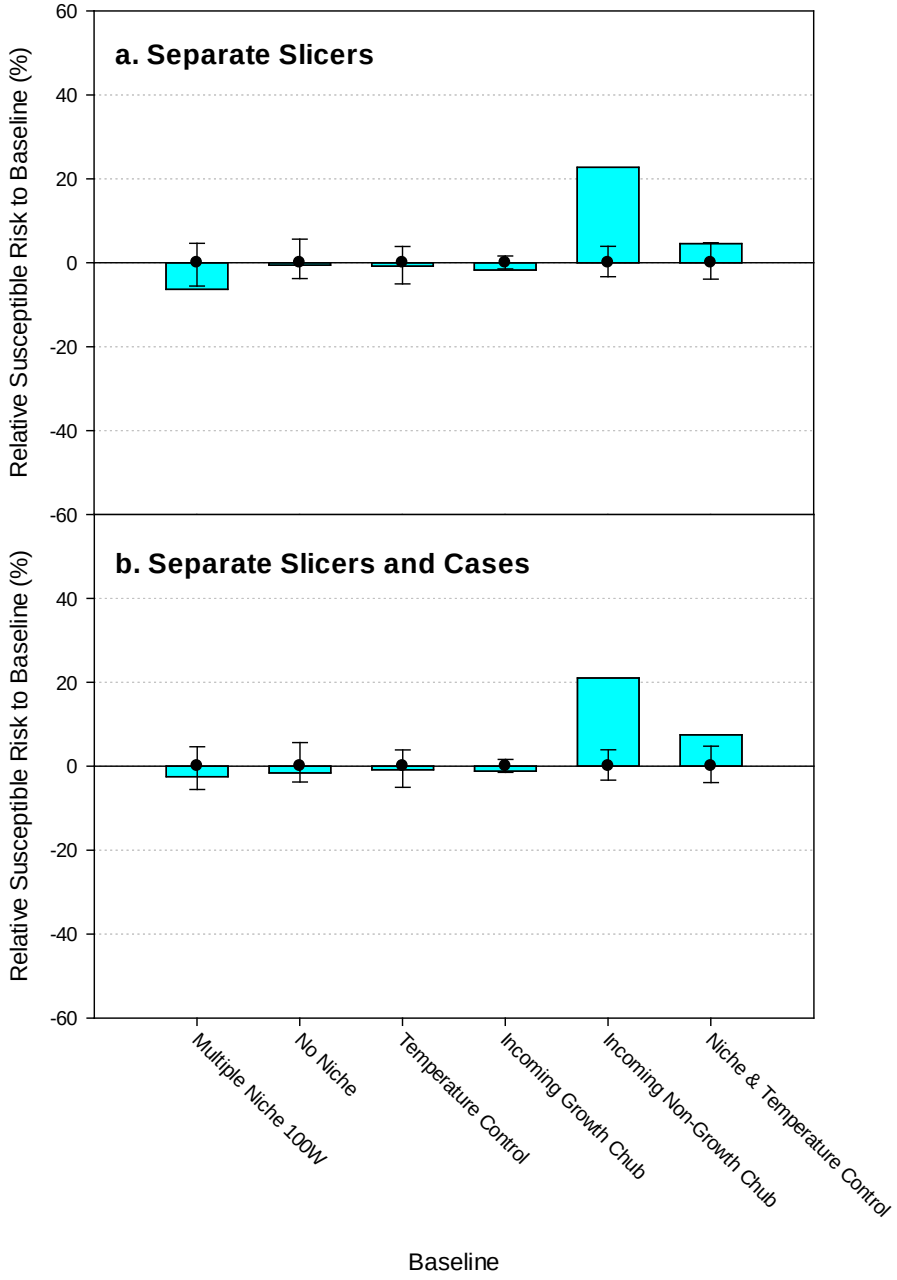



**Figure 55: Relative risk comparison for separate slicers and cases**

**Separate Slicer**: use a separate slicer for RTE products that support growth versus those that do not; **Separate Slicer Case**: use a separate slicer and a separate case for RTE products that support growth versus those that do not.

Figure 55 shows that there was minimal impact on the predicted risk relative to the baseline associated with establishing one slicer for RTE product that supports the growth of *L. monocytogenes* and another for RTE product that does not support the growth of *L. monocytogenes*. The exception was the condition where a contaminated chub did not support the growth of *L. monocytogenes*. Similar impacts on the calculated relative risk were observed when separate slicers were used and the different RTE products were put into separate deli cases. This may be related to the fact that in the baseline matrix of contacts (Section 6.5.1), it was assumed that in larger retail deli with two slicers, one slicer is used only for deli cheese and that the other slicer is used for deli meat and deli cheese. In the separate slicer scenario, since one slicer would be used exclusively for high growth product, the slicer for the contaminated cheese would be used for more products, and, as a consequence, the contaminated cheese would incidentally contaminate more products than in the baseline, including some additional “low growth” product. The resulting risk would be higher. Other matrix of contacts could be tested in the future.

### 7.3.9 What if food workers do not slice RTE products directly onto their gloved hands?

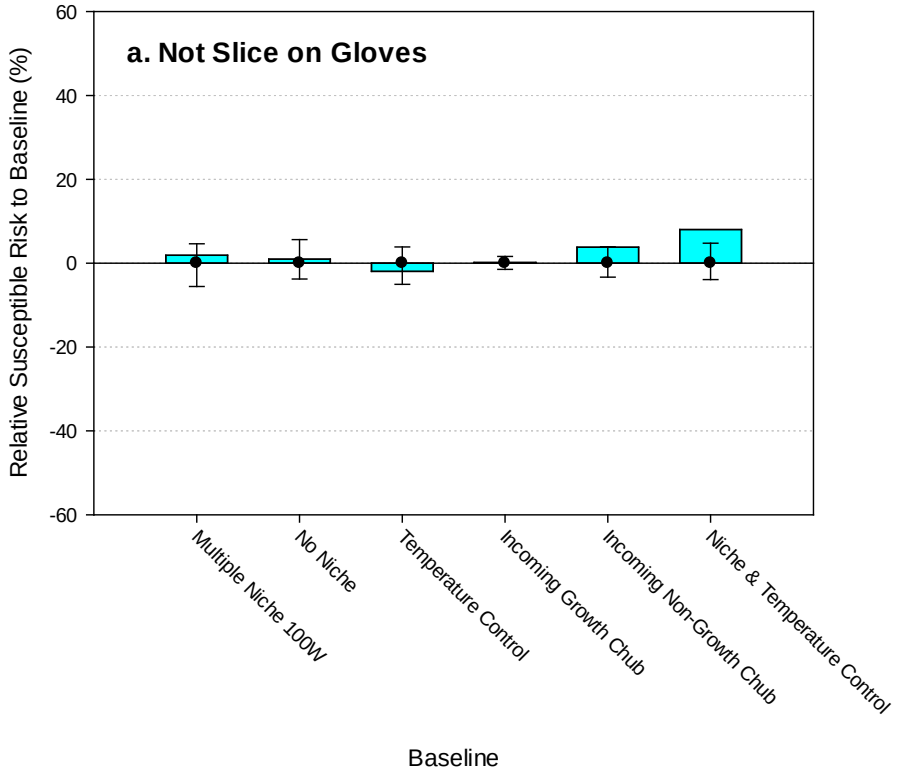



**Figure 56: Relative risk comparison for not slicing onto gloves**

**Do Not Slice Onto Gloves**: the food worker collects the sliced RTE product directly onto a deli tissue rather than slicing it directly onto a gloved hand, which represents the baseline condition..

Figure 56 suggests that slicing RTE product onto deli paper rather than onto gloves had little impact on the relative risk predicted by the model. Slicing onto gloves was a behavior observed during the observational study [28]. The model suggests that eliminating this practice would not play a major role compared to some of the other mitigations directed at preventing cross contamination.

### 7.3.10 What is the impact of *L. monocytogenes* growth in retail delis?

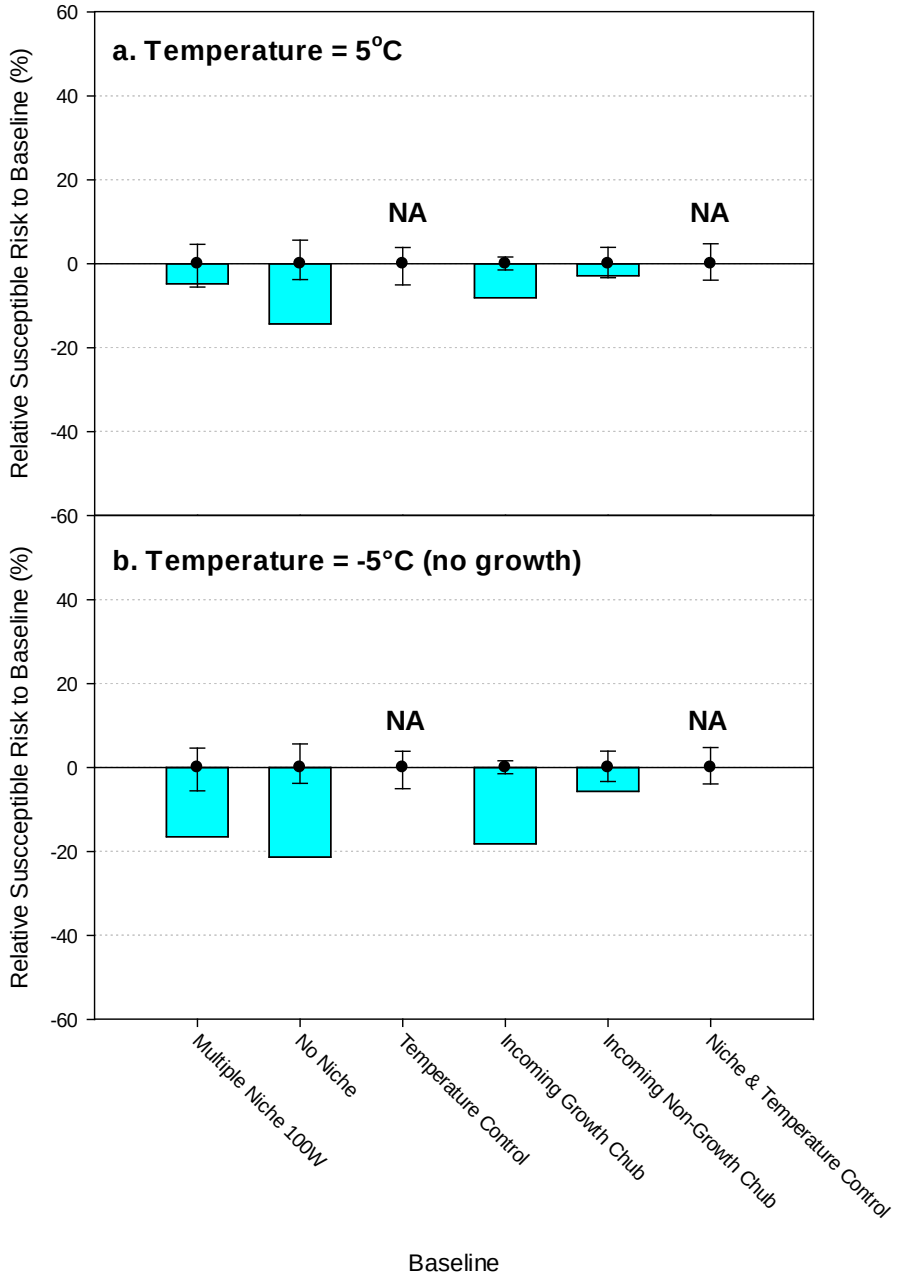



**Figure 57: Relative risk comparison for fixed temperature control**

**Baseline:** Retail deli all RTE product in cases maintained at the actual temperatures observed in Ecosure dataset [19];

**Temp = 5°C:** Retail deli all RTE products in cases consistently maintained at a temperature of 5°C (41°F); **No Growth (T = -5°C)**: Retail deli all RTE products in case consistently maintained at a temperature of -5°C (23°F) (no potential *L. monocytogenes* growth).

