Salmonella Enteritidis Risk Assessment

Shell Eggs and Egg Products

Final Report

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Prepared for The Food Safety and Inspection Service
by the *Salmonella* Enteritidis Risk Assessment Team

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The *Salmonella* Enteritidis Risk Assessment Team wishes to explicitly state that the results of our efforts in producing this document were only possible because of the help we received from many individuals who are recognized as experts in their respective fields. It is because we were able to stand on the shoulders of these experts, who are giants in their fields, that we were able to see further. In the words of Samuel Taylor Coleridge, "A dwarf sees farther than the giant when he has the giant's shoulders to mount on." (The Friend, sect. I. essay viii).

The *Salmonella* Enteritidis Risk Assessment Team acknowledges the contributions of Kaye Wachsmuth to developing the capacity of the Food Safety and Inspection Service for conducting risk assessment and to developing the skills of the *Salmonella* Enteritidis Risk Assessment Core Group.

We also acknowledge the members of the Resource Group for their critical review of early drafts and for providing data with which to support the *Salmonella* Enteritidis Risk Assessment for Shell Eggs and Egg Products. They were invaluable to our effort. We thank them, and we salute them.

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Executive Summary

This document summarizes the risk assessment process from the development of a conceptual framework to the careful organization of information obtained from published scientific literature and unpublished academic, government and industry sources, to the incorporation of available data into a comprehensive quantitative model which characterizes the public health effects associated with the consumption of *Salmonella* Enteritidis-infected shell eggs and egg products.

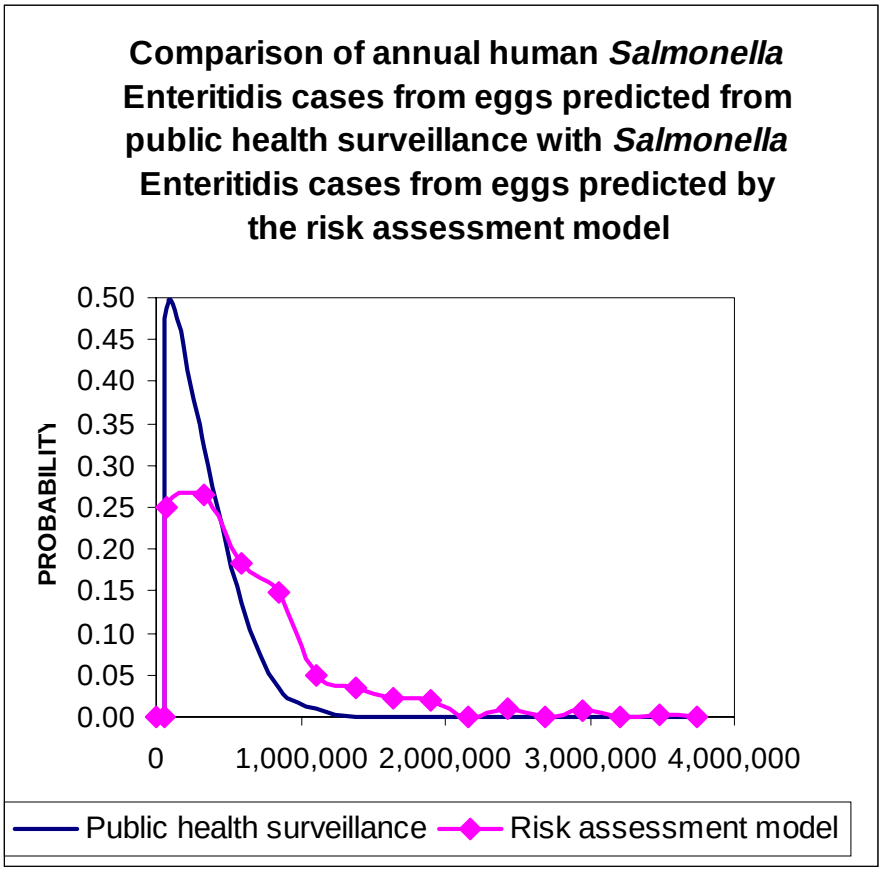
The Food Safety and Inspection Service (FSIS) began a comprehensive risk assessment of *Salmonella enterica* serotype Enteritidis (*Salmonella* Enteritidis) in December 1996 in response to an increasing number of human illnesses associated with the consumption of shell eggs. The objectives of this risk assessment are to: establish the unmitigated risk of foodborne illness from *Salmonella* Enteritidis, identify and evaluate potential risk reduction strategies, identify data needs, and prioritize future data collection efforts. The risk assessment model consists of five modules. The first module, the Egg Production Module, estimates the number of eggs produced that are infected (or internally contaminated) with *Salmonella* Enteritidis. The Shell Egg Module, the Egg Products Module, and the Preparation and Consumption Module estimate the increase or decrease in the numbers of *Salmonella* Enteritidis organisms in eggs or egg products as they pass through storage, transportation, processing, and preparation. The Public Health Module then calculates the incidences of illnesses and four clinical outcomes (recovery without treatment, recovery after treatment by a physician, hospitalization, and mortality) as well as the cases of reactive arthritis associated with consuming *Salmonella* Enteritidis positive eggs.

The baseline model for shell eggs presented in this report simulates an average production of 46.8 billion shell eggs per year in the U.S., 2.3 million of which contain *Salmonella* Enteritidis. The consumption of these eggs results in a mean of 661,633 human illnesses per year ranging from 126,374 to 1.7 million cases per year (5^{th} and 95^{th} percentiles) as shown in Table 3. It is estimated that about 94% of these cases recover without medical care, 5% visit a physician, an additional 0.5% are hospitalized, and 0.05% of the cases result in death. Twenty percent of the population is considered to be at a higher risk for salmonellosis from *Salmonella* Enteritidis (i.e. infants, elderly, transplant patients, pregnant women, individuals with certain diseases) because they may be more susceptible to infection and because they may disproportionately experience the manifestations of *Salmonella* Enteritidis infection.

A comparison of the total number of illnesses due to *Salmonella* Enteritidis positive eggs simulated with this model, with a distribution of illnesses from *Salmonella* Enteritidis positive eggs predicted from national public health surveillance shows substantial overlap between these two independently derived distributions (see **Figure 1**). The surveillance data has been used to derive an estimate of *Salmonella* Enteritidis related human illnesses averaging 637,000 cases per year with a range from 254,000 to 1,167,000 cases of human illness from *Salmonella* Enteritidis positive eggs. The median estimates for this simulation model and the surveillance data are 504,082 cases and 332,400 cases of human illness from *Salmonella* Enteritidis positive eggs per year, respectively. Such agreement suggests the model is reasonably accurate in its depiction of the number of cases of human illnesses due to *Salmonella* Enteritidis positive eggs in the U.S.

Figure 1

The baseline egg products model predicts that the probability is low that any cases of *Salmonella* Enteritidis will result from the consumption of pasteurized egg products. However, the current FSIS time and temperature regulations do not provide sufficient guidance to the egg products industry for the large range of products the industry produces. Time and temperature standards based on the amount of bacteria in the raw product, how the raw product will be processed, and the intended use of the final product will provide greater protection to the consumers of egg products.



Mitigation elasticity is an indication of how changes in module variables affect model output. For example, a 25 percent reduction in a few input variables were simulated as examples of how this elasticity could be used. No single input variable modeled as a potential mitigation achieved an equivalent reduction (i.e. 25%) in total human illnesses. However, combinations of mitigations may potentially be more effective in reducing total human illnesses (i.e., a Mitigation elasticity $\geq$ 1). In one such combination of mitigations in the Production Module and in the Preparation & Consumption Module an equivalent reduction (i.e. 25%) in human illnesses resulted. This finding implies that a broadly based policy may be more effective than a policy directed solely at one area of the egg production-to-consumption chain.

The percent reduction for total human illnesses was calculated for two scenarios within the Shell Egg Processing and Distribution module. In the first scenario we found a 12% reduction in human illnesses if all eggs are **immediately cooled after lay to an internal temperature of 45° F**, then maintained at that temperature throughout shell egg processing and distribution as opposed to the current diversity of temperatures experienced throughout this stage of production. In the second scenario we found a 8% reduction in illnesses when **eggs are maintained at an ambient (i.e air) temperature of 45° F throughout shell egg processing and distribution** compared to current practices. These two scenarios represent the best results that could be expected from implementing temperature strategies during shell egg processing and distribution.

Executive Summary

Mitigation elasticity measures the effect of specific interventions. We compared the effect of diverting eggs from *Salmonella* Enteritidis positive flocks out of the shell egg market and into the egg products market for pasteurization and found a substantial reduction in the number of illnesses.

Some cautions on the appropriate use of this risk assessment are in order. This risk assessment effort is a significant advancement in our ability to comprehensively model risk throughout the egg and egg products continuum. The model can continually be refined and updated for use in future risk assessments for shell eggs and egg products. Furthermore, the farm-to-table approach provides a framework for developing similar risk assessment efforts for other pathogen-product pairs, or for other livestock production systems. However, the risk assessment results provide only part of the information needed by decision makers and regulators. Cost-benefit analyses will need to be applied to the risk assessment results to provide additional information for formulating efficient policy. The risk assessment results detailed in this Final Report will be used by the agency, working in conjunction with economists from within and from outside the agency, to conduct cost-effectiveness studies and cost-benefit analysis in order to set forth recommendations for policy.

Introduction

Human illnesses attributed to the consumption of shell eggs has increased in recent years. From 1976 to 1995, the occurrence of *Salmonella enterica* serotype Enteritidis in humans increased from 1,207 isolates identified in 1976 (0.6 isolates/100,000 population) to 10,201 in 1995 (4.0/100,000 population). *Salmonella* Enteritidis was the serotype most frequently reported to the Centers for Disease Control and Prevention in 1990, 1994, 1995, and 1996. *Salmonella* Enteritidis accounted for 24.5% of all Salmonella isolates reported in 1996 (CDC, 1996). Costs associated with human salmonellosis due to *Salmonella* Enteritidis are estimated to range from $150 million to $870 million annually.

Outbreaks and sporadic cases of *Salmonella* infections continue to show an association with the consumption of raw or undercooked shell eggs, a source which was first identified by St Louis et al. in 1988 (St. Louis, 1988; Hedberg, 1993; Passaro, 1996). A vehicle was implicated in 45% of the human outbreaks of *Salmonella* Enteritidis: shell eggs constituted 82% of this group (38% of total outbreaks) between 1985 and 1991 (Mishu, 1994).

The results of a USDA survey of spent hens at slaughter and unpasteurized liquid eggs at breaker plants in 1991 and 1995 reveals an increase in the prevalence of *Salmonella* Enteritidis isolates overall in most regions of the U.S. (Hogue, 1997a). These survey data are consistent with human isolate data in that neither poultry nor human data shows a decline in SE since 1991. However, there is no apparent correlation between SE in humans, layer flocks, and unpasteurized liquid egg across regional areas of the US. Controls for SE at the national level including the SE trace back regulation (USDA, 1991) and intensified efforts to educate food handlers and enforce safe food handling practices have not reduced human SE isolates or the prevalence of SE in flocks or unpasteurized liquid eggs (Hogue, 1997b).

Project History

The Food Safety and Inspection Service (FSIS) began a comprehensive risk assessment of *Salmonella* Enteritidis in December 1996. The agency initiated this project in response to an increasing number of human illnesses attributed to the consumption of eggs, despite implementation of the USDA SE regulation from 1990 to 1995 and the intensified efforts to educate food handlers and enforce safe food handling practices. The report documents the objectives and results of this risk assessment which are: 1) to model from farm to table the unmitigated risk of foodborne illness due to SE from the consumption of eggs and egg products; 2) to identify target areas along the farm-to-table continuum for potential risk reduction activities; 3) to compare the public health benefits accruing from the mitigated risk of SE foodborne illness with the implementation of various intervention strategies; 4) to provide information on risk-effectiveness of mitigation to be utilized by the agency for subsequent cost-effectiveness and cost-benefit analysis; 5) to identify data gaps and guide future research and data collection efforts. This quantitative risk assessment for shell eggs and egg products extends from pullet through production, processing, transportation, preparation, consumption, to human illness (production-to-consumption).

Introduction

The risk assessment provides FSIS and the Food and Drug Administration (FDA) decision makers with a tool to develop an integrated risk reduction strategy. Regulatory authority for shell eggs and egg products is shared between FSIS and FDA. FSIS has sole authority for egg products processing under the Egg Products Inspection Act (EPIA). FDA has authority after shell eggs and egg products leave officially inspected plants.

The shell eggs and egg products risk assessment group is a project team consisting of a multi-disciplinary group of scientists drawn from a range of government agencies and academia. Team members were selected for their technical skills and capability for working in a team environment. The team is composed of a core or working group of seven individuals and a resource group. The core group had primary responsibilities for model research, development and documentation, quantitative risk assessment, sensitivity analyses, identification of data needs, and project planning, coordination and report writing. The resource group was a pool of technical specialists which was available for support in the identification of data sources and intervention strategies, and for support in model refinement, evaluation and interpretation.

Transparency of the process and input from stakeholders are essential features of a successful risk assessment. Stakeholder input was solicited on several occasions throughout the risk assessment process. On September 3, 1997, a Technical Meeting was held in Arlington, VA to inform the public about the current status of the risk assessment. The technical meeting was announced 1) in a Federal Register notice, 2) on the FSIS website and 3) through several electronic list servers. A document entitled "Parameter Values for a Risk Assessment of *Salmonella* Enteritidis in Shell Eggs and Egg Products" was placed on the FSIS website during the week prior to the meeting, distributed at the meeting, and remains available on the website. The document described the general structure of the risk assessment and tentative values (based on evidence) to be used in the development of a quantitative model. During the meeting, presentations were made by the core risk assessment team detailing the model development process, data that had been assembled and evaluated to date, and the anticipated schedule for project completion. Requests for feedback and additional input were made throughout the meeting.

The core risk assessment team also accepted two invitations to present the current work on the risk assessment model. Both occasions were viewed as additional opportunities to engage stakeholders in the risk assessment process and obtain their input. The first invited presentation was at the Veterinary Epidemiology and Economics Conference held in August, 1997 at Fort Collins, CO. Presentations during this conference were of a similar nature to those made during the Technical Meeting in September. The second invited presentation was at the International Poultry Exposition on January 20, 1998 in Atlanta, GA. The current status of the risk assessment model was presented, including influence diagrams and evidence that was to be used in conducting the risk assessment. At both meetings, feedback and additional input were again requested.

All comments, data and feedback received from the above meetings were evaluated and incorporated into the risk assessment where appropriate. Feedback received by the FSIS dockets office or by the core team members from all three meetings was limited. As stakeholder input is received, or other forms of data such as new relevant research becomes available, such information will be evaluated and incorporated as evidence into the risk assessment.

Model Description and Uses

A. Conceptual Framework

During the first phase of the risk assessment, a process flow chart for shell eggs and egg products was developed to guide evidence gathering and the initial stages of modeling (see **Figure 2**, page 8). The general model was subdivided into 5 modules: egg production, shell egg processing and distribution, egg products processing and distribution, food preparation and consumption, and public health. Inputs and outputs for each module were established early in the model development to guide evidence collection and insure that information generated in one module would be useable in the next module. Extensive literature searches were conducted to identify the issues and data relevant to the quantitative risk assessment. Evidence collected from both published and unpublished sources underwent critical evaluation with respect to study design and quality of collected data.

The next phase of the risk assessment was the development and refinement of the five modules. Detailed influence diagrams were developed to represent the relevant risk pathways in each module (see individual module documentation for influence diagrams). A second and more focused literature search was conducted to fill data gaps. Requests for specific data were also extended to researchers, regulatory agencies and the egg industry during this time period. The available data was incorporated into spreadsheets (Microsoft Excel®) consistent with the established pathways described in the influence diagrams. The modules were linked into a single model and estimates of the incidence of human illness and of the values for intermediate steps in the model were calculated using a commercial risk assessment software package (@Risk®, Palisade Corporation). Sensitivity analysis was performed on the modules to determine the variables that most influenced the distribution of SE positive eggs and the distribution of SE organisms in positive eggs. The modules were sequentially linked to simulate the distribution of human illnesses due to SE.

B. Module Descriptions

1. Egg Production Module: The purpose of the egg production module is to simulate the annual SE positive egg frequency for U.S. commercial flocks (see module diagram on Page 29). The module simulates mitigation strategies that affect the frequency of SE positive eggs. The input to this module is the number of commercial egg production flocks. Outputs from this module are the number (or frequency) of SE-positive eggs produced by the number of egg production flocks considered. The number of SE organisms per SE-positive egg is also an output from this module. Flocks are categorized into different groups based on the within-flock prevalence of SE and the molting status of the flock.

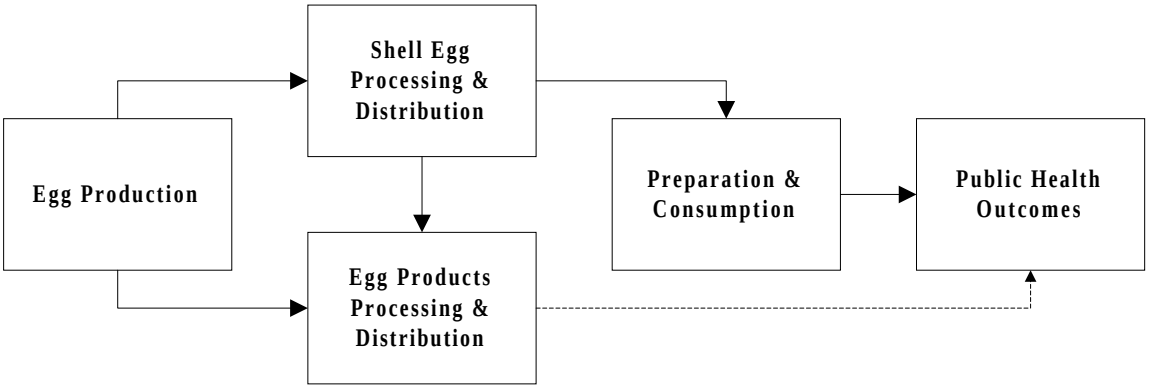
2. Shell Egg Processing & Distribution Module: This module follows the shell eggs from collection on the farm through processing, transportation, and storage. Output from this module goes to the Preparation and Consumption Module (see module diagram on page 77). The eggs remain intact throughout this module, therefore, the primary factors affecting the SE are the cumulative temperatures and times of the various processing, transportation, and storage stages. The two important modeling components of this module are the time until the yolk membrane loses its integrity and the growth rate of SE in eggs after breakdown of the yolk membrane. Estimates of the times and temperatures and their ranges for various processing, transportation, and storage stages are included.