Improving temperature controls in display cases to limit growth resulted in a lower predicted relative risk across all retail deli types. Baseline retail delis that included temperature control as part of the baseline are not shown. Note that the Temp = 5ºC (41°F) alternative represents an increase in the temperature for some of the RTE products, compared to the baseline. By reducing temperature of display cases to 5ºC, the overall predicted risk was still reduced. The "no growth" scenario (i.e., deli case temperature set to -5ºC) results in a 20% reduction in predicted risk. This further demonstrates the importance of controlling the growth of *L. monocytogenes* in RTE products, as suggested in previous risk assessments [3, 59].

### 7.3.11 What would be the potential public health impact of complete compliance to the cold holding requirements for certain RTE foods in deli cases (hold at 41°F (5°C) or less)?

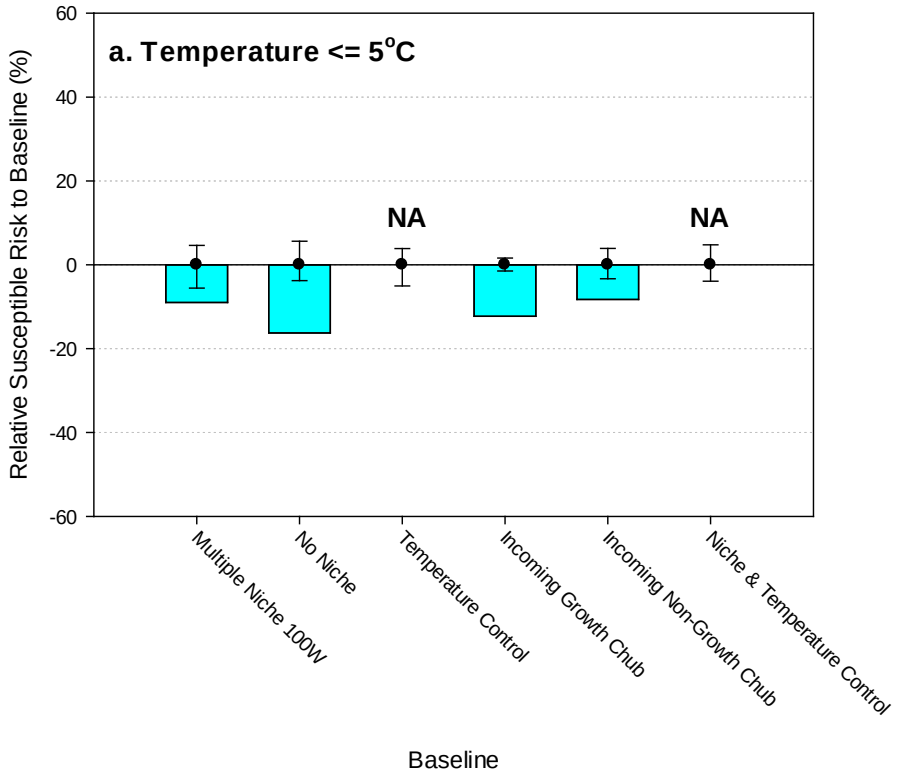



**Figure 58: Relative risk comparison for temperature control**

**Temp <= 5°:** Use the case temperature distribution as observed [19], but remove any temperatures greater than 5°C (41°F). This implies that all retail delis exceeding the FDA Food Code recommendation come into compliance.

Unlike the previous analysis where all retail delis were set to a fixed temperature, this analysis uses the existing temperature distribution but removes those which exceed 5ºC. The model was used to study the effect that full compliance with the 2009 FDA Food Code [27] temperature requirements would have on the predicted risk as compared to what Ecosure data suggests is typical practice. An approximate 10-15% reduction in predicted risk was achieved. The effect was greatest in a retail deli without any niches. The model predictions suggest that a reduction of the risk of listeriosis could be achieved by a better compliance with recommended RTE product storage temperatures in the deli environment. FDA's 2008 Retail Risk Factor Study revealed that in delis the failure to control RTE product holding temperatures and times was the risk factor with the highest "Out of Compliance" percentage. For example, in 60% of the 98 retail delis studied by FDA in 2008, at least one observation was made in which food requiring temperature control was not held at 41ºF or below as specified in the FDA Food Code [18].

### 7.3.12 What would be the potential public health impact of shortening the time a RTE product can be used in retail deli departments?

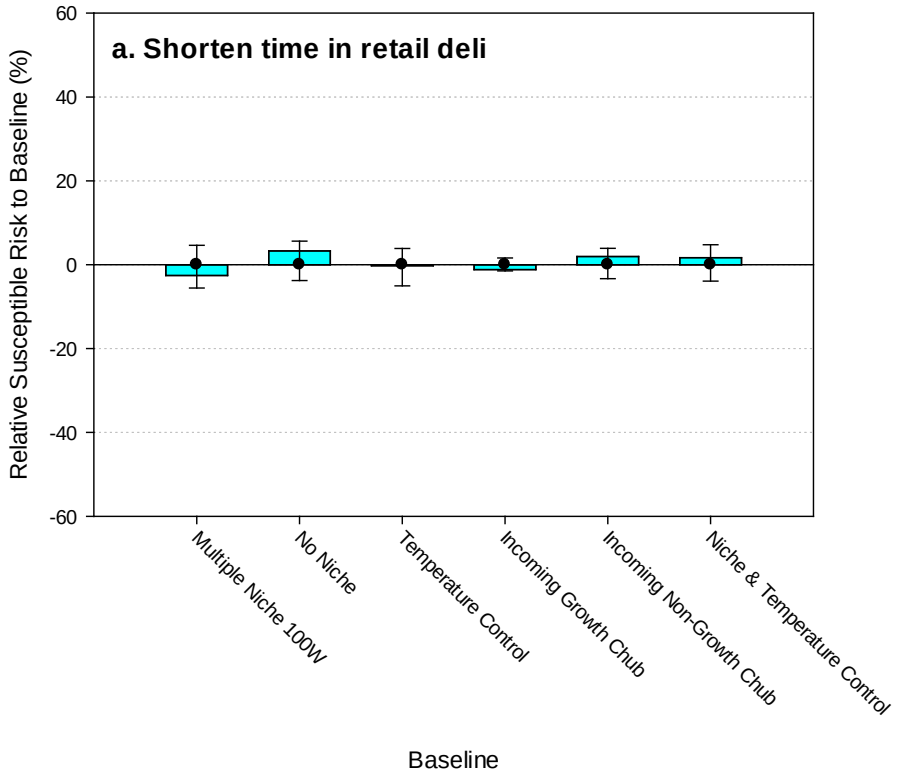



**Figure 59: Relative risk comparison for shortening the time a RTE product can be used in a retail deli department**

**Shorten the time a RTE product can be used**: shorten the length of time RTE product can be held in the retail deli before being sold or disposed from 7 to 4 days.

Figure 59 suggests that shortening, from 7 days to 4 days, the maximum time that a refrigerated RTE product that supports the growth of *L. monocytogenes* is allowed remain on-hand in the retail deli after opening or preparation has a little effect on the predicted risk. Under the current model, the time from when the chub is opened until it is completely sold is generally shorter than the 7-day FDA Food Code requirement. Note that the model does not currently simulate refrigerated storage prior to the chub/deli salad bulk being opened.

### 7.3.13 What would be the potential public health impact if all or none of the RTE products (e.g., deli meat, deli salads, and cheese) coming into the retail deli were formulated with growth inhibitors?

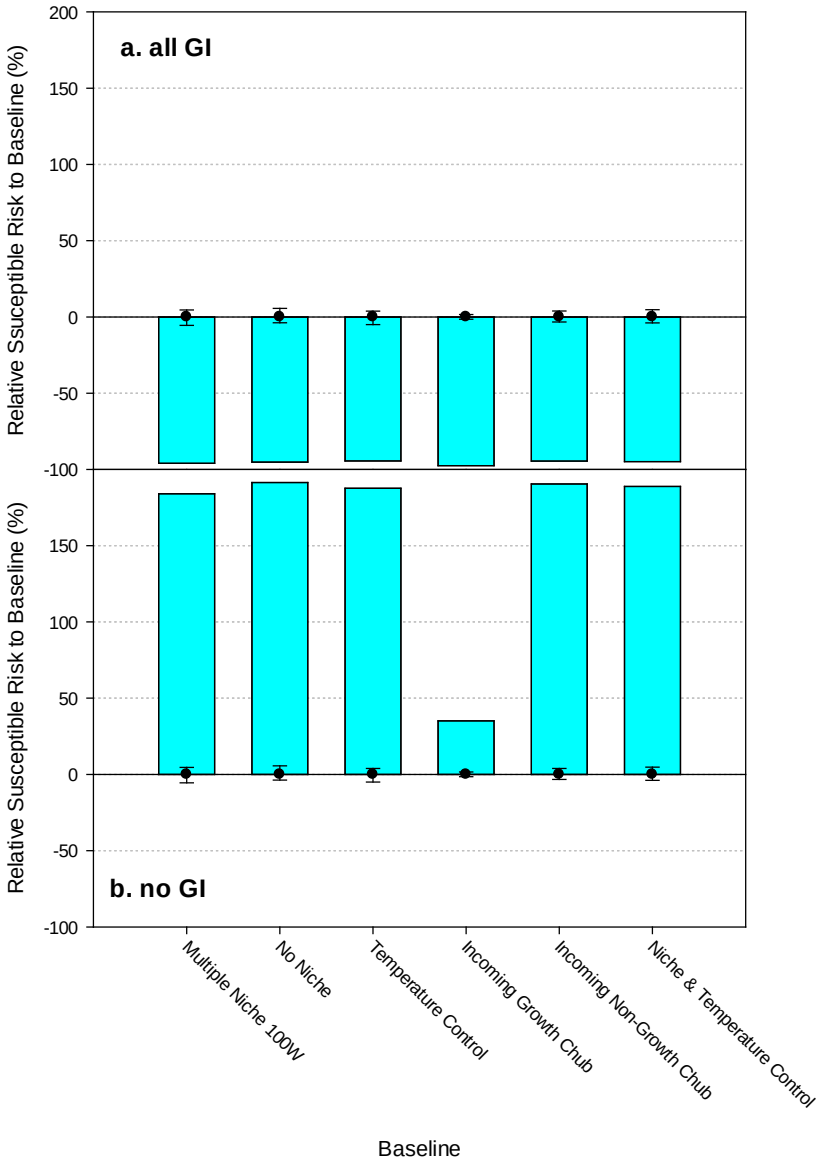



**Figure 60: Relative risk comparison for growth inhibitor use**

**All GI**: all RTE products sold that support growth are considered to have growth inhibitors; **No GI:** none of the RTE products that support growth are considered to have growth inhibitors

Of all the mitigations tested, increasing or decreasing the percentage of RTE meat and poultry products and deli salads that contain *L. monocytogenes* growth inhibitors consistently had the greatest impact on the relative risk of listeriosis predicted by the model. Note that the risk scale (y-axis) is different for

Figure 60 than for the other figures. Using growth inhibitors in deli meats and deli salads almost completely mitigated the risk of listeriosis – by almost 100% reduction for all risk assessment model baselines considered in this analysis. Growth inhibitors continue to prevent growth even after the RTE product leaves the retail deli. If all RTE meat and poultry products and deli salads contained no growth inhibitors, then the risk assessment model predicts an almost doubled risk of listeriosis from these products over most baseline conditions. The exception was for a contaminated growth-supporting deli meat chub where the absolute risk of listeriosis was greatest. Therefore the percentage increase in relative risk was more modest. This result confirms the overwhelming importance of the growth of *L. monocytogenes* during retail and home storage compared to other parameters in *L. monocytogenes* risk assessments, as has been consistently observed [3, 59].

## *7.4. Verification*

Given the over parameterization in the risk assessment model, a formal calibration (e.g., minimizing some objective function) or a validation is currently not possible. Nevertheless, some checks and controls were done with regards to the available literature and through studies specifically developed to inform the current risk assessment model.