3. Egg Products Processing & Distribution Module: This module tracks the change in numbers of SE in egg processing plants from receiving through pasteurization (see module diagram on page 115). The results of simulations of mitigation strategies are compared with the baseline levels to determine the effect of a mitigation or a group of mitigations on the frequency of SE in egg products. There are two sources of SE in egg products: SE from the internal contents of eggs (from the Production Module) and SE from cross-contamination during breaking.

4. Preparation & Consumption Module: This module describes exposure from the consumption of eggs and egg-containing foods that are contaminated with SE (see module diagram on page 149). Shell eggs for end-user consumption are assumed to have an associated probability and level of contamination. The effect of further storage times and ambient temperatures on growth of the organisms is modeled. Common preparation and cooking methods and their

Figure 2

Farm-to-table Risk Assessment Model for Eggs and Egg Products



effect on decreasing the level of exposure are also modeled.

5. Public Health Module: This module links exposure to foods containing SE from eggs with the public health outcomes of morbidity and mortality which arise from the ingestion of SE organisms (see module diagram on page 195). These public health outcomes include infection without illness, illness, and the subsequent consequences of illness which may include physician visits, treatment, hospitalization, post-infection sequelae, and death. The outcome from exposure to foods containing SE from eggs for the individual varies widely and is a function of the individual's age, health status, immune status, number of bacteria consumed, the fat content of the food vehicle, and other factors such as pregnancy and the presence of liver disease or kidney disease.

C. Scope of This Risk Assessment

The scope of this risk assessment is to model *Salmonella* Enteritidis from internally contaminated eggs (eggs that have SE bacteria inside the shell when the eggs are laid) from production, through consumption and human illness. The model calculates a baseline occurrence of human illness from current data on the prevalence of SE positive eggs and from current egg production, processing, distribution, and consumption practices in the U.S. Several mitigations are modeled and the resulting number of human illnesses is compared with the baseline as a means for measuring the expected benefit of the mitigation.

This risk assessment models *Salmonella* Enteritidis from internally contaminated eggs (i.e. eggs that have SE bacteria inside the shell when the eggs are laid). Several sources of contamination are excluded by modeling only internally contaminated eggs:

1) *Salmonella* Enteritidis contamination of eggs which occurs after eggs are laid is not considered in the shell egg module. Shell penetration by *Salmonella* spp. or other bacteria can occur when bacteria migrate through pores in the shell of the egg. Shell penetration has been demonstrated experimentally by cooling eggs in a water bath containing bacteria. Water and bacteria are drawn through the shell as the air sac within the egg contracts. Although shell penetration by *Salmonella* spp. can occur, it probably does not occur frequently under commercial conditions because serotypes other than *S*. Enteritidis are rarely found in the internal contents of eggs. If shell penetration was a common mechanism of *Salmonella* entry into eggs, then *Salmonella* of all serotypes common to poultry would be expected to be found in the egg contents at frequencies similar to that of *S*. Enteritidis. This condition, however, is not the case.

In the egg products module *Salmonella* Enteritidis from all sources including contamination during breaking is modeled. This exception was made because preliminary modeling efforts indicated that the contamination during the process

of breaking eggs was a significant source of *Salmonella* Enteritidis in egg products. Efforts to reduce the load of SE in egg products must consider the source of contamination.

2) Human illness from sources other than eggs is not considered in this model. Eggs are the most commonly identified source of SE in cases of human illness from SE, but eggs are not the only source of SE in cases of human illness. A vehicle was implicated in 45% of the human outbreaks of SE: shell eggs constituted 82% of this group (38% of total outbreaks) between 1985 and 1991 (Mishu, 1994). Illness from SE can occur from a food source other than eggs.

The number of SE positive eggs is calculated from current data on the prevalence of SE positive eggs and from current egg production practices in the U.S. Several important considerations are excluded by modeling the current situation in the U.S. without considering changes likely to occur over time:

1) SE phage type 4 (SE pt4) has recently emerged in the egg industry in the western U.S. concurrent with a sharp increase in the number of sporadic cases of human salmonellosis due to SE phage type 4 (SE pt4) in California and Utah. From April to July 1994, 496 cases of SE infection were reported in Los Angeles County; nearly five times the number of cases reported from April to July 1993 (Passaro, 1996). In a 1995 survey of unpasteurized liquid egg, SE pt4 was the predominant phage type found in the Western APHIS Region of the U.S. (Hogue, 1997a). A survey of spent hens at slaughter also found SE pt4 to be one of the predominant phage types in the Western Region. Except for one liquid egg sample from the Southeast Region, all SE pt4 isolates found in both surveys were from the Western Region. In contrast, SE pt4 was not detected in the 1991 spent hen or liquid egg surveys (Ebel, 1992).

Although not clearly defined, the potential threat of SE pt4 to both human health and the poultry industry may be greater than that of other phage types. Some SE phage type 4 strains may be better adapted to withstand current food preparation practices (Humphrey, 1995). SE pt4 has become a problem in the broiler industry in the United Kingdom where the phage type contributes to human illness from the consumption of contaminated poultry meat. In the SE pandemic which has affected Europe and the UK since 1980, the rate of human salmonellosis has increased and SE pt4 has become the predominant *Salmonella* phage type. The current situation in the U.S. appears to be following a similar epidemic pattern (Hogue, 1997b).

2) There is evidence that over time SE is becoming a more common cause of salmonellosis in humans in the U.S., however, this trend is not reflected in the model. From 1976 to 1995 the occurrence of SE in humans increased from 1,207 isolates identified in 1976 (0.6 isolates/100,000 population) to 10,201 in 1996 (4.0/100,000 population) (CDC, 1996).

3) The proportion of the U.S. production of eggs used by the egg products industry has increased significantly in recent years and will likely continue to increase. Since egg products are processed very differently than shell eggs, the level of exposure to SE from egg products is significantly different from the level of exposure to SE from shell eggs. The increasing trend in the use of egg products in the U.S. is not part of the model structure.

Several mitigations are modeled and the resulting number of human illnesses is compared with the baseline as a means of measuring the expected benefit of the mitigation. Several important considerations are excluded from the modeling of a mitigation:

1) The mitigations which are modeled are not a comprehensive listing of all possible mitigations but are simply examples of some mitigations. Agencies with authority over portions of the farm-to-table continuum can use the baseline model and example mitigations to develop and evaluate other mitigations the agencies are considering. Various combinations of mitigations can also be simulated with this model to identify the most effective and feasible approaches to the reduction of human illness due to SE in eggs and egg products.

2) The results provided for mitigation modeling here do not include the costs of the mitigations which is an important consideration from a risk management perspective.

3) The model does not report the effect of current mitigations separate from the baseline results. For example, egg producers are enrolled in quality assurance programs to reduce the level of SE in their flocks, and food handlers take measures to reduce cross contamination and ensure that adequate cooking occurs. To the extent that these practices are reflected in the data used to develop this model, the results include these effects.

4) Based on FoodNet data it appears that on the average people experience 1.3 cases of diarrhea per person per year. It is generally recognized that 80-95% of cases of diarrhea are due to non-bacterial causes. For this reason it is very unlikely for an individual to experience more than one case of salmonellosis from SE-positive eggs per year. For the purposes of this model the assumption is made that no one individual experiences more than one case of salmonellosis from SE-positive eggs per year. It is difficult to determine whether there are individuals who are exposed to SE-positive eggs more than once per year and have one or more episodes of salmonellosis from SE-positive eggs or develop intestinal immunity to SE. For the purposes of the model a simplifying assumption is made that no individual experiences more than one case of salmonellosis from SE-positive eggs per year.

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Results of Baseline Model

The objective of the baseline model is to provide a point of reference for modeling strategies intended to reduce the occurrence of SE infection in humans from eggs and egg products. The model consists of five modules. The modules are specified using available data which represents our best understanding of the ecology of SE in layer hens, shell eggs, and human behavior in the U.S. The baseline results are also not time-specific, nor do they refer to any specific year's egg production or human illness incidence. However, the data used to develop the module variables generally references the period from 1989, when SE became a recognized problem in the U.S., to the present.

The baseline model estimates the potential number of human illnesses per year in the U.S. using the five modules' reference specifications. The baseline model results for eggs consumed as shell eggs reflect all the information and uncertainty contained within the Production Module, Shell Egg Processing/Transportation Module, Preparation/Consumption Module, and Public Health Outcomes Module.

Baseline model reference specifications and results are expressed as a probability vs. frequency distributions rather than as point estimates. These distributions reflect our current state of knowledge about particular variables based on the available evidence. For example, current knowledge of the number of SE in a infected egg at lay is limited. Only two studies exist with relatively few data points and the reported values are widely spread. The model reflects this dearth of information by using a wide probability distribution for this variable.