### 7.4.1 Mass balance

*Mass Balance, Transfer Matrix*

Figure 61 depicts the sources of incoming and outgoing *L. monocytogenes* for the retail deli system. *L. monocytogenes* enter the retail deli through *i*) contaminated incoming raw RTE products; *ii*) niches (as currently written, the risk assessment model does differentiated the source of *L. monocytogenes* from a niche in the retail deli versus those resulting from contaminated incoming RTE product); or *iii*) the growth of *L. monocytogenes* on RTE product. *L. monocytogenes* are either on outgoing RTE product sold to consumers, eliminated through wiping, washing and disinfection of retail deli surfaces, or disposed of in the trash (e.g., on used gloves or expired RTE product).

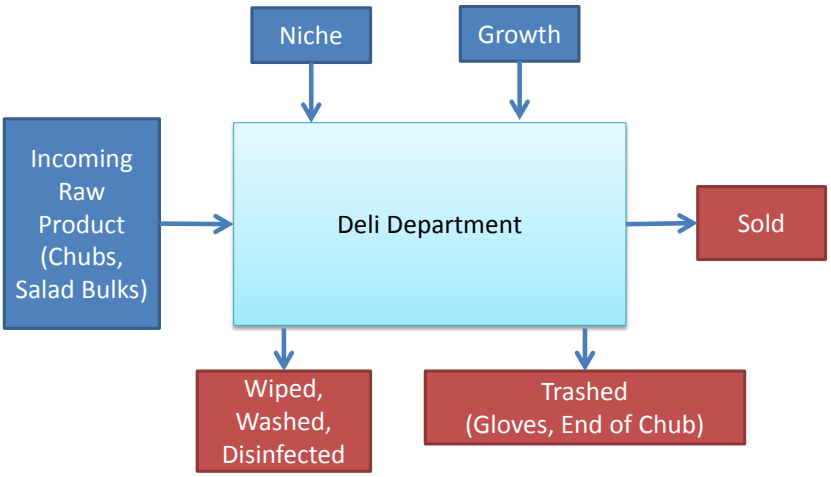



**Figure 61. Incoming and outgoing bacteria in the *L. monocytogenes* in retail model.**

At any time, the sum of the *L. monocytogenes* entered in the system was equal to the sum of the *L. monocytogenes* currently in the system with the sum of the *L. monocytogenes* that went out of the system. The checking of this mass balance was additionally afforded a cross-check of proper functioning of this risk assessment model. The mass balance was controlled in all scenarios described in this report.

### 7.4.2 Surveys of *L. monocytogenes* in RTE foods

While validation is preferable, survey data were used to help establish parameters within the model. Two large data sets are available that describe the distribution of *L. monocytogenes* concentrations in RTE products. The first is a study by the National Food Processors Association [14] and the second is derived from a National Alliance for Food Safety and Security (NAFSS) study [16] [6]. Figure 62 illustrates the upper predicted tail of the cumulative distribution function for the incoming deli products and the deli products leaving the retail deli with niches and those without any niches (baselines). Superimposed are the NAFSS points for deli meat, the only food groups studied. It appears that the different retail deli baselines capture this critical portion of the distribution.

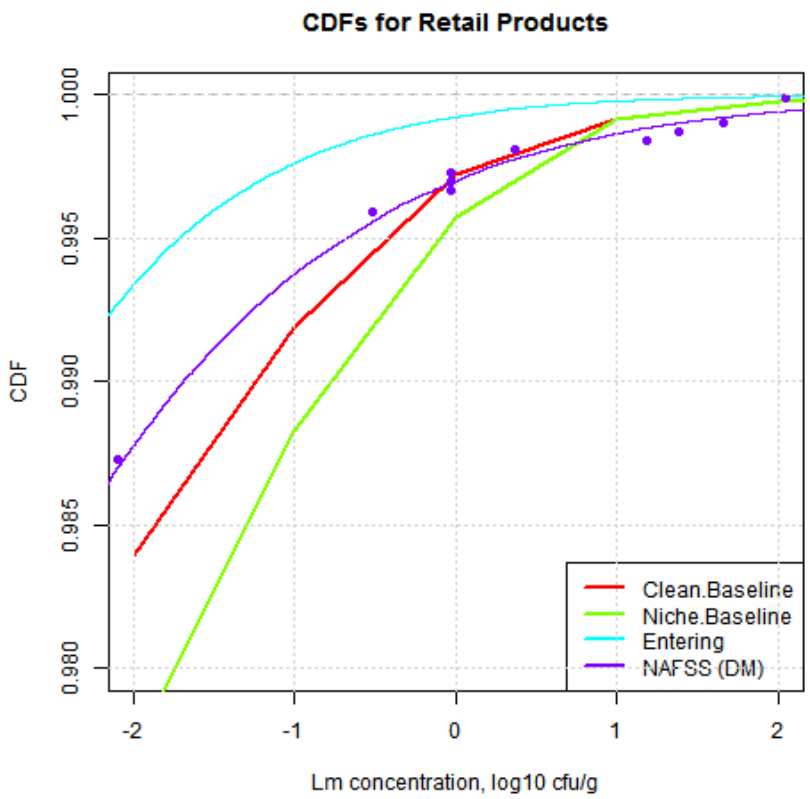



**Figure 62: Comparison of predicted model distributions with observed retail deli observations**

While this comparison should not be considered as a complete validation because various pathways could lead to these results, this graph indicates that the model results are not inconsistent with observed data.

### 7.4.3 Virginia Tech mock deli

A mock retail deli study [29] was conducted where known sites were contaminated using an abiotic surrogate (GloGerm$^{TM}$), the mock retail deli was operated for a fixed period, and the resulting contaminated location recorded. Photographs under UV light were evaluated by a trained sensory panel to estimate levels of surrogate contamination. As a manipulative study, the research directly links contaminated sites to resulting contaminated locations. Early results from this research were used to identify missing transfer events within the cross contamination model. Results are shown in Figure 63, with the color intensity and size of the circle indicating the amount of GloGerm$^{TM}$ transfer from an initially contaminated site to another site in the deli. In general, initial glove and initial slicer blade contamination spread the surrogate across the most sites. This study serves as a validation of the conceptual model shown in Figure 4 and mass transfers illustrated in Figure 63.

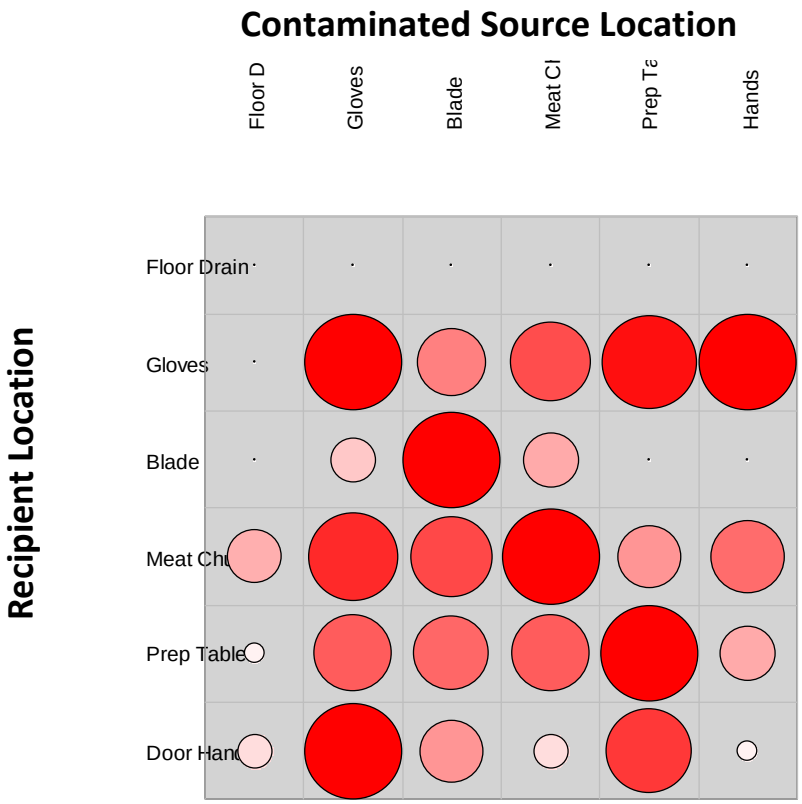



**Figure 63: Mock retail deli results [29]. Size and color intensity indicate amount of surrogate transferred from source to recipient location.**

### 7.4.4 Cornell University expert elicitation

Hoelzer *et al*. [31] published an expert elicitation study on *L. monocytogenes* transfer within retail delis. Table 17 presents the major conclusions and compares these to the conceptual cross contamination model. The first four columns are adapted from the authors' paper. The "Median Result" represents the percentage of experts who believe that the given transfer can occur. The "Percent Very Confident Experts" indicates a self-reported degree of confidence in their answers. The final column added for this report represents whether a given transfer can occur within the model.

**Table 17: Comparison of expert elicitation to cross contamination model structure**

| *L. monocytogenes* transfer | | Median Result (%) (Source [31]) | **Percent "very confident" experts** (Source [31]) | **Included in Model?** |
|---|---|---|---|---|
| **Source** | **Recipient** | | | |
| Slicer blade | RTE product[a] | 86 | 89 | Yes |
| Slicer blade | RTE product[b] | 48 | 22 | Yes |
| Slicer blade | Hands | 23 | 39 | Yes |
| Slicer blade guard | Hands | 22 | 35 | Yes, but slicer treated as one location. |
| Cutting board | RTE product | 75 | 56 | Yes, if cutting board treated as FCS. |
| Cutting board | Hands | 47 | 39 | No |
| Scale touchpad | Hands | 55 | 59 | Yes, but scale treated as one location. |
| Scale weigh table | RTE product | 15 | 43 | Yes, but scale treated as one location. |
| Deli case handle | Hands | 53 | 90 | Yes |
| Deli case | RTE product | 86 | 58 | No |
| Deli preparation sink[c] | RTE product | 48 | 41 | Yes |
| Deli preparation sink[d] | RTE product | 5 | 47 | No |
| Walk-in cooler door handle | Hands | 63 | 47 | No, walk in cooler not included as a site. |
| Walk-in cooler floor | FCS | 4 | 47 | No, walk in cooler not included as a site. |
| Knife rack | FCS | 41 | 22 | Yes, indirectly (Utensils, e.g., knives, can contact RTE product and hands.) |
| Central floor drain | FCS | 5 | 15 | No |

[a]Transfer to first slice sliced on contaminated slicer; [b]Transfer to 10th slice sliced on contaminated slicer; [c]chub set down in sink during unwrapping; [d]chub not set down in sink during unwrapping.

The model thus includes all the perceived major routes of transfer. The major exceptions are the lack of a walk-in cooler site within the model and the lack of transfer from case to RTE product. The risk assessment model includes and assumption that the RTE product chubs are always wrapped when returned to the retail deli, thus limiting contact.

# 8. Summary of Risk Assessment Results

This QRA provides information on the predicted risk of listeriosis associated with the consumption of RTE foods prepared and sold in the deli of a retail food store and examines how the predicted risk may be impacted by different practices in a retail deli (e.g., sanitation, temperature control, and worker behavior).

## *8.1. Predictions of Absolute Risk*

The predicted risk of listeriosis per serving of RTE food (hereinafter referred as "absolute risk"[37]) was evaluated for two U.S. populations: 1) the "susceptible population" (e.g., older adults, fetuses, newborns, and those who have immune-compromising conditions, as defined by FAO/WHO [59]); and 2) the remaining U.S. population (i.e., referred to as the "general population" in this QRA). Table 18 shows the predicted absolute risk to the two populations and six different baseline conditions that may characterize a retail deli and the RTE food it serves at different times over the course of operations. The baseline conditions are:

1) a retail deli with multiple niches or environmental transfers that regularly releases *L. monocytogenes* to food contact surfaces;
2) a retail deli with no niches or environmental *L. monocytogenes* transfer;
3) a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product supports growth;
4) a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product does not support growth;
5) a retail deli with multiple niches and compliant with the 2009 FDA Food Code guidance for temperature control (≤41°F); and,
6) a retail deli without any niches and with compliant temperature control (≤41°F).

In general, across all six baseline conditions, the predicted absolute risk for the susceptible population is much higher compared to the general population (Table 18). This result is expected because of the

[37] When interpreting the results, it is important to keep in mind that the specific values used in the QRA to characterize the baseline conditions are merely representative of a range of values that could possibly occur. For example, not all retail deli niches will transfer a mean of 100 cfu on a weekly frequency, as modeled in the "Multiple Niche 100W" baseline. Also, not all incoming contaminated product will have a mean contamination of -5 $\log_{10}$ cfu/g as the incoming product baselines are modeled. The range of values used in the models for various scenarios are evaluated through the sensitivity analysis discussed in Section 7.2.1.

differences in the dose response relationships for these two populations (see Section 6.4.4). For any given dose of ingested *L. monocytogenes*, individuals from the susceptible population are predicted to have a higher probability of illness, compared to the general population. The predicted absolute risk to consumers in the general population ranges from $1.5 \times 10^{-9}$ to $37.3 \times 10^{-9}$ per serving and for susceptible consumers ranges from $1.2 \times 10^{-7}$ to $16.6 \times 10^{-7}$ (a ~45-fold higher risk under all baseline conditions examined in this QRA).

**Table 18: Predicted absolute risk of invasive listeriosis per serving of ready-to-eat food sliced or prepared and sold at retail delis.**

| U.S. Populations Evaluated[1] | Baseline Retail Deli Conditions[2] | | | | | |
|---|---|---|---|---|---|---|
| | **Multiple Niche 100W** | **No Niche** | **Incoming Growth Chub** | **Incoming Non-growth Chub** | **Temp. Control** | **Niche & Temp. Control** |
| Susceptible population | $1.7\times10^{-7}$ | $1.4\times10^{-7}$ | $16.6\times10^{-7*}$ | $2.8\times10^{-7**}$ | $1.2\times10^{-7}$ | $1.5\times10^{-7}$ |
| General population | $3.8\times10^{-9}$ | $3.1\times10^{-9}$ | $37.3\times10^{-9}$ | $6.3\times10^{-9}$ | $2.7\times10^{-9}$ | $3.3\times10^{-9}$ |

Note: Detailed discussion of QRA model mathematics, assumptions, and data are provided earlier in this technical report.

[1]The U.S. population was divided in two subpopulations for the purpose of this risk assessment: the susceptible population (e.g., older adults, fetuses, newborns, and those who have immune-compromising conditions, according to FAO/WHO [59] definition) and the remaining population (referred to as the "general population").

[2]Description of the baseline conditions: **Multiple Niche 100W** = a retail deli with multiple niches that releases *L. monocytogenes* to food contact surfaces at a rate of 100 cfu on an average weekly frequency; **No Niche** = a retail deli with no niches or environmental *L. monocytogenes* transfer; **Incoming Growth Chub** = a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product supports growth. **Incoming Non-growth Chub** = a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product does not support growth; **Niche & Temperature Control** = a retail deli with multiple niches and compliant with the 2009 FDA Food Code guidance for temperature control (≤41°F): **Temperature Control** = a retail deli without any niches and with compliant temperature control.

* The corresponding risk was $2.9 \times 10^{-7}$ when the servings directly from the incoming highly contaminated product are removed from the calculation of the risk (see Section 7.2.1).

** The corresponding risk was $2.3 \times 10^{-7}$ when the servings directly from the incoming highly contaminated product are removed from the calculation of the risk (see Section 7.2.1).

## *8.2. Evaluation of the Impact of Differences in Baseline Conditions*

Comparisons among the six baselines provide insight to the extent some retail conditions impact the predicted risk of listeriosis. Two example comparisons follow to illustrate the impact of retail conditions on the predicted absolute risk estimates shown in Table 18.

*Temperature Control:*

A comparison of retail delis that do not have niches or environmental transfer of *L. monocytogenes* ("No Niche" column) to those that also ensure storage temperatures are maintained at ≤41°F ("Temp. Control" column), results in a reduction in the predicted absolute risk (from $1.4 \times 10^{-7}$ to $1.2 \times 10^{-7}$ for the susceptible population). A similar reduction (i.e., from $1.7 \times 10^{-7}$ to $1.5 \times 10^{-7}$ for the susceptible population) was predicted for retail delis with niches ("Multiple Niche 100W" column) when compared to those with niches that also maintained strict temperature control ("Niche & Temp. Control" column). The importance of the temperature control within a baseline condition is further illustrated in the Scenario Analysis section below.

L. monocytogenes *on Incoming RTE Products:*

A comparison of retail delis that do not have niches or environmental transfer of *L. monocytogenes* ("No Niche" column) to similar retail delis that also have more highly contaminated incoming RTE products (whether or not they support growth) provides information on the increased predicted risk from both the highly contaminated incoming product and those products subsequently cross contaminated in the deli.

When the incoming highly contaminated RTE product is one that does not support the growth of *L. monocytogenes* the predicted absolute risk increases from $1.4 \times 10^{-7}$ to $2.8 \times 10^{-7}$ for the susceptible population (compare "No Niche" with "Incoming Non-growth Chub"; Table 18). When the highly contaminated incoming RTE product is one that supports the growth of *L. monocytogenes,* the predicted absolute risk increases to $16.6 \times 10^{-7}$ for the susceptible population (compare "No Niche" with "Incoming Growth Chub"). The predicted absolute risk of product from stores that have a highly contaminated incoming RTE product that supports growth of *L. monocytogenes* is 6-times higher than the risk from stores that have a highly contaminated incoming RTE product that does not support growth of *L. monocytogenes* ($16.6 \times 10^{-7}$ vs. $2.8 \times 10^{-7}$).

However, when the servings directly associated with the incoming highly contaminated product are removed from the calculation of the risk, the increase in the predicted absolute risk is only the risk associated with retail cross contamination. When the highly contaminated incoming RTE product is one that does not support the growth of *L. monocytogenes*, the predicted absolute risk increases from $1.4 \times 10^{-7}$ ("No niche"; Table 18) to $2.3 \times 10^{-7}$ (Table 18 footnote and Section 7.2.1). This is almost the same increase in predicted absolute risk as when all RTE servings are included in the risk calculation (i.e., $2.8 \times 10^{-7}$). Most of the increase in the predicted absolute risk of products from these stores results from cross contamination. This result, in addition to the ones evaluating cross contamination (see Scenario

Analysis section below), illustrates the importance of retail cross contamination for RTE products that do not support the growth of *L. monocytogenes*.

When the servings directly associated with the incoming highly contaminated product are removed from the calculation of the risk for the highly contaminated incoming RTE product that supports the growth of *L. monocytogenes*, the predicted absolute risk increases from $1.4 \times 10^{-7}$ ("No niche"; Table 18) to $2.9 \times 10^{-7}$ for the susceptible population (Table 18 footnote and Section 7.2.1). The slightly higher predicted absolute risk for highly contaminated incoming RTE products that support growth ($2.9 \times 10^{-7}$ vs. $2.3 \times 10^{-7}$) is due to growth of *L. monocytogenes* on the products while in the retail delis, allowing for additional *L. monocytogenes* to cross contaminate other RTE foods. Most notably, however, is that the majority of the predicted absolute risk results directly from product contaminated during processing and growth of *L. monocytogenes* on these products during retail and home storage (i.e., $16.6 \times 10^{-7}$ vs. $2.9 \times 10^{-7}$ when only cross contaminated servings are considered). This result, in addition to the ones evaluating the impact of growth inhibitors (see "Scenario analysis" section below), illustrates the overwhelming importance of the growth of *L. monocytogenes* during retail and home storage for RTE products that support the growth of *L. monocytogenes*.

Overall the baseline conditions indicate that 1) retail delis without niches and retail delis that control temperature lead to lower predicted risk of listeriosis; and 2) retail delis with incoming RTE products that are highly contaminated with *L. monocytogenes*, notably if this product supports growth, or retail delis with niches lead to higher predicted risk of listeriosis.

### *8.3. Scenario Analysis*

For each of the six baseline retail conditions (listed above), this QRA was used to evaluate the public health impact of twenty-two different "what if" scenarios (i.e., changes in sanitary practices, worker behaviors, product formulation, cross contamination, and product storage temperature and duration). In total, this QRA provides 126 summary public health findings related to retail practices (Table 19).

In Table 19, each column represents one of six different baseline conditions that may be present in retail delis. Each row shows the percentage change in the risk per serving for the susceptible population relative to the baseline condition for each "what if" scenario (hereinafter referred as "relative risk"). The scenarios are organized by those that evaluate changes in: 1) sanitation; 2) worker behavior; 3) use of growth inhibitors; 4) cross contamination; and 5) storage temperature control. In this table, positive values represent an increase, while negative values represent a decrease in the predicted relative risk per serving.

[Note: Table 19 provides a summary of the results for each scenario, relative to the baseline for only the susceptible population. While the predicted absolute risks were different between the susceptible populations and general population, the predicted relative change in risk is similar for both populations].

The relative effectiveness of a mitigation applied to a specific baseline condition can be assessed by reading Table 19 down a column. The effectiveness of a single mitigation across different operating conditions can be assessed by reading the Table 19 across each row, keeping in mind the magnitude of the predicted risk for that scenario (shown in Table 18). Some scenarios predict that the mitigation would not be very effective in reducing the predicted risk on a per serving basis (e.g., no contact between the glove and the case), while others (e.g., pre-slicing) can either be slightly beneficial or highly detrimental depending on retail deli baseline conditions.

*Sanitation Related Scenarios*

Sanitation practices were a key driver in reducing the predicted risk of listeriosis. When sanitation activities were not modeled ("No Sanitation"), the predicted increase in risk could be as much as 50.2% (i.e., under retail deli conditions in which there were niches of *L. monocytogenes* and lack of temperature control to prevent growth. see "Niche & Temp. Control" column). The smallest predicted increase in risk from omitting sanitation was 2.9% ("Incoming Growth Chub" column); in this scenario, the impact of sanitation was overwhelmed by the additional bacteria from the incoming product and the potential growth of *L. monocytogenes* while the product is in the retail deli. While no individual changes in sanitation practices appear to substantively reduce the relative risk of listeriosis per serving of RTE food sliced or prepared in retail delis for all baselines, the substantive increase in risk (up to 50%) when sanitation is omitted is an indicator of the importance of sanitation at retail.

*Worker Behavior Related Scenarios*

The impact of QRA simulated changes to worker behavior on the change in predicted relative risk varied depending on the baseline retail deli condition. For example, if the retail deli had multiple niches ("Multiple Niche 100W), using separate slicers reduced the predicted relative risk by 6.3%. If workers did not use gloves, the predicted relative risk increased (5.1 to 8.5 %). In other cases, the public health benefits of some interventions appear to have been overwhelmed by other factors. For example the benefit of pre-slicing product in the morning after cleaning was offset when incoming RTE products that support the growth of *L. monocytogenes* were highly contaminated.

*Growth Inhibitor Related Scenarios*

Of all the scenarios tested, growth inhibitor usage had the greatest impact on the predicted relative risk. The use of growth inhibitors in all products almost completely eliminated the predicted relative risk (reductions ranged from 94.4 to 97.5%). This level of predicted relative risk reduction (approximately 95%) is a significant finding, given that a 100% reduction would indicate no risk. In practice, however, not all products are amenable to incorporating growth inhibitors, and therefore these results represent upper bounds in potential effectiveness.

The baseline scenarios consider that products in the retail deli are a mixture of products that include growth inhibitors and products that do not. In a comparison scenario where no products in the retail deli contained growth inhibitors ("No GI"), the predicted risk nearly doubles to between 184.1 and 191.5%, as compared to the baselines. The only apparent exception is in the "Incoming Growth Chub" baseline, where the estimated relative increase in risk was only 35.1%. This relatively low value is somewhat misleading, because as mentioned above (see Table 18), the predicted absolute risk for this baseline was already almost 10 times higher than other baselines.

These findings illustrate the importance of the growth of *L. monocytogenes* during retail and home storage for RTE products that support the growth of *L. monocytogenes*.