Baseline model results are generated by linking together the Production, Shell Egg Processing/Distribution, Preparation/Consumption, and Public Health Outcomes modules into one spreadsheet program. One simulation of this model comprises 1000 iterations. Each iteration consists of randomly selecting a single value from each of the probability vs. frequency distributions represented in the model, then completing all calculations using these randomly selected values. The complete model was developed using Excel® (Microsoft Corporation), and simulations were completed using @Risk® (Palisades Corporation). The sampling method used during simulations was Latin Hypercube (Vose, 1996).

During each iteration of a simulation, the Production module calculates the number of SE-positive eggs produced in one year, as well as the number of these eggs that are marketed as shell eggs. For each iteration, the Shell Egg Processing/Distribution module calculates the time, temperature, and SE-growth for the number of SE-positive shell eggs calculated in the Production module. Similarly, the Preparation/Consumption module calculates the final number of SE organisms per meal served - and the total number of servings at the various dose levels - for SE-positive shell eggs calculated in the Production module after those eggs have been processed and distributed. Finally, the Public Health Effects module calculates the number of human illnesses resulting from exposure to meals containing varying levels of SE per serving.

Results

The number of iterations used in the baseline model should be sufficiently large to produce stable results. Model convergence measures the percent change in results over successive iterations of a model. We analyzed the total number of human SE-cases per year as the output from the baseline model to measure that model's convergence. The model was considered stable when the percent change in the mean and standard deviation of human SE-cases per year was less than 1.5% from one iteration to the next. The baseline model converged just before its 1000th iteration. To accomplish a 1000 iteration simulation of the baseline model took approximately 3 hours.

Number of SE Infected Eggs

The Production Module estimates that of the total of 65 billion eggs produced per year, 47 billion eggs are consumed as shell (or table) eggs and 18 billion eggs are sent to egg breaker plants for the production of egg products. The Production Module estimates 2.3 million shell eggs (of the 47 billion shell eggs) are, on average, SE-positive eggs. The number of SE bacteria per egg ranges from 1 to 400 SE bacteria, with most eggs containing less than 40 SE bacteria. Because eggs are pooled and used as ingredients during the preparation of meals in institutions, restaurants and homes, the Preparation & Consumption Module predicts that these contaminated eggs will contribute to an average of 10.2 million individual servings (i.e., an average of 4.0 servings per egg). Of these 10.2 million potentially risky servings, an average of 73% contain no SE bacteria. In these cases, the SE bacteria originally inside of shell eggs were destroyed during cooking. Therefore, all human illnesses result from the 2.7 million servings per year which contain one or more SE bacteria.

Number of Illnesses

Results of the SE risk assessment model are presented on the basis of human illnesses. Human illnesses are stratified into four mutually exclusive categories: illness and recovery without medical care, illness with a physician visit, illness with hospitalization, and illness resulting in death. A specific case is assigned to one of these four categories depending on the most severe outcome. Therefore, a case resulting in hospitalization is only recorded as such, even though it probably involved a physician visit as well. Reactive arthritis, a sequel to some cases of salmonellosis, is reported as a separate outcome. Reactive arthritis is a subgroup of illness and not a separate illness grouping (i.e., reactive arthritis may be a sequela to cases who recovered without medical care, or from those cases who visited a physician, or were hospitalized).

The baseline model predicts a mean of 18.8 human illnesses in the U.S. per year per million eggs consumed as shell eggs with a range of 4.0 to 45.8 human illnesses (5th and 95th percentiles). Alternatively, based on simulations of 47 billion shell eggs produced annually, 2.3 million of which contain SE, the consumption of those eggs result in a mean of 661,633 cases of human illness per year with the 5th and 95th percentiles of this distribution at 126,374 and 1.7 million cases, respectively.

The baseline model predicts there are about 188 billion egg-containing servings prepared from shell eggs each year (i.e., 47 billion shell eggs X 4 servings/egg). From these servings, the model predicts an average of 661,633 human cases of SE. Therefore, the predicted average risk is 3.5 SE illnesses per 1 million egg-containing servings per year.

Results

The human health impact was calculated for normal and susceptible populations. The susceptible population includes infants, elderly, pregnant women, and people with medical conditions that compromise their immune system. The susceptible population is estimated to be about 20% of the U.S. population. Total illnesses in the normal and susceptible sub-populations occur at frequencies roughly consistent with the proportion of the population in each group. Using mean illnesses per million eggs consumed, approximately 9.55 (68%) of the 14.08 cases are predicted to occur in normal individuals and the remaining 32% of cases are predicted to occur in susceptible individuals.

However, susceptible individuals experience more severe manifestations of SE infection than normal individuals. In addition to their disproportionate contribution to deaths, susceptible individuals represent 57% (0.04 ÷ 0.07) of the hospitalized SE cases, and 40% (0.31 ÷ 0.77) of cases requiring a physician visit. Of all surviving cases, almost three in every one hundred cases are predicted to experience reactive arthritis subsequent to their illness. Susceptible individuals are not over-represented in this group.

Table 1. Number of Predicted Illnesses and Sequelae in the United States per Million Shell Eggs Consumed

Total Shell Eggs	***Baseline model results***		
47 billion per year	*Normal*	*Susceptible*	**Total**
Acute Illness			
Recovery without medical care	9.05	4.18	13.23
Physician visit	0.46	0.31	0.77
Hospitalization	0.03	0.04	0.07
Death	0.00	0.01	0.01
Total	**9.55**	**4.53**	**14.08**
Post-Illness Sequelae			
Reactive arthritis	0.29	0.14	0.43

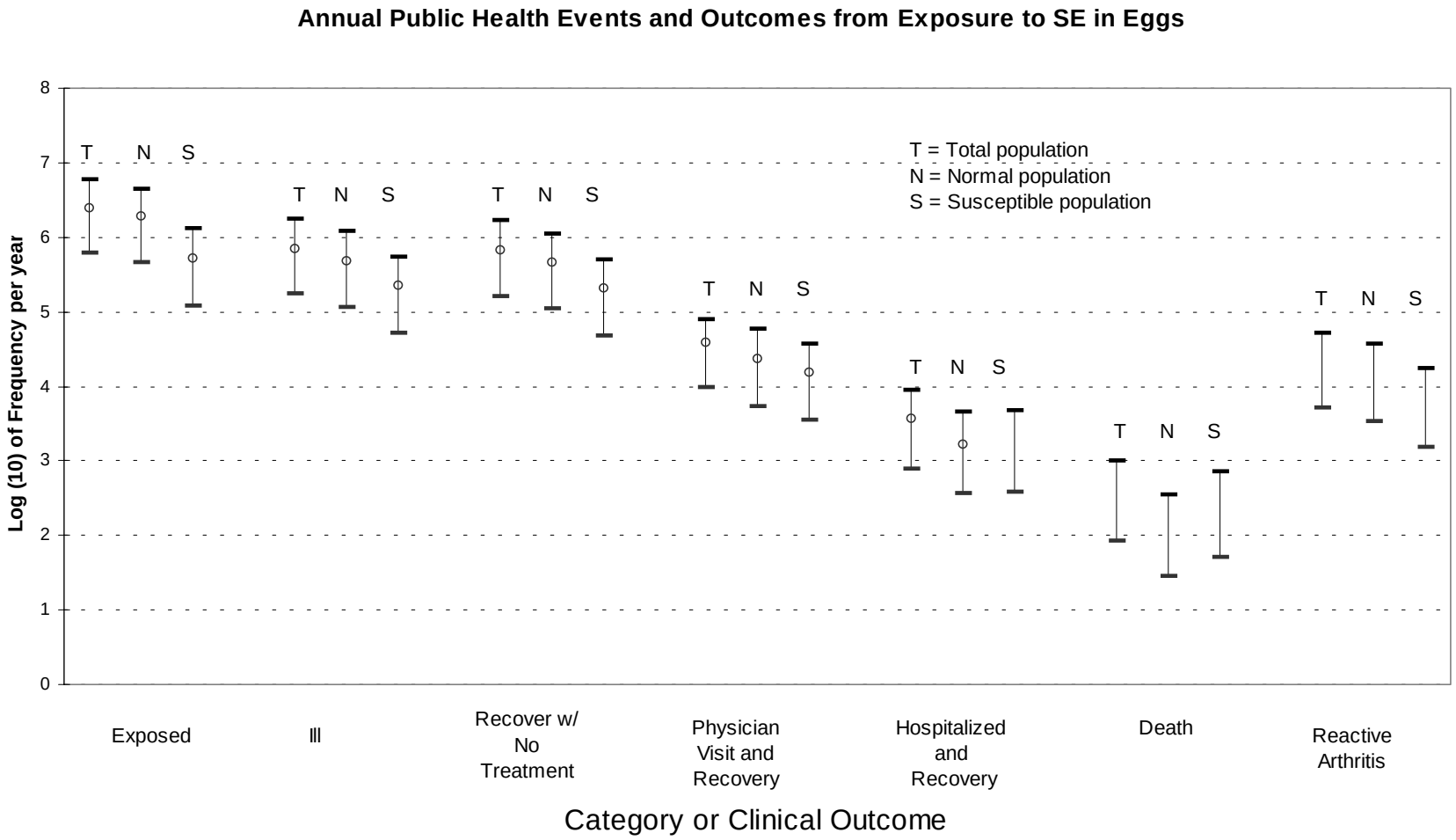
The means, 5th percentiles, and 95th percentiles for the probability distributions against number of persons annually exposed to SE from eggs and the number of resulting clinical outcomes (which include illness, recovery without medical treatment, physician visit and recovery without hospitalization, physician visit and recovery after hospitalization, death, and reactive arthritis, a post-illness sequel to infection) are presented graphically in **Figure 3** for the total, normal, and susceptible populations. Although the entire distribution is not shown here, all the distributions are lognormally distributed. The 5th and 95th percentiles form the upper and lower bounds of the 90% confidence intervals of these distributions. Most outputs typically have a 90% confidence interval that spans one order of magnitude. Most persons, who become ill, recover without

medical treatment but the number of persons in each successive clinical outcome (physician visit and recover, hospitalization and recovery, and death) declines about 1 order of magnitude. This pattern is consistent for the normal, susceptible, and total populations.