*Cross Contamination Related Scenarios*

Table 19 shows that controlling cross contamination in retail delis is important in mitigating the risk of listeriosis. The QRA scenarios where cross contamination does not occur in the retail deli (i.e., the transfer coefficient for all sites <u>and</u> slicer were set to 0; see "Transfers and Slicer to 0" column), the predicted relative risk reduction was significant (ranging from 9.5% and 60.8%). However, when *L. monocytogenes* transfers from the slicer were not eliminated ("Transfers to 0" scenario), there was no significant reduction in the predicted relative risk. This highlights the importance of the slicer in retail delis as the nexus for cross contamination.

In addition to examining the relative risk values in Table 19, examining the absolute risk estimates reported in Section 7.2 of this report provides further insight to the role that cross contamination plays in the risk of RTE products prepared in retail delis. The absolute risk for a "No Niche" baseline when cross contamination is eliminated (i.e., "Transfer and Slicer to 0") is $1.1 \times 10^{-7}$ (see Figure 24). The absolute risk increases to $1.4 \times 10^{-7}$ when there is cross contamination (see Table 18, "No Niche"). When an "Incoming Non-growth Chub" is introduced to a "No Niche" retail deli where there is no cross contamination, the risk remains essentially the same as the "No Niche, Transfer and Slicer to 0" scenario

($1.1 \times 10^{-7}$; Figure 34), indicating that if there is no cross contamination at retail, then the introduction of highly contaminated incoming RTE that does not support growth of *L. monocytogenes* does not result in any substantive increase in risk. However, when cross contamination does occur in these situations, the predicted absolute risk significantly increases (to $2.8 \times 10^{-7}$; Table 18). This QRA illustrates that any increase in *L. monocytogenes* on incoming RTE product (even those that do not support the growth of *L. monocytogenes*) increases the predicted risk of listeriosis on a per serving basis as a result of cross contamination.

Interestingly, Table 19 also shows that reducing the mean incoming *L. monocytogenes* levels in all RTE foods by a factor of 2 (0.3 $\log_{10}$ units) significantly reduces the predicted relative risk (between 1.1 and 24.2%, see "Reduce Level" scenario). This finding suggests that a continued effort to prevent even low levels of *L. monocytogenes* contamination during processing prevents illnesses from these products and other RTE foods.

*Storage Temperature and Duration Control Related Scenarios*

Controlling the deli case temperature significantly reduced the predicted risk. For the scenario where the RTE foods are held at the recommended temperature ("Temp ≤5°C"), the predicted reduction in risk is roughly the same as the reduction associated with holding RTE foods at temperatures that completely prevents growth of *L. monocytogenes* ("No Growth, T=-5°C"). This is an important finding because maintaining products in the deli display at a temperature recommended by the FDA Food Code prevents almost all additional risk linked to the bacterial growth in retail. These findings highlight the importance of temperature control at retail.

**Table 19: Predicted percent change in the risk of invasive listeriosis per serving of ready-to-eat food sliced or prepared and sold at retail delis for the susceptible population according to various scenarios, as estimated by the *L. monocytogenes* in retail delicatessens risk assessment model.**

**(percent change in the risk relative to the respective baseline condition)** [1]

| Scenario | Baseline Conditions[2] | | | | | |
|---|---|---|---|---|---|---|
| | Multiple Niche 100W | No Niche | Incoming Growth Chub | Incoming Non-growth Chub | Temp. Control | Niche & Temp. Control |
| **Sanitation Related Scenarios:** | | | | | | |
| **Wash & Sanitize**: Increase the effectiveness of cleaning from simply washing to washing and sanitizing. | -1.6 | 1.7 | -0.6 | 2.0 | -1.3 | **-7.6*** |
| **Clean 8 Sporadic**: Double the number of sites cleaned from 4 to 8. | -4.2 | **-4.1*** | -0.7 | -1.9 | -0.5 | 1.3 |
| **No Sanitation**: No wiping, washing, or sanitizing. | **41.3*** | **7.9*** | **2.9*** | **23.5*** | **11.9*** | **50.2*** |
| **No Sporadic Cleaning**: Clean as required by the 2009 FDA Food Code, but no additional sporadic cleanings. | 3.0 | -3.0 | -0.4 | 1.7 | 1.7 | 3.5 |
| **NFCS As FCS**: Workers clean deli NFCSs at same rate as FCSs | -3.0 | 0.7 | -0.6 | 0.3 | **-5.4*** | 0.9 |
| **Worker Behavior Related Scenarios:** | | | | | | |
| **No Glove**: Workers do not use gloves when serving customers. | **5.1*** | 2.5 | 1.2 | **8.5*** | **6.0*** | **7.0*** |
| **Gloves Every Serving**: Workers change gloves before every sale. | 4.1 | 0.7 | 0.7 | 0.6 | -0.2 | 0.6 |
| **No Contact Glove Case**: Workers do not use their hands to open the deli case (e.g. if a floor switch is used). | -1.4 | -3.4 | -1.3 | 1.3 | 1.3 | -0.3 |
| **Pre-slice**: Workers pre-slice RTE products in the morning, after cleaning | **6.0*** | **24.9*** | **49.5*** | **-34.4*** | **19.2*** | 1.0 |
| **Separate Slicer**: Workers use a separate slicer for RTE products that support growth of *L. monocytogenes.* | **-6.3*** | -0.6 | **-1.7*** | **22.7*** | -0.8 | 4.6 |
| **Do Not Slice On Gloves**: Workers collect the slices of RTE products on tissue paper rather than on his/her gloved hand. | 1.9 | 1.0 | 0.2 | 3.8 | -1.9 | **8.0*** |
| **Growth Inhibitor Related Scenarios:** | | | | | | |
| **All GI:** Reformulate all RTE products sold at the retail deli that would otherwise support *L. monocytogenes* growth to include growth inhibitors. | **-96.0*** | **-95.2*** | **-97.5*** | **-94.5*** | **-94.4*** | **-94.8*** |
| **No GI:** Reformulate all RTE products that support *L. monocytogenes* growth that are sold at the retail deli to not include GI to restrict *L. monocytogenes* growth. | **184.1*** | **191.5*** | **35.1*** | **190.5*** | **187.7*** | **188.9*** |

| Scenario | Baseline Conditions[2] | | | | | |
|---|---|---|---|---|---|---|
| | **Multiple Niche 100W** | **No Niche** | **Incoming Growth Chub** | **Incoming Non-growth Chub** | **Temp. Control** | **Niche & Temp. Control** |
| **Cross Contamination Related Scenarios:** | | | | | | |
| **Transfers to 0**: Cross contamination would only result from the deli slicer. | -4.3 | 2.5 | 1.0 | 3.7 | 0.2 | -0.3 |
| **Transfers and Slicer to 0**: No cross contamination in the retail deli. | **-33.8*** | **-18.6*** | **-9.5*** | **-60.8*** | **-19.2*** | **-30.4*** |
| **Reduce Level**: Mean incoming *L. monocytogenes* concentration in all RTE products lowered from -9.2 to -9.5 $\log_{10}$ cfu/g. | **-21.6*** | **-24.2*** | -1.1 | **-9.8*** | **-22.5*** | **-15.6*** |
| **Separate Slicer Case**: Workers use a separate slicer and a separate deli case for RTE products that support the growth of *L. monocytogenes*. | -2.5 | -1.6 | -1.2 | 21.0* | -0.9 | **7.5*** |
| **Lower Env Cont**: Reduce transfer of *L. monocytogenes* among RTE products, FCSs, and NFCs (i.e., reduce transfer coefficients by 50%). | -4.5 | **-4.4*** | -1.4 | 0.4 | 1.6 | 0.9 |
| **Storage Temperature and Duration Control Related Scenarios:** | | | | | | |
| **Temp = 5°C**: Set the retail deli case temperature to 5°C (41°F) (i.e., in compliance with the 2009 FDA Food Code) for all delis, instead of using the deli case temperatures reported by Ecosure. | -4.8 | **-14.3*** | **-8.1*** | -2.8 | NA | NA |
| **No Growth (T=-5°C):** At this temperature, no *L. monocytogenes* growth will occur. | **-16.5*** | **-21.3*** | **-18.2*** | **-5.7*** | NA | NA |
| **Temp ≤ 5°C**: Use only the retail deli case temperatures observed in the Ecosure dataset at or below 5°C (41°F). | **-9.0*** | **-16.3*** | **-12.3*** | **-8.2*** | NA | NA |
| **Shorten Time in Retail Delis**: Reduce the length of time RTE products are held before they are sold or disposed from 7 to 4 days. | -2.5 | 3.3 | -1.2 | 2.0 | -0.2 | 1.7 |

Readers should refer to the body of the document for further details on the assumptions, model, data, baselines and scenarios. See Table 18 for the predicted absolute risk of the baseline conditions.

* bold: Outside the 95% confidence interval for the median.

NFCS = non-food contact surface; FCS = food contact surface; Temp. = Temperature; NA= not applicable to this scenario; Chub refers to bulk product (deli meat or cheese) before it is sliced.

[1]the US population was split in two subpopulations for purpose of this risk assessment: the susceptible population (e.g., older adults, fetuses, newborns, and those who have immune-compromising conditions, according to FAO/WHO 2004 definition) and the remaining population. The results for the susceptible population only are presented as this population comprises 80-98% of the public health burden for listeriosis

[2]Description of the baseline conditions: **Multiple Niche 100W** = a retail deli with multiple niches that releases *L. monocytogenes* to food contact surfaces at a rate of 100 cfu on an average weekly frequency; **No Niche** = a retail deli with no niches or environmental *L. monocytogenes* transfer; **Incoming Growth Chub** = a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product supports growth. **Incoming Non-growth Chub** = a retail deli with no niche and with an incoming RTE product more highly contaminated with *L. monocytogenes* than current average FSIS inspected plant data indicate and the incoming contaminated RTE product does not support growth; **Niche & Temperature Control** = a retail deli with multiple niches and compliant with the 2009 FDA Food Code guidance for temperature control (≤41°F): **Temperature Control** = a retail deli without any niches and with compliant temperature control.

# 9. Conclusions

This QRA represents the first large-scale effort to model *L. monocytogenes* cross contamination at retail. The risk assessment model contributes to our understanding of *L. monocytogenes* transmission, survival, and growth in the retail environment and was used to evaluate how retail practices may impact the predicted risk of listeriosis. The approach used was to evaluate the public health effect of various mitigations under six different baseline conditions that may characterize a retail deli and the RTE food its serves.

The key findings from this assessment of risk of listeriosis associated with RTE foods prepared and served in retail deli operations include:

- **Control Growth**. Employing practices that prevent bacterial growth dramatically reduced the predicted risk of listeriosis, as observed in other *L. monocytogenes* risk assessments. The use of growth inhibitors for suitable products prevents growth of *L. monocytogenes* in RTE foods both at retail and during consumer home storage, leading to an overall dramatic reduction in the predicted risk of listeriosis (ca. 95%, see table). The strict control of temperature during refrigerated storage in retail delis did reduce the predicted risk. The impact of this control is nevertheless lower as it reduces growth only during this specific storage (5-20% reduction according to the baseline and the scenario) (cf. “Temperature Control” baseline and growth inhibitor scenarios).
- **Control Cross Contamination**. Cross contamination of *L. monocytogenes* in the retail environment dramatically increases the predicted risk of listeriosis. Cross contamination during the routine operation of the retail deli is not amenable to a simple solution (cf. “Transfers and Slicer to 0” scenarios).
- **Control Contamination at its Source**. Increasing the concentration and transfers of *L. monocytogenes* from incoming products, the environment, or niches directly increases the predicted risk of illness. Increasing *L. monocytogenes* concentration in incoming product increased the predicted risk of listeriosis whether or not the contaminated RTE product itself supported growth. The increase in predicted risk was greater when the equivalent contamination occurred on product that supported the growth of *L. monocytogenes* (*cf.* predicted risks for “Incoming Growth Chub” baseline and “Incoming Non-growth Chub” baseline, as well as “Reduce Level” scenarios).

- **Continue Sanitation.** Sanitation practices that eliminate *L. monocytogenes* from the deli area food contact surfaces results in a reduction in the predicted risk of illness. Cleaning and sanitizing food contact surfaces reduced the predicted *L. monocytogenes* levels in the deli area (*cf.* "No Sanitation" scenario). Wearing gloves while serving customers reduces the estimated risk of listeriosis.
- **Identify Key Routes of Contamination**. The slicer (for deli meats and cheeses) and the salad utensils (for deli salads) are sources of *L. monocytogenes* cross contamination to RTE foods. Control of *L. monocytogenes* cross contamination at these points during retail preparation and handling of RTE foods reduced the predicted risk of listeriosis (*cf.* "Transfers to 0" versus "Transfers and Slicer to 0" scenarios).

In summary, this risk assessment improves our understanding of *L. monocytogenes* in the retail deli and should encourage improvements to retail food safety practices and mitigation strategies to further control *L. monocytogenes* in RTE foods. The 'what if' scenarios modeled in this risk assessment provide insight on how cross contamination, sanitary practices, and temperature control impact the predicted risk of listeriosis. This risk assessment is based on an extensive amount of information gathered through partnerships with academia and input from stakeholders. Additional data would be useful to refine and improve the predictions made by the "Virtual Deli" model. Additional data would be useful to further explore how more specific retail practices and conditions (e.g., equipment design) impact the risk of listeriosis.

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## Appendix 1: The Secondary Growth Model

The Mejlholm and Dalgaard model [75] is a predictive microbiology secondary models. It predicts the change in the primary model parameters according to a change in the growth environment. This model use the gamma concept [65]. The model used here is limited to T, pH, $a_w$, nitrites, LAC, DAC, and their interaction. It is written:

$$\mu = \mu_{ref} \cdot \gamma_T(T) \cdot \gamma_{pH}(pH) \cdot \gamma_{a_w}(a_w) \cdot \gamma_{nit}(nit) \cdot \gamma_{LAC}(LAC) \cdot \gamma_{DAC}(DAC) \cdot \xi_{\text{int}}(T, pH, a_w, nit, LAC, DAC)$$

where

- $\mu_{ref} = 0.419\ \text{h}^{-1}$ is equal to $\mu_{opt}$ at a reference temperature ($T_{ref}$) of 25°C in the RTE product;
- $\gamma_T(T) = \begin{cases} \left(\dfrac{T+2.83}{T_{ref}+2.83}\right)^2 & if\ T > -2.83°C \\ 0 & if\ T \le -2.83°C \end{cases}$ with $T$, the temperature in degrees Celsius.

  Note that this model for temperature is equivalent to a Ratkowsky [68] model, as used in [3], with $T_{min}$, the minimal temperature of growth for *Listeria* equals to -2.83°C (26.91°F);
- $\gamma_{a_w}(a_w) = \begin{cases} \dfrac{(a_w - 0.923)}{(1-0.923)} & if\ a_w > 0.923 \\ 0 & if\ a_w \le 0.923 \end{cases}$ with $a_w$ , the water activity of the RTE product;
- $\gamma_{pH}(pH) = \begin{cases} 1-10^{(4.97-pH)} & if\ pH > 4.97 \\ 0 & if\ pH \le 4.97 \end{cases}$ with pH, the pH of the RTE product;
- $\gamma_{nit}(nit) = \begin{cases} \left(\dfrac{350-nit}{350}\right)^2 & if\ nit < 350\ ppm \\ 0 & if\ nit \ge 350\ ppm \end{cases}$ with *nit* the concentration of nitrites (ppm);
- $\gamma_{LAC}([LAC_U]) = \begin{cases} \left(1-\dfrac{[LAC_U]}{3.79}\right) & if\ [LAC_U] < 3.79\ mM \\ 0 & f\ [LAC_U] \ge 3.79\ mM \end{cases}$ with $[LAC_U]$, the concentration (mM) of undissociated lactic acid.
- $\gamma_{DAC}([DAC_U]) = \begin{cases} \left(1-\sqrt{\dfrac{[DAC_U]}{4.80}}\right) & if\ [DAC_U] < 4.80\ mM \\ 0 & if\ [DAC_U] \ge 4.80\ mM \end{cases}$ with $[DAC_U]$, the concentration (mM) of undissociated diacetate.

The value of [$LAC_U$] from the concentration of growth inhibitors in the RTE product is evaluated in two steps: First, the total lactic acid concentration ($LAC_{tot}$, %) is evaluated from the concentration in sodium lactate (NaL, %), the concentration in potassium lactate (KL, %), and the concentration in lactic acid (LAC, %) using their respective molecular weight, as:

$$LAC_{tot} = 90.08 \times \left( \frac{NaL}{112.1} + \frac{KL}{128.2} + \frac{LAC}{90.08} \right).$$

Then, the concentration in undissociated lactic acid (mM) is evaluated from the total concentration of lactic acid using the Henderson-Hasselbach equation:

$$pH = pK_a + \log_{10} \frac{[A-]}{[A_U]}$$

leading to

$$[LAC_U] = \frac{LAC_{tot} \times \frac{10000}{90.08}}{1 + 10^{pH-3.86}};$$

The pKa dependence on temperature was found to be negligible for lactic acid [125] and assumed so for diacetate. Similarly, the total diacetate concentration ($DAC_{tot}$, %) is evaluated from the concentration in sodium lactate (NaDAC, %) and the concentration in diacetate (DAC, %) using their respective molecular weight, as:

$$DAC_{tot} = 119.1 \times \left( \frac{NaDAC}{142.09} + \frac{DAC}{119.1} \right).$$

The concentration in undissociated diacetate (mM) is evaluated from the total concentration of diacetate using:

$$[DAC_U] = \frac{DAC_{tot} \times \frac{10000}{119.1}}{1 + 10^{pH-4.76}};$$

As for the interaction term, Mejlholm and Dalgaard [75] use the Le Marc [71] approach, i.e.:

$$\xi(T, a_w, pH, nit, [LAC_U], [DAC_U]) = \begin{cases} 1 & if\ \psi \le 0.5 \\ 2(1-\psi) & if\ 0.5 < \psi < 1 \\ 0 & if\ \psi \ge 1 \end{cases}$$

where

$$\psi = \sum_i \left( \frac{\varphi(i)}{2\prod_{j \ne i}(1-\varphi(j))} \right) = 0.5 \times \left( \frac{\sum_i \varphi(i)(1-\varphi(i))}{\prod_i (1-\varphi(i))} \right)$$

with

$$\varphi(T) = \left(1 - \frac{T + 2.83}{T_{ref} + 2.83}\right)^2,$$

$$\varphi(a_w) = \left(1 - \sqrt{\frac{a_w - 0.923}{1 - 0.923}}\right)^2,$$

$$\varphi(pH) = \left(1 - \sqrt{1 - 10^{(4.97 - pH)}}\right)^2,$$

$$\varphi(nit) = \left(1 - \frac{350 - nit}{350}\right)^2 \text{ and}$$

$$\varphi([LAC_u];[DAC_U]) = \left(1 - \left(1 - \sqrt{\frac{[LAC_U]}{3.79}}\right) \cdot \left(1 - \sqrt{\frac{[DAC_U]}{4.80}}\right)\right)^2.$$

The growth model was slightly adapted to fit the structure of the present model. Nevertheless, these adaptations were made with no change in the mathematical model.

*Simplification of the model*

We first simplify the final evaluation of $\xi$. We have:

$$\xi = \begin{cases} 0 & 2(1-\psi) \le 0 \\ 2(1-\psi) & 0 < 2(1-\psi) < 1 \\ 1 & 2(1-\psi) \ge 1 \end{cases}.$$

Define $\chi = 2(1 - \psi)$. We have:

$$\chi = 2 - \frac{\sum_i \varphi_i (1 - \varphi_i)}{\prod_i (1 - \varphi_i)}$$

Then we can rewrite ξ simply as:

$$\xi = \begin{cases} 0 & \chi \le 0 \\ \chi & 0 < \chi < 1 \\ 1 & \chi \ge 1 \end{cases}$$

*Mathematical derivation when one parameter only is varying*

A given RTE product has a set of chemical characteristics (pH, $a_w$, [LAC]tot, [DAC]tot, nit). We will consider those characteristics as constant all over the process, from the entry in the deli to the

consumption. Only one parameter is considered: temperature $T$. The following procedure will help us to evaluate the growth of the RTE product while the temperature varies in the process.

The gamma concept with interaction is written, for $i \in \{T, pH, a_w, nit, [LAC]_{tot}, [DAC]_{tot}\}$:

$$\mu = \mu_{opt} \times \prod_i \gamma_i(x_i) \times \xi = \left(\mu_{opt} \times \prod_{i \neq T} \gamma_i(x_i)\right) \times \gamma_T(T) \times \xi \ .$$

$\left(\mu_{opt} \times \prod_{i \neq T} \gamma_i(x_i)\right)$ is characteristic of the RTE product. In our particular process, it is a constant.

We have:

$$\chi = 2 - \frac{\sum_i \varphi_i(1-\varphi_i)}{\prod_i (1-\varphi_i)} = 2 - \frac{\sum_{i \neq T} \varphi_i(1-\varphi_i) + \varphi_T(1-\varphi_T)}{\prod_{i \neq T}(1-\varphi_i) \times (1-\varphi_T)}, \text{ then}$$

$$\chi = 2 - \frac{\sum_{i \neq T} \varphi_i(1-\varphi_i)}{\prod_{i \neq T}(1-\varphi_i) \times (1-\varphi_T)} - \frac{\varphi_T}{\prod_{i \neq T}(1-\varphi_i)}$$

Define $\chi_{i \neq T}$ the factor $\chi$ for all parameters but $T$. We have:

$$\chi_{i \neq T} = 2 - \frac{\sum_{i \neq T} \varphi_i(1-\varphi_i)}{\prod_{i \neq T}(1-\varphi_i)}$$

Then:

$$\chi = 2 - \frac{(2 - \chi_{i \neq T})}{(1-\varphi_T)} - \frac{\varphi_T}{\prod_{i \neq T}(1-\varphi_i)}$$

Then, $\xi = \chi$ if $0 < \chi < 1$; $\xi = 1$ if $\chi > 1$ and $\xi = 0$ if $\chi < 0$.

Note moreover that at $T = T_{\text{ref}}$, $\gamma_T = 1$, $\varphi_T = 0$. We can thus define our parameters at $T = T_{\text{ref}}$ since $\gamma_{Tref} = \gamma_{i \neq T}$, $\chi_{Tref} = \chi_{i \neq T}$.

*In practice*

For a given RTE product with a different set of parameters (pH, aw, [LAC], [DAC]) and a $\mu_{ref}$. Assume that only the temperature changes. The following process may be used to evaluate the growth at a temperature $T$.

For a given RTE product, at $T = T_{ref}$

1. Evaluate and store $\gamma_{T_{ref}} = \prod_i \gamma_i$ . If $\gamma_{Tref} = 0 \Rightarrow$ No growth $\forall T$

2. Evaluate and store $A_{T_{ref}} = \prod_i (1-\varphi_i)$

3. Evaluate and store $\chi_{T_{ref}} = 2 - \dfrac{\sum_i \varphi_i (1-\varphi_i)}{A_{T_{ref}}}$ . If $\chi_{Tref} \le 0 \Rightarrow$ No growth $\forall T$

For a given temperature $T$ If $T \le T_{min} \Rightarrow$ No growth for $T$

4. Evaluate $\gamma_T = \left(\dfrac{T - T_{\min}}{T_{ref} - T_{\min}}\right)^2 = \left(\dfrac{T + 2.83}{27.83}\right)^2$

5. Evaluate $\varphi_T = \left(1 - \left(\dfrac{T + 2.83}{27.83}\right)\right)^2 = \left(1 - \sqrt{\gamma_T}\right)$

6. Evaluate $\chi = 2 - \dfrac{2 - \chi_{T_{ref}}}{1 - \varphi_T} - \dfrac{\varphi_T}{A_{T_{ref}}}$ If $\chi \le 0 \Rightarrow$ No growth for $T$

7. If if $\chi \ge 1$, set $\xi = 1$; else $\xi = \chi$

8. Evaluate $\mu = \left(\mu_{ref} \times \gamma_{T_{ref}}\right) \times \gamma_T \times \xi$

# Appendix 2: Consumption Data

The objective was to derive a distribution for serving sizes for "Deli meat," "Deli Cheese," and "Deli Salad." Consumption data were extracted from the 1999-2006 National Health and Nutrition Examination Survey (NHANES, a USDA / DHHS survey) results using the FARE™ Program (Food Analysis and Residue Evaluation Program, v. 8.63) developed by Exponent®. Briefly, the nutritional assessment component of the NHANES includes a 24-hour dietary recall interview for participants of all ages. Dietary recall interviews are conducted in person by trained dietary interviewers fluent in Spanish and English. Each dietary interview room contains a standard set of measuring guides. These tools are used to help the respondent report the volume and dimensions of the food items consumed. They are not intended to represent any one particular food, but rather are designed to help respondents estimate portion sizes. This set of measuring guides is designed specifically for use in the current NHANES setting with a target population of non-institutionalized U.S. civilians.