Figure 3 displays these large changes using a log scale on the y-axis; however, this tends to disguise the smaller changes that occur between the number exposed, the number ill, and the number recovering without medical treatment. The relative changes in these categories are easier to analyze in nominal terms (see page 19, Table 3). Using the mean value as the reference point, about 24% (448,803 ÷ 1,889,200 from Table 3) of those in the normal sub-population who are exposed become ill. About 41% (212,830 ÷ 521,705 from Table 3) of the susceptible sub-population who are exposed become ill. Over 90% of the ill people in both sub-populations recover without medical treatment. As the severity of the clinical outcome increases, the disparity between the rates per person exposed or per person ill increases. In the normal population, about 4.8% (21,717 ÷448,803) of those who become ill are treated by physician and recover, 0.35% are hospitalized and recover, and 0.03% die. In the susceptible population, 6.8% (14,491 ÷212,830) of those who become ill are treated by physician and recover, 0.83% are hospitalized and recover, and 0.13% die. Thus, compared to a normal person who becomes ill, a susceptible person who becomes ill is 1.4 (6.8% ÷ 4.8%) times more likely to be treated by a physician, 2.4 (0.83% ÷ 0.35%) times more likely to be hospitalized, and 4.3 (0.13% ÷ 0.03%) times more likely to die. The rate of reactive arthritis for persons who become ill is about 3% in each group; the rate is slightly higher in the normal population because more of those who become ill survive than in the susceptible population and thus a larger proportion are potentially able to develop post-illness sequelae such as reactive arthritis.

Results

Figure 3



Results

Model Validation Using Surveillance Data

Statistics reported by the CDC were used to determine the number of illnesses predicted from national public health surveillance. There is an average of 40,000 *Salmonella* isolates reported to CDC each year via their passive surveillance system. Of these isolates, 25% are serotype SE. Therefore, 10,000 SE isolates were used as our basis for estimating the total number of SE cases per year.

Although an average of 10,000 cases of SE are reported per year, it is understood that this number represents only a proportion of all SE illnesses occurring per year. To determine the probability of a human case being reported, the following data was used:

Table 2. Probability that illness from *Salmonella* Enteritidis will be reported

Data sources	P(reported|ill)	Calculations
Chalker et al, 1988 (carriage rates)	0.0108	=1/(3,700,000/40000)
Chalker et al, 1988 (analysis of artifacts)	0.0256	=1/39
Chalker et al, 1988 (outbreak analysis)	0.0205	=1/(Pert(5.5,19,211))
Aserkoff et al, 1970	0.012	=1/(Pert(4,29,379))
Todd , 1989	0.0028	=1/350

Chalker et al. (1988) used three methods for estimating total human *Salmonella* species cases. The incidence of human cases per year was estimated by evaluating the proportion of *Salmonella* species carriers in the general population. This estimate, divided by the number of cases reported, determines a multiplier for extrapolating from the number of reported cases of illness to the suspected number of actual cases of illness. The reciprocal of the multiplier is the probability of a case being reported, given illness has occurred. Another multiplier estimated by Chalker et al. (1988) was based on analysis of the chain of events that occur from the point an individual becomes ill to the point where the case is actually incorporated into the public health surveillance system (i.e., reporting artifacts). A third multiplier is based on analysis of cases associated with outbreaks. The number of additional illnesses detected via investigation of *Salmonella* outbreaks provides an estimate of cases that otherwise would go unreported. The range of values from outbreak investigations, and the median value of all investigations, reported by Chalker et al., were incorporated into a Pert(min, mode, max) distribution in order to make an estimate of the probability of a case being reported. Information reported by Aserkoff et al. (1970) was also incorporated using a similar method. Todd (1989) reported a multiplier of 350 based on his analysis of the Canadian *Salmonella* surveillance program. This multiplier of 350 is also used in our analysis.

Results

Table 3. Public Health Outcomes Summary

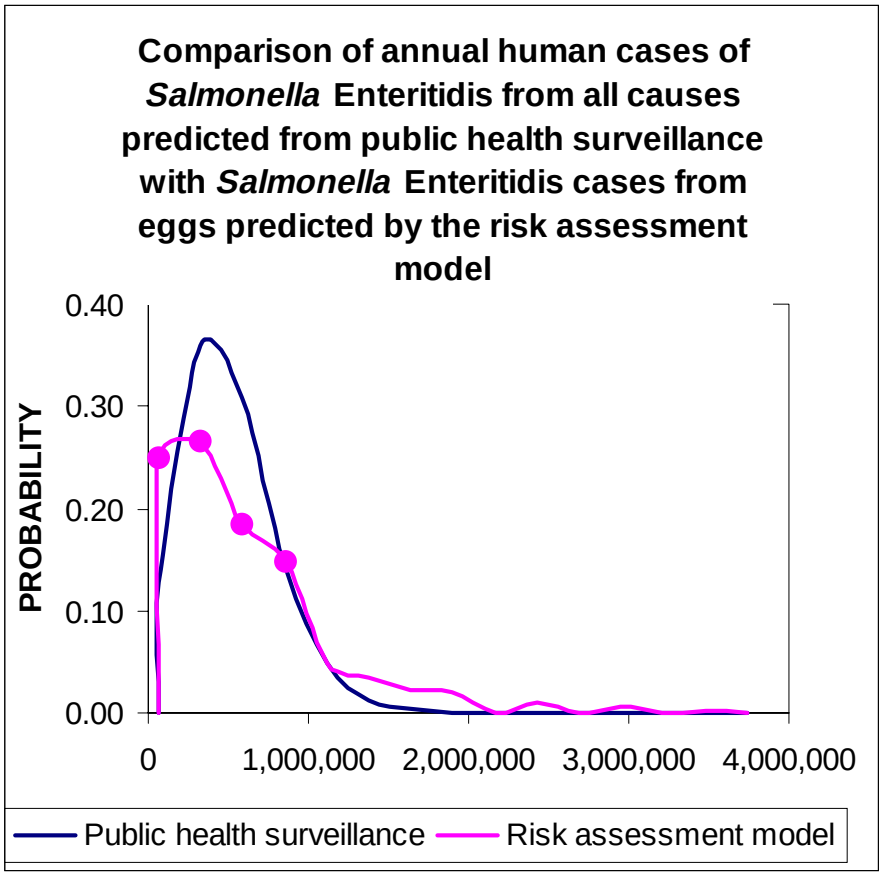
	Category	5th percentile	mean	95th percentile
Normal Population	Exposed	419,559	1,889,200	4,533,566
	ill	80,631	448,803	1,188,635
	Recover w/ no treatment	76,485	425,389	1,151,290
	Physician visit and recovery	3,733	21,717	58,556
	Hospitalized and recovered	256	1,574	4,386
	Death	20	123	350
	Reactive Arthritis	2,341	13,578	38,268
Susceptible Population	Exposed	116,111	521,705	1,255,584
	ill	43,448	212,830	550,891
	Recover w/ no treatment	40,130	196,295	506,557
	Physician visit and recovery	2,898	14,491	37,860
	Hospitalized and recovered	324	1,776	4,802
	Death	41	269	756
	Reactive Arthritis	1,263	6,416	17,384
Total Population	Exposed	536,583	2,410,904	5,836,237
	ill	126,374	661,633	1,742,592
	Recover w/ no treatment	118,806	621,684	1,626,680
	Physician visit and recovery	7,235	36,208	93,259
	Hospitalized and recovered	627	3,350	9,382
	Death	68	391	1,050
	Reactive Arthritis	3,631	19,994	55,915

Results

Given the number of SE cases reported per year and the probability of a case being reported, the Negative Binomial (or Pascal) distribution was used to estimate the total number of cases that occur per year. This total number of illnesses per year equals S + NegBinomial(S+1,*p*), where *S* is the number of reported cases and p is the probability of a case being reported. The distribution for *p* was based on the average of the data presented above. The distribution from this model can be compared with the distribution for total reported illnesses.

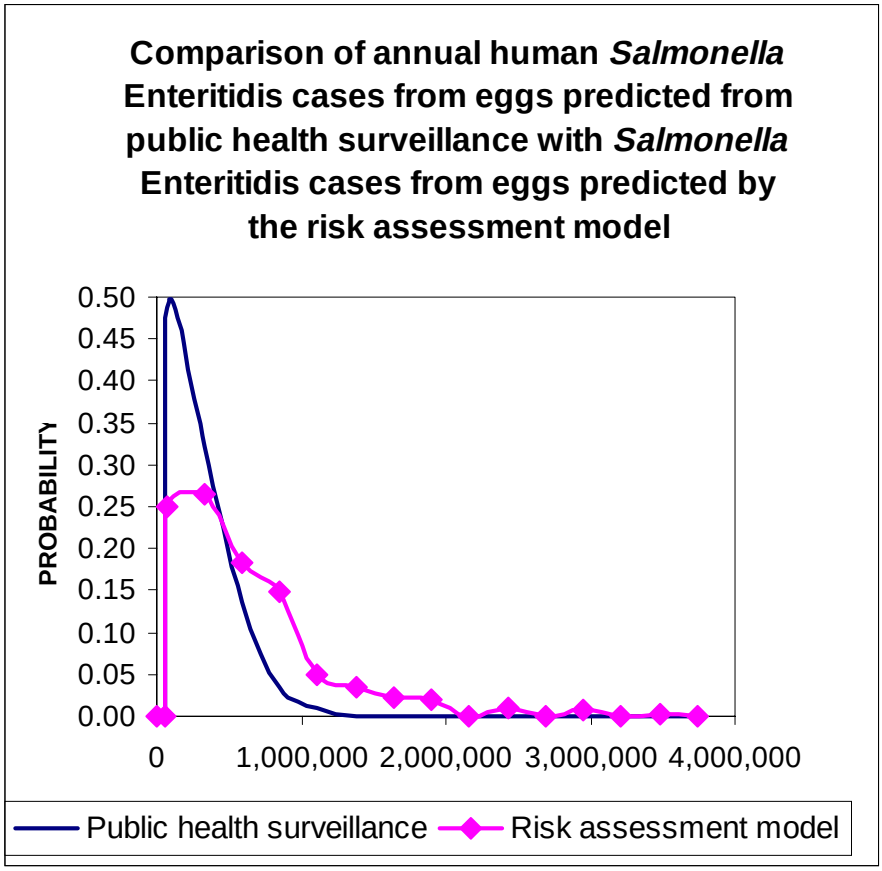
The distribution for the total number of illnesses per year predicted using the national public health surveillance data has a mean of 637,000 cases, and 5th and 95th percentiles of 254,000 and 1,167,000, respectively (see **Figure 4**). The mean of this distribution is less than the mean from the baseline risk assessment model (i.e., 661,633), and the median of the distributions are very close in numerical value (626,000 for public health surveillance versus 504,082 for the risk assessment model). The risk assessment model's distribution is skewed to the right. This implies that our model predicts some probability of extremely high numbers of SE cases per year when compared to public health surveillance (see **Figure 4**). Given the uncertain specifications of our model, this finding is not surprising.

Figure 4



Although the simulation results of this model correspond well with other estimates of the number of cases of human SE illnesses per year, this model is limited to describing SE illnesses caused by the consumption of eggs internally contaminated with SE. Therefore, this model does not account for other sources of human illness due to SE in the U.S. These other sources, if included, would increase the predicted annual SE cases. The objective of the baseline model is to describe the unmitigated risk of human illness due to SE from eggs in the U.S. On-going mitigation activities by producers, processors, and consumers is constantly changing the true incidence of illness due to SE positive eggs, and these mitigation activities make the accuracy of this model difficult to assess.

Figure 5



One adjustment to the human surveillance estimate that can be made is to account for the proportion of human SE cases that are not a result of SE in eggs. To incorporate this concept, we multiply the number of cases predicted from the public health surveillance data by a Uniform distribution ranging from 20% to 100%. This adjustment implies that the proportion of predicted human illnesses that are egg associated may range from just 20% of all cases, to 100% of these cases. Using this adjustment, the curves for the predicted cases from the public health surveillance data and the risk assessment model are shown in Figure 5. In this case, the mean number of illnesses predicted by the public health surveillance data is 381,500, and the median is 332,400. Such reductions clearly imply that the distribution for illnesses predicted by the baseline model exceeds that predicted from public health reporting, although there remains considerable overlap of the two distributions. Neither of these distributions can be verified. It is possible that predictions based on the public health data under (or over) represent the annual occurrence of human SE illnesses per year. The baseline model may also inaccurately specify the production, processing, or preparation of SE-positive eggs, as well as the dose-response relationship for SE-positive meals. Nevertheless, the fact that these distributions overlap suggests that the baseline model is a reasonable depiction of the farm to table continuum. To evaluate the effect of interventions, where the most important measurement is the resulting difference in human cases, the model is a powerful tool.

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Todd, E.C.D., 1989. Preliminary estimates of the cost of foodborne disease in the United States. J Food Protection, Vol. 52, pp.595-601.

Vose, D. 1996. Quantitative Risk Analysis: A guide to Monte Carlo Simulation Modelling. John Wiley & Sons Ltd. Chichester, West Sussex, England.

Modeling Mitigations

Sensitivity analysis results from the Production, the Shell Egg Processing and Distribution, and the Preparation and Consumption modules suggest possible strategies for reducing the total human illnesses due to SE. Other strategies have been suggested by producers, public health officials, and regulatory officials. We determined mitigation elasticity for variables that were considered possible useful mitigations or had been suggested as possible mitigations by producers, public health officials, or regulatory officials.

A. Mitigation Elasticity

Mitigation elasticity (ME) is an indication of how changes in module variables affect model output. This concept is similar to the sensitivity analysis that was conducted for the variables in each of the modules. Nevertheless, the complexity of this risk assessment precludes traditional sensitivity analysis for the model as a whole. Thus, we use mitigation elasticity to evaluate the effects of changing module variables on the baseline model output.

1. Calculating Mitigation Elasticity

Mitigation elasticity is defined as the ratio of the percent change in negative outcome (total human illness) to a fixed percent decrease in a model variable that resulted in the change. For example, if a 25% decrease in a model variable resulted in a 30% decrease in human illness the resulting mitigation elasticity would be 30/25 or 1.20. If a 25% decrease in a model variable resulted in only a 5% decrease in human illnesses the mitigation elasticity would be 5/25 or 0.20.

2. Limitations of Mitigation Elasticity

Mitigation elasticity can be used to help evaluate the effect of possible interventions. The mitigation elasticity cannot, however, be used to determine which of several possible interventions would be best. The analysis requires extensive cost and benefit information for each of the possible interventions.

B. Evaluation of Possible Interventions

In this risk assessment, we calculated some example mitigation elasticities for variables within the Production, and Preparation and Consumption modules. The mitigations were selected to illustrate the process of calculating mitigation elasticities. No recommendation or endorsement of these intervention strategies is implied in this analysis. To fully evaluate any mitigation, extensive economic analysis is needed along with the calculation of mitigation elasticity. Table 4 below shows the expected total number of human illnesses after implementing each mitigation or each set of mitigations and the resulting mitigation elasticities.

To allow for direct comparison of mitigations, we chose to modify each example variable to the same extent. Therefore, each variable was adjusted to reflect a 25% reduction in its value. This

level of effect is not necessarily supported by research, but provides a reasonable assessment of the relative effects of the variables in the model.

Storage time and temperature of eggs in homes, institutions, and at retail were modified in the Preparation and Consumption module. To model a mitigating effect on storage times, we adjusted the distribution for storage time in these three settings by multiplying the full distribution by 0.75. This modification had the effect of reducing all storage times by 25%. To model a mitigating effect on storage temperatures, we adjusted the storage temperature distributions by multiplying the proportion of these distributions that exceeded 45° F by 0.75. This modification had the effect of reducing the number of eggs that experienced storage temperatures above 45° F by 25%. Separate mitigation scenarios for storage time and storage temperature were assessed by calculating the mitigation elasticity based on the mean reduction in human cases relative to the baseline model's mean. The combined effect of mitigating time and temperature in all three settings was also evaluated.

The prevalence of SE-positive flocks in the largest flock-size strata and the proportion of high prevalence flocks were modified in the Production module. These variables were modified by multiplying their distributions by 0.75. This modification had the effect of reducing the number of SE-positive flocks in the largest size strata, and the number of high prevalence flocks, by 25%.

Another mitigation evaluated in this analysis was the effect of diversion of SE-positive eggs from the shell egg market to the egg products market. This mitigation was modeled by multiplying the number of SE-positive eggs entering the Shell Egg Processing and Distribution module by 0.75. Such an adjustment resulted in 25% fewer SE-positive eggs available for shell egg consumers.

A final mitigation scenario evaluated in this analysis was the combining of reduced prevalence in the largest flocks and reduced storage time in homes, institutions, and retail. Each variable in this scenario was reduced by 25% using the methods reported above.

None of the individual mitigations had an elasticity greater than one. When separate mitigations within the Preparation and Consumption module or within the Production and Preparation and Consumption modules are combined, a mitigation elasticity of more than 1 is calculated. In other words, 25% reductions in factors at both production and preparation were necessary to achieve a 25% reduction in total human illnesses.

This finding implies that a policy directed solely at one area of the food chain will be less effective than a policy that has broad based approach. As an example a policy that encourages quality assurance programs at the production level, cooling of eggs during processing and distribution, and proper food handling techniques is likely to be more effective than a policy which only includes one of these actions.