*Method*

All analyses were performed using the following options:

- Database: NHANES, combined 1999-2006 data, using only the first day of intake data;
- Use statistical weights, does not divide intake by body weight;
- Intake timing by specific meal and snack period. For meal and snack period, brunch and lunch were combined, as well as supper and dinner. All snacks were gathered daily as a single eating occasion;
- The population was the standard U.S. population (all season, region, age, sex, and ethnicity), the pregnant 13+ population and the senior (55+) population.

## Deli Meat

An analysis by ingredient ("RAC", Raw Agricultural Commodities) was used, because a part of this deli meat is used within complex food, such as sandwiches. First, the software extracted from the NHANES database all recorded eating occasions of any of the foods-as-eaten items listed, considered as including a "Deli Meat" as ingredient (Table 20). The list is an update of the 2003 FDA/FSIS risk assessment list (provided in [3], appendix 5, p.419). Then, the "Meat" part of these food items was extracted using recipe translation files included with the FARE™ program.

**Table 20: Food items considered as including "Deli Meat".**

| CODE | Description |
|---|---|
| 22301000 | Ham, fresh, cooked, NS as to fat eaten |
| 22301110 | Ham, fresh, cooked, lean and fat eaten |
| 22301120 | Ham, fresh, cooked, lean only eaten |
| 22311000 | Ham, smoked or cured, cooked, NS as to fat eaten |
| 22311010 | Ham, smoked or cured, cooked, lean and fat eaten |
| 22311020 | Ham, smoked or cured, cooked, lean only eaten |
| 22311200 | Ham, smoked or cured, low sodium, cooked, NS as to fat eaten |
| 22311210 | Ham, smoked or cured, low sodium, cooked, lean and fat eaten |
| 22311220 | Ham, smoked or cured, low sodium, cooked, lean only eaten |
| 22311450 | Ham, prosciutto |
| 23322100 | Deer bologna |
| 24201500 | Turkey, light or dark meat, smoked, cooked, NS as to skin eaten |
| 24201510 | Turkey, light or dark meat, smoked, cooked, skin eaten |
| 24201520 | Turkey, light or dark meat, smoked, cooked, skin not eaten |
| 25220010 | Cold cut, NFS |
| 25220390 | Bologna, beef, lowfat |
| 25220400 | Bologna, pork and beef |
| 25220410 | Bologna, NFS |
| 25220420 | Bologna, Lebanon |
| 25220430 | Bologna, beef |
| 25220440 | Bologna, turkey |
| 25220450 | Bologna ring, smoked |
| 25220460 | Bologna, pork |
| 25220470 | Bologna, beef, lower sodium |
| 25220480 | Bologna, chicken, beef, and pork |
| 25220490 | Bologna, with cheese |
| 25220500 | Bologna, beef and pork, lowfat |
| 25220710 | Chorizos |
| 25221210 | Mortadella |
| 25221250 | Pepperoni |
| 25221480 | Mettwurst |
| 25221500 | Salami, NFS |
| 25221510 | Salami, soft, cooked |
| 25221520 | Salami, dry or hard |
| 25221530 | Salami, beef |
| 25221710 | Souse |
| 25221810 | Thuringer |
| 25230110 | Luncheon meat, NFS |
| 25230210 | Ham, sliced, prepackaged or deli, luncheon meat |
| 25230220 | Ham, sliced, low salt, prepackaged or deli, luncheon meat |
| 25230230 | Ham, sliced, extra lean, prepackaged or deli, luncheon meat |
| 25230310 | Chicken or turkey loaf, prepackaged or deli, luncheon meat |
| 25230410 | Ham loaf, luncheon meat |
| 25230430 | Ham and cheese loaf |
| 25230450 | Honey loaf |
| 25230510 | Ham, luncheon meat, chopped, minced, pressed, spiced, not canned |
| 25230520 | Ham, luncheon meat, chopped, minced, pressed, spiced, lowfat, not canned |
| 25230560 | Liverwurst |
| 25230610 | Luncheon loaf (olive, pickle, or pimiento) |
| 25230710 | Sandwich loaf, luncheon meat |
| 25230790 | Turkey ham, sliced, extra lean, prepackaged or deli, luncheon meat |
| 25230800 | Turkey ham |

| CODE | Description |
|---|---|
| 25230810 | Veal loaf |
| 25230820 | Turkey pastrami |
| 25230840 | Turkey salami |
| 25230900 | Turkey or chicken breast, prepackaged or deli, luncheon meat |
| 25230905 | Turkey or chicken breast, low salt, prepackaged or deli, luncheon meat |
| 25231110 | Beef, sliced, prepackaged or deli, luncheon meat |
| 25231150 | Corned beef, pressed |
| 27500050 | Sandwich, NFS |
| 27500100 | Meat sandwich, NFS |
| 27500200 | Wrap sandwich, filled with meat, poultry, or fish, vegetables, and cheese |
| 27500300 | Wrap sandwich, filled with meat, poultry, or fish, and vegetables |
| 27510910 | Corned beef sandwich |
| 27510950 | Reuben sandwich (corned beef sandwich with sauerkraut and cheese), with spread |
| 27511010 | Pastrami sandwich |
| 27513010 | Roast beef sandwich |
| 27513020 | Roast beef sandwich, with gravy |
| 27513030 | Roast beef sandwich dipped in egg, fried, with gravy and spread |
| 27513040 | Roast beef submarine sandwich, with lettuce, tomato and spread |
| 27513050 | Roast beef sandwich with cheese |
| 27513060 | Roast beef sandwich with bacon and cheese sauce |
| 27513070 | Roast beef submarine sandwich, on roll, au jus |
| 27520110 | Bacon sandwich, with spread |
| 27520120 | Bacon and cheese sandwich, with spread |
| 27520130 | Bacon, chicken, and tomato club sandwich, with lettuce and spread |
| 27520135 | Bacon, chicken, and tomato club sandwich, with cheese, lettuce and spread |
| 27520140 | Bacon and egg sandwich |
| 27520150 | Bacon, lettuce, and tomato sandwich with spread |
| 27520160 | Bacon, chicken, and tomato club sandwich, on multigrain roll with lettuce and spread |
| 27520165 | Bacon, chicken fillet (breaded, fried), and tomato club with lettuce and spread |
| 27520166 | Bacon, chicken fillet (breaded, fried), and tomato club sandwich with cheese, lettuce and spread |
| 27520170 | Bacon on biscuit |
| 27520250 | Ham on biscuit |
| 27520300 | Ham sandwich, with spread |
| 27520310 | Ham sandwich with lettuce and spread |
| 27520320 | Ham and cheese sandwich, with lettuce and spread |
| 27520330 | Ham and egg sandwich |
| 27520350 | Ham and cheese sandwich, with spread, grilled |
| 27520360 | Ham and cheese sandwich, on bun, with lettuce and spread |
| 27520370 | Hot ham and cheese sandwich, on bun |
| 27520380 | Ham and cheese on English muffin |
| 27520390 | Ham and cheese submarine sandwich, with lettuce, tomato and spread |
| 27520410 | Cuban sandwich, (Sandwich cubano), with spread |
| 27520540 | Ham and tomato club sandwich, with lettuce and spread |
| 27540110 | Chicken sandwich, with spread |
| 27540130 | Chicken barbecue sandwich |
| 27540290 | Chicken submarine sandwich, with lettuce, tomato, and spread |
| 27540310 | Turkey sandwich, with spread |
| 27540330 | Turkey sandwich, with gravy |
| 27540350 | Turkey submarine sandwich, with cheese, lettuce, tomato and spread |
| 27541000 | Turkey, ham, and roast beef club sandwich, with lettuce, tomato and spread |
| 27560000 | Luncheon meat sandwich, NFS, with spread |
| 27560110 | Bologna sandwich, with spread |
| 27560120 | Bologna and cheese sandwich, with spread |

| CODE | Description |
|---|---|
| 27560510 | Salami sandwich, with spread |
| 27560910 | Cold cut submarine sandwich, with cheese, lettuce, tomato, and spread |

## Deli Cheese

For deli cheese, an analysis using the same option of the FARE™ program was performed on the food items shown Table 21. The analysis was based on Dun & Bradstreet (DNB) ingredients (USDA Nutrient Databank Identifier).

**Table 21: Food items considered as including "Deli Cheese".**

| NDB Code | Description |
|---|---|
| 1004 | Cheese, blue |
| 1005 | Cheese, brick |
| 1009 | Cheese, cheddar |
| 1011 | Cheese, colby |
| 1018 | Cheese, edam |
| 1020 | Cheese, fontina |
| 1022 | Cheese, gouda |
| 1023 | Cheese, gruyere |
| 1024 | Cheese, limburger |
| 1025 | Cheese, monterey |
| 1030 | Cheese, muenster |
| 1035 | Cheese, provolone |
| 1040 | Cheese, swiss |
| 1042 | Cheese, pasteurized process, american, with di sodium phosphate |
| 1043 | Cheese, pasteurized process, pimento |
| 1044 | Cheese, pasteurized process, swiss, with di sodium phosphate |
| 1046 | Cheese food, pasteurized process, american, without di sodium phosphate |

## Deli Salad

The list of foods-as-eaten used to identify deli salad is an update (Table 22) of the one provided for the 2003 FDA/FSIS risk assessment (see [3] appendix 5, p. 429).