Table 4. Predicted Number and Reduction of SE Cases from Five Mitigations						
	Mitigation Category	**Mitigation Subcategory**	**Mean number of SE cases**	**SE Cases Reduced**	**% Reduction**	**ME[1]**
	Baseline		661,633			
1	Reduce storage time by 25% or reduce occurrences of temperature abuse by 25% in homes, institutions, and retail or reduce both time and temperature	Time	575,621	86,102	13.0%	0.52
		Temp	584,884	76,749	11.6%	0.46
		Time & Temp	522,028	139,605	21.1%	0.84
2	Reduce prevalence of SE in flocks >100K by 25%		561,065	100,568	15.2%	0.61
3	Reduce number of high prevalence SE flocks by 25%		567,681	93,952	14.2%	0.57
4	Divert 25% of all eggs from SE-positive flocks		496,225	165,408	25.0%	1.00
5	Reduce prevalence of SE in flocks >100K by 25% and reduce storage by 25% in homes. Institutions, and retail		449,910	211,723	32.1%	1.28

[1] ME - mitigation elasticity

C. Evaluating Shell Egg Cooling Strategies

We calculated the percent reduction in total human illnesses resulting from two scenarios with the Shell Egg Processing and Distribution module. We did not calculate mitigation elasticities for these scenarios because we decreased the variables by more than 25%. Thus, these scenarios are not comparable to those shown in Table 5 below.

Shell egg processing and distribution is the focus of possible regulatory action dealing with the refrigeration of eggs. We evaluated the effect of this module using a best case focus. In the first scenario, we assume that eggs are immediately cooled after lay to 45° F, then maintained at an ambient temperature of 45° F throughout the Shell Egg Processing and Distribution module. To model this effect, we simply set the internal temperature of eggs to 45° F when laid (down from a baseline setting 99° F), then truncate the distribution of all the ambient temperature variables within the Shell Egg Processing and Distribution module so that ambient temperature cannot exceed 45° F. In the second scenario, we assume that eggs are immediately subjected to an ambient temperature of 45° F and maintained at this ambient temperature throughout the Shell Egg Processing and Distribution module. To model this effect, we do not adjust the internal temperature of eggs at lay. Instead, eggs start at an internal temperature of 99° F. The distributions of all the ambient temperature variables in the Shell Egg Processing and Distribution module are truncated so that ambient temperature cannot exceed 45° F.

Mitigations

These two scenarios represent base-case results predicted from implementing the temperature strategies within the Shell Egg Processing and Distribution module. These scenarios modify the ambient temperature of all eggs from the point of lay through delivery to the Preparation and Consumption module. These modifications also assume 100% compliance and success in achieving ambient air temperatures at or below 45° F for eggs. Furthermore, the first scenario assumes there exists a process for immediately cooling eggs at the time they are laid.

This analysis shows that modifying ambient temperatures of eggs throughout the Shell Egg Processing and Distribution module will result in a 8% average reduction in human SE illnesses (Table 5). Such a result is surprising given that eggs in the baseline model do not experience any SE growth within the Shell Egg Processing and Distribution module. This module is responsible for some of the membrane breakdown that occurs within SE-positive eggs. Therefore, eggs leave the Shell Egg Processing and Distribution module with an increased potential (relative to when they are laid) for supporting SE growth within the Preparation and Consumption module. These results imply that reduced ambient temperatures within the Shell Egg Processing and Distribution module have a substantial sparing effect on the integrity of yolk membranes in SE-positive eggs.

The typical egg is in shell egg processing and distribution for about 3 days. This period encompasses the time of lay through delivery to retail outlets or institutional users. During this period, the internal egg temperature is equilibrating with the ambient temperature in the various stages of the Shell Egg Processing and Distribution module. The model depicts higher average ambient temperatures in the Shell Egg Processing and Distribution module than in the Preparation and Consumption module. As a result of this ambient temperature difference, there may be more benefit gained - as measured by reduced human illnesses - from modifying the temperature variables in the Shell Egg Processing and Distribution module than similarly modifying temperatures in the Preparation and Consumption module.

Our analysis of the magnitude of illnesses foregone as a result of setting the ambient temperature of eggs in the Shell Egg Processing and Distribution to 45° F or less suggests that cooling of eggs while in this module is critical. In fact, if the model is simulated without eggs going through this module, the percent reduction in human illnesses predicted is less than percent reductions of scenarios shown in Table 5. This finding demonstrates the value of time spent cooling eggs.

These results also show that keeping eggs at an internal temperature of 45° F is only a slight improvement over keeping eggs at an ambient temperature of 45° F. Within the Shell Egg Processing and Distribution module are equations which predict the rate of yolk membrane breakdown. These equations are dependent on internal egg temperature. However, these equations also stipulate that there is an inherent delay - a time before SE growth can begin - of approximately 11 days at an internal egg temperature of 80° F, or 30 days at an internal egg temperature of 60° F. This inherent resistance to SE growth within eggs means that it is critical that the internal temperature of the egg is reduced to 45° F before the inherent resistance to yolk membrane breakdown is exhausted. The results in Table 5 demonstrate that, on average, eggs laid at 99° F will achieve internal temperatures of 45° F or less before the inherent resistance to yolk membrane breakdown is exhausted when the eggs are maintained at an ambient temperature of 45° F.

Mitigations

Table 5. Effect of Different Interventions within the Shell Processing and Distribution Module on Total Human Illnesses in the *Salmonella* Enteritidis Risk Assessment	
Intervention	*Percent Decrease in Total Human Illnesses*
Keep internal egg temperature starting at 99° F. Set all ambient air temperatures to 45° F.	8%
Start internal egg temperature 45° F. Set all ambient air temperatures to 45° F.	12%

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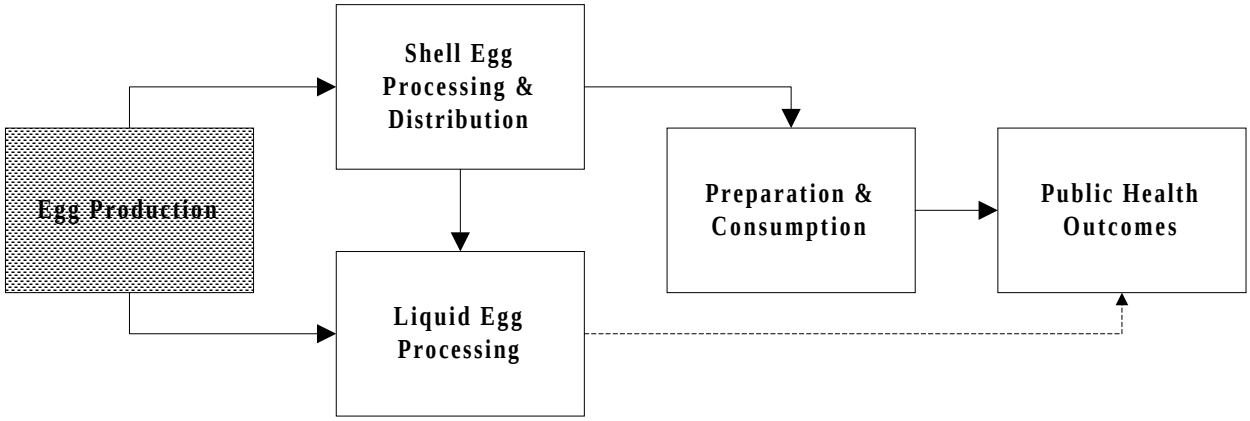
Production Module