**Table 22: Food items considered as "Deli Salad".**

| Code | Description |
|---|---|
| 25240000 | Meat spread or potted meat, NFS |
| 25240110 | Chicken salad spread |
| 25240220 | Ham salad spread |
| 25240310 | Roast beef spread |
| 25240320 | Corned beef spread |
| 27416250 | Beef salad |
| 27420020 | Ham or pork salad |
| 27446200 | Chicken or turkey salad |

| Code | Description |
|---|---|
| 27446205 | Chicken or turkey salad with nuts and/or fruits |
| 27446220 | Chicken or turkey salad with egg |
| 27446300 | Chicken or turkey garden salad (chicken and/or turkey, tomato and/or carrots, other vegetables), no dressing |
| 27446310 | Chicken or turkey garden salad (chicken and/or turkey, other vegetables excluding tomato and carrots), no dressing |
| 27446315 | Chicken or turkey garden salad with bacon (chicken and/or turkey, bacon, cheese, lettuce and/or greens, tomato and/or carrots, other vegetables), no dressing |
| 27446320 | Chicken or turkey (breaded, fried) garden salad with bacon (chicken and/or turkey, bacon, cheese, lettuce and/or greens, tomato and/or carrots, other vegetables), no dressing |
| 27446350 | Oriental chicken or turkey garden salad (chicken and/or turkey, lettuce, fruit, nuts), no dressing |
| 27446355 | Oriental chicken or turkey garden salad with crispy noodles (chicken and/or turkey, lettuce, fruit, nuts, crispy noodles), no dressing |
| 27446360 | Chicken or turkey caesar garden salad (chicken and/or turkey, lettuce, tomato, cheese), no dressing |
| 27446362 | Chicken or turkey (breaded, fried) caesar garden salad (chicken and/or turkey, lettuce, tomatoes, cheese), no dressing |
| 27450010 | Crab salad |
| 27450020 | Lobster salad |
| 27450030 | Salmon salad |
| 27450060 | Tuna salad |
| 27450070 | Shrimp salad |
| 27450080 | Seafood salad |
| 27450090 | Tuna salad with cheese |
| 27450100 | Tuna salad with egg |
| 27450110 | Shrimp garden salad (shrimp, lettuce, eggs, tomato and/or carrots, other vegetables), no dressing |
| 27450120 | Shrimp garden salad (shrimp, lettuce, eggs, vegetables excluding tomato and carrots), no dressing |
| 27450130 | Crab salad made with imitation crab |
| 27450180 | Seafood garden salad with seafood, lettuce, vegetables excluding tomato and carrots, no dressing |
| 27450190 | Seafood garden salad with seafood, lettuce, tomato and/or carrots, other vegetables, no dressing |
| 27450200 | Seafood garden salad with seafood, lettuce, eggs, vegetables excluding tomato and carrots, no dressing |
| 27450210 | Seafood garden salad with seafood, lettuce, eggs, tomato and/or carrots, other vegetables, no dressing |
| 27460490 | Julienne salad (meat, cheese, eggs, vegetables), no dressing |
| 27460510 | Antipasto with ham, fish, cheese, vegetables |
| 27520340 | Ham salad sandwich |
| 27540120 | Chicken salad or chicken spread sandwich |
| 27540320 | Turkey salad or turkey spread sandwich |
| 27550710 | Tuna salad sandwich, with lettuce |
| 27550720 | Tuna salad sandwich |
| 27550750 | Tuna salad submarine sandwich, with lettuce and tomato |
| 32103000 | Egg salad |
| 32203010 | Egg salad sandwich |
| 41203020 | Kidney bean salad |
| 41205070 | Hummus |
| 58101930 | Taco or tostada salad with beef, beans and cheese, fried flour tortilla |
| 58101940 | Taco or tostada salad, meatless, with cheese, fried flour tortilla |

| Code | Description |
|---|---|
| 58148110 | Macaroni or pasta salad |
| 58148120 | Macaroni or pasta salad with egg |
| 58148130 | Macaroni or pasta salad with tuna |
| 58148140 | Macaroni or pasta salad with crab meat |
| 58148150 | Macaroni or pasta salad with shrimp |
| 58148160 | Macaroni or pasta salad with tuna and egg |
| 58148170 | Macaroni or pasta salad with chicken |
| 58148180 | Macaroni or pasta salad with cheese |
| 58148500 | Pasta or macaroni salad with oil and vinegar-type dressing |
| 58148550 | Pasta or macaroni salad with meat |
| 71601010 | Potato salad with egg |
| 71602010 | Potato salad, German style |
| 71603010 | Potato salad |
| 72116140 | Caesar salad (with romaine) |
| 73101010 | Carrots, raw |
| 73101110 | Carrots, raw, salad |
| 73101210 | Carrots, raw, salad with apples |
| 74506000 | Tomato and cucumber salad made with tomato, cucumber, oil, and vinegar |
| 75140500 | Broccoli salad with cauliflower, cheese, bacon bits, and dressing |
| 75141000 | Cabbage salad or coleslaw, with dressing |
| 75141100 | Cabbage salad or coleslaw with apples and/or raisins, with dressing |
| 75141200 | Cabbage salad or coleslaw with pineapple, with dressing |
| 75142500 | Cucumber salad with creamy dressing |
| 75142550 | Cucumber salad made with cucumber, oil, and vinegar |
| 75142600 | Cucumber salad made with cucumber and vinegar |
| 75143000 | Lettuce, salad with assorted vegetables including tomatoes and/or carrots, no dressing |
| 75143050 | Lettuce, salad with assorted vegetables excluding tomatoes and carrots, no dressing |
| 75143100 | Lettuce, salad with avocado, tomato, and/or carrots, with or without other vegetables, no dressing |
| 75143200 | Lettuce, salad with cheese, tomato and/or carrots, with or without other vegetables, no dressing |
| 75143300 | Lettuce, salad with egg, tomato, and/or carrots, with or without other vegetables, no dressing |
| 75143350 | Lettuce salad with egg, cheese, tomato, and/or carrots, with or without other vegetables, no dressing |
| 75144100 | Lettuce, wilted, with bacon dressing |
| 75145000 | Seven-layer salad (lettuce salad made with a combination of onion, celery, green pepper, peas, mayonnaise, cheese, eggs, and/or bacon) |
| 75146000 | Greek Salad |
| 75147000 | Spinach salad, no dressing |
| 75148000 | Cobb salad with dressing |
| 75201030 | Artichoke salad in oil |
| 75302080 | Bean salad, yellow and/or green string beans |
| 75416500 | Pea salad |
| 75416600 | Pea salad with cheese |

*Results*

The FARE™ program provides bins of grams per eating occasion and corresponding weighted occurrences for breakfast, lunch, dinner and snack as well as a Total. As an example, 537,349 (weighted) eating occasions of (0.35-0.70)g of deli cheese are recorded in the 1999-2006 NHANES data base.

| g | | | Occurrences per defined eating occasion (1000): | |
|---|---|---|---|---|
| per eating occ | | | SNACKS | Total |
| 0 | to | 0.3 | 123313 | 222637 |
| 0.3502069 | to | 0.7004138 | 211539 | **537349** |
| 0.700414 | to | 1.050621 | 214141 | 787902 |
| 1.050621 | to | 1.400828 | 163497 | 763834 |
| 1.400828 | to | 1.751034 | 185311 | 744600 |
| 1.751034 | to | 2.101241 | 100822 | 908607 |
| 2.101241 | to | 2.451448 | 337827 | 1246231 |
| 2.451448 | to | 2.801655 | 34015 | 643428 |
| 2.801655 | to | 3.151862 | 136648 | 579838 |
| 3.151862 | to | 3.502069 | 72437 | 536624 |
| … | | | | |

The cumulative distribution of the serving size per eating occasion for deli meat, deli cheese, and deli salad for the total, the pregnant, and the senior populations are provided in Figure 64, Figure 65 and Figure 66.

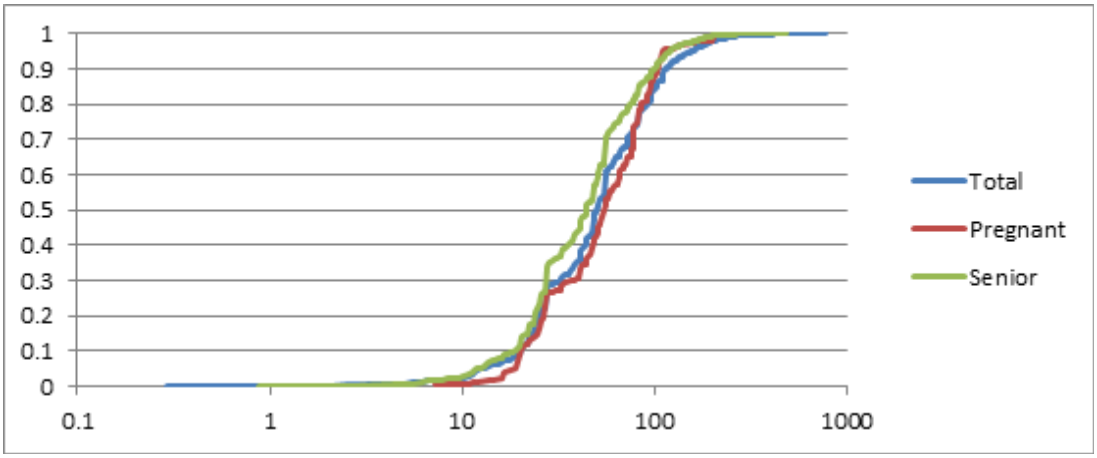


**Figure 64: Empirical cumulative density function of the serving size per eating occasion (unit: g/EO) for deli-meat for the total population, the pregnant women and the seniors (55+): data NHANES 1999-2006.**

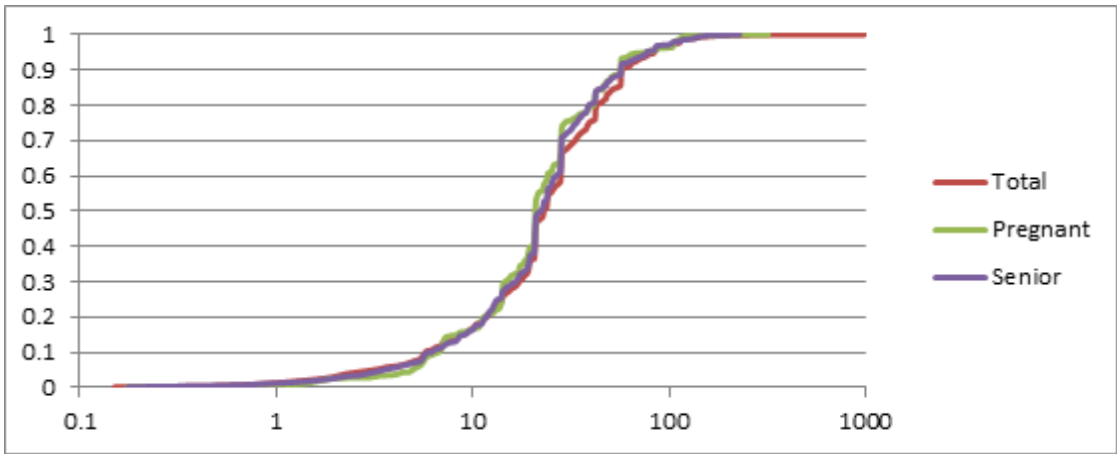


**Figure 65: Empirical cumulative density function of the serving size per eating occasion (unit: g/EO) for deli-cheese for the total population, the pregnant women and the seniors (55+): data NHANES 1999-2006**

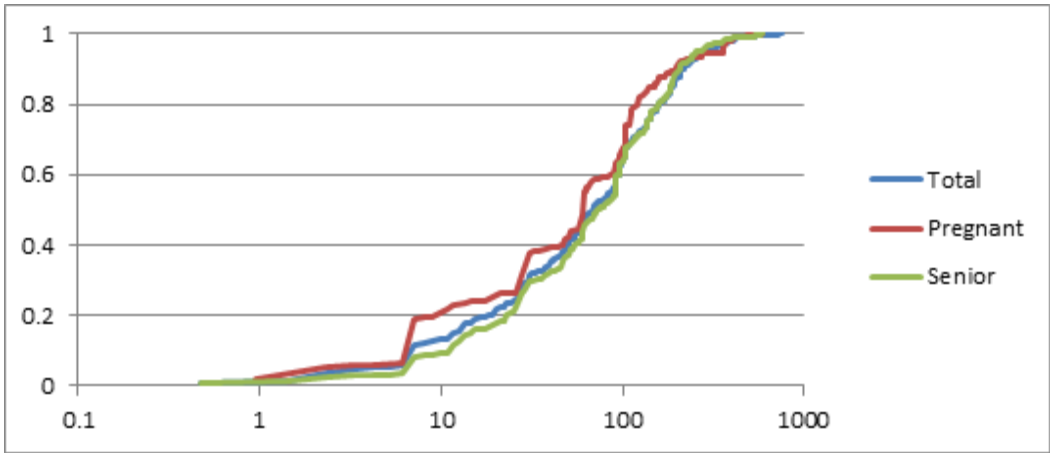


**Figure 66: Empirical cumulative density function of the serving size per eating occasion (unit: g/EO) for deli-salad for the total population, the pregnant women and the seniors (55+): data NHANES 1999-2006**

*Simulation*

In order to provide simulated serving sizes within this interagency *L. monocytogenes* in retail risk assessment model, we use the following algorithm:

- from the FARE results, one bin is randomly sampled proportionally to its number of occurrence;
- then, a serving size is randomly sampled uniformly within the bounds of this bin;
- the value is rounded to the upper gram.

The resulting empirical cumulative distributions and their relative statistics for the overall population are provided Figure 11 of this document.