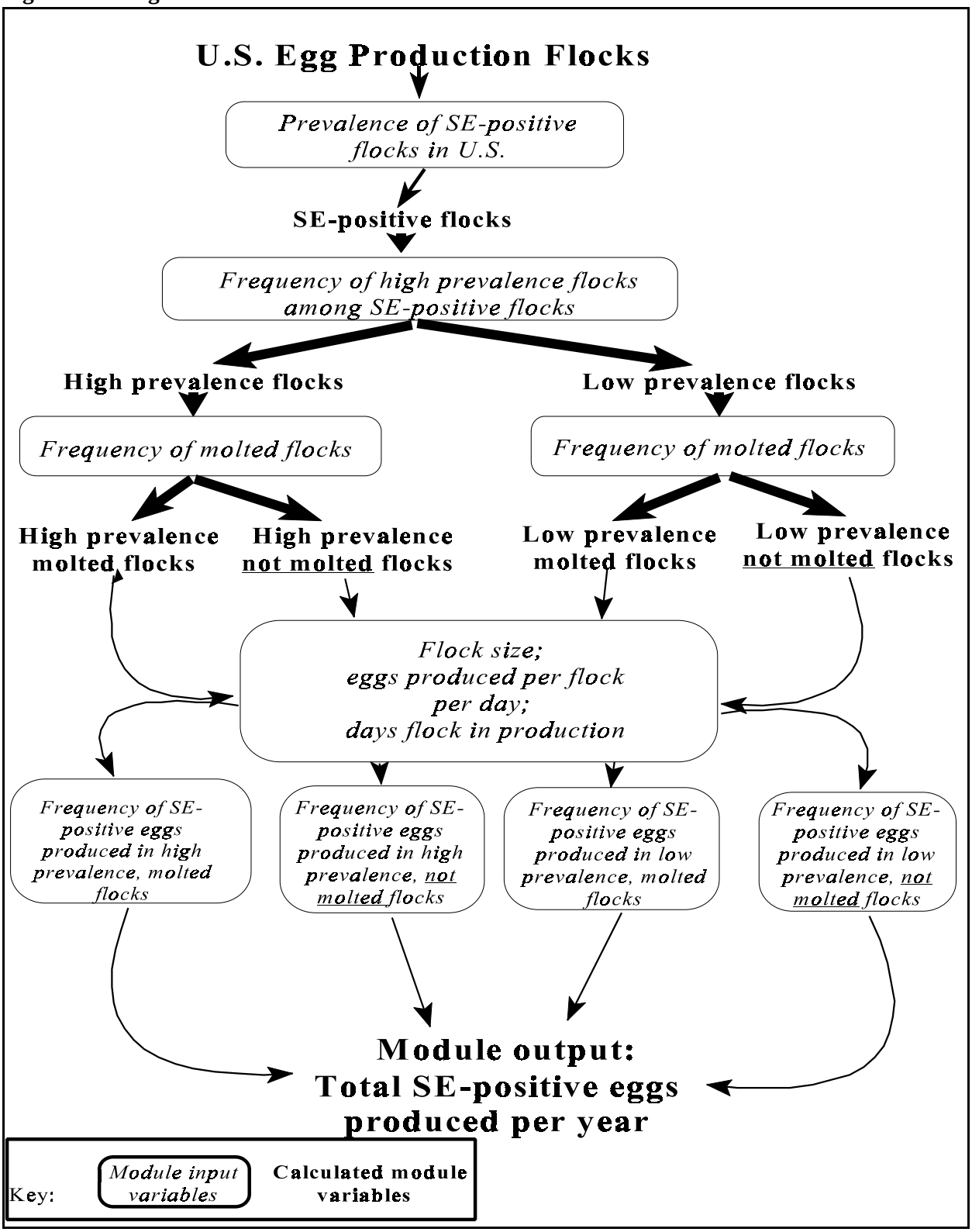
A. Summary of Production Module

The purpose of the production module is to simulate the annual production of SE-positive eggs in the USA. Through the incorporation of epidemiologically relevant variables, this production module may also be used to simulate the effects of specific mitigation strategies on the annual production of SE-positive eggs.

The production module is the first stage of a farm-to-table quantitative risk assessment of the exposure of the human population to SE-positive eggs and the adverse medical outcomes which may occur as a result of this exposure. Once the total number of egg-producing flocks is specified, this module completes probability calculations to determine the number of SE-positive flocks and the number of SE- negative flocks within the total number of egg-producing flocks. SE-positive flocks are further differentiated into 'low prevalence SE-positive flocks' and into 'high prevalence SE-positive flocks'. Low prevalence SE-positive flocks are defined as flocks which produce SE-positive eggs, but produce SE-positive eggs at a very low rate - e.g. 1 SE-positive egg per 17,000 eggs laid by the low prevalence SE-positive flock. High prevalence SE-positive flocks are defined as flocks which produce SE-positive eggs, and produce SE-positive eggs at a higher rate - e.g. 1 SE-positive egg per 1400 eggs laid by the high prevalence SE-positive flock . For a given number of SE-positive flocks, the module then determines the number of these SE-positive flocks that would be expected to be 'high prevalence SE-positive flocks' and the number of these SE-positive flocks that would be expected to be 'low prevalence SE-positive flocks'. Some egg laying hens also go through a molting process during which they are rejuvenated to lay eggs for a longer period of time. Molting is associated with an increased rate of SE-positive eggs within SE-positive flocks. In recognition of this fact, the production module also calculates the number of SE-positive flocks that are molted. Consequently, the model calculates the number of SE-positive flocks in each of the following categories:

Production Module

Figure A-1 Diagram of Production Module.



a) high prevalence SE-positive flock, molted,
b) high prevalence SE-positive flock, not molted,
c) low prevalence SE-positive flock, molted, and
d) low prevalence SE-positive flock, not molted.

The production module calculates the number of SE-positive eggs produced annually for each of these categories. The sum of these calculations is the total number of SE-positive eggs produced annually by the egg industry, and this sum is the primary output of the production module.

As a final step in the production module, the number of SE-positive eggs marketed to shell egg processing & distribution and the number of SE-positive eggs marketed to liquid egg processing is estimated. This step determines the total number of SE-positive eggs which the Shell Egg Processing & Distribution Module will handle and the total number of SE-positive eggs which the Liquid Egg Processing Module will handle.

B. Inputs to Production Module

The number of flocks modeled in the production module is constant and is equal to 5028 flocks, a figure adapted from the 1992 U.S. Agriculture Census data. To account for the variability in egg production for different sized flocks, the total number of flocks are stratified by size according to 1992 U.S. Agriculture Census data (Table A-1).

For the purposes of this model, a flock is defined as a group of hens of similar age which are housed together. The U.S. Agriculture Census reports in units of farms, which may contain one or more flocks. To calculate the number of flocks in each size strata, farm and flock were equated for each stratum with less than 100,000 hens per farm. For farms with more than 100,000 hens, an average capacity of 110,000 hens per flock was used .

Table A-1. Four strata of flock size used in production module.

Strata & Number of hens per flock (range)	Number of flocks in each stratum
10,000-19,999	1892
20,000-49,999	1134
50,000-99,999	519
$\geq$ 100,000	1483
Total	5028

C. Production Module Variables

1. Prevalence of SE-positive flocks

a. Evidence

The prevalence of SE-positive flocks (which produce SE-positive eggs) is used to determine the number of SE-positive flocks in the production module.

Prevalence surveys conducted in 1991 (Ebel et al.,1992) and 1995 (Hogue et al. 1997) allow development of the estimate of the national prevalence of SE-positive flocks. In 1991, 111 (27%) of 406 flocks sampled were SE-positive. In 1995, 136 (45%) of 305 flocks sampled were SE-positive.

The prevalence of SE-positive flocks for the above studies was determined through slaughter surveys of spent hens. Spent hens are hens which no longer lay eggs at a rate which is commercially viable, and these hens are considered 'spent'. Spent hens are removed from production; typically via slaughter. These slaughter surveys of spent hens used a two-stage sampling design whereby flocks were initially selected and then intestinal tract samples from 300 hens in each flock were collected and cultured for SE.

Because of seasonal effects in the results, data from the 1995 spent hen survey conducted by Hogue et al. (1997) and data from the 1991 national spent hen survey by Ebel et al. (1992) are combined in the estimation of national prevalence of SE-positive flocks. We assume that combining both surveys may more accurately reflect an average prevalence over a full year. Therefore, our analysis begins with an assumption that 247 (i.e., 111 + 136) of 711 (406 + 305) flocks sampled in the spent hen surveys were SE-positive.

The 1991 and 1995 national spent hen surveys evaluated prevalence of SE-positive flocks at the regional level. Regions were not necessarily sampled in proportion to the actual number of flocks resident in each region (Table 2). As Table A-2 shows, 310 (44%) of 711 flocks were sampled in the Northern region in the 1991 and 1995 surveys, yet only 27% of the U.S. flock resides in the Northern region. To use the regional spent hen data to estimate a national prevalence of SE-positive flocks, the regional results must be weighted by the proportion of the national flock in each region. These weights are calculated on the basis of the 1992 Agriculture Census and are equal to 27%, 33%, 26%, and 14% for the Northern, Southeastern, Central, and Western regions, respectively.

Table A-2. Combined 1991 and 1995 spent hen survey results by U.S. regions[1] and percent of U.S. flock in each region[2].

U.S. Regions	Number of flocks sampled	Number of flocks SE-positive (%) in survey	Percent of U.S. flock located in region
Northern	310	163 (52%)	27
Southeastern	92	7 (8%)	33
Central	232	59 (25%)	26
Western	77	18 (23%)	14
Total	711	247 (35%)	100

1. Adapted from Hogue et al. (1997).
2. Adapted from 1992 Agriculture Census.

For each region in Table A-2, the prevalence of SE-positive flocks is estimated as a Beta function with parameters of s+1 and n-s+1 - Beta(s+1, n-s+1), where s is the number of positive flocks and n is the total number of flocks sampled in each region. Regional prevalence is multiplied by the proportion of US flocks in the region to determine the contribution of each region to the national prevalence of SE-positive flocks. The sum of these calculations is the apparent national prevalence of SE-positive flocks. Apparent prevalence is an epidemiologic term which refers to prevalence calculated without adjustments for the sensitivity of surveillance tests used (Martin et al., 1987). In our case, the mean apparent prevalence is calculated as 28%.

The national prevalence estimate using the spent hen survey data is further adjusted to account for imperfect surveillance sensitivity. Higher prevalence flocks are more likely to be detected than lower prevalence flocks. Within-flock prevalence results from the combined 1991 and 1995 national spent hen surveys are shown in Table A-3. The most frequent within-flock prevalence detected in these surveys was 0.33%. Surveillance sensitivity [p (detection | truly positive flock)] is calculated as $1 - (1\text{-wprev})^n$ where 'wprev' is the within-flock prevalence and 'n' is the number of birds sampled. For a within-flock prevalence of 0.33% , the surveillance sensitivity of 300 samples is 63%. This result means that if 100 flocks of hens which all have a within-flock prevalence level of 0.33% were tested according to the spent hen protocol (i.e. 300 samples from each flock), then 37 flocks (100 flocks × (1-0.63) = 37) would be incorrectly classified as negative flocks.

Production Module

To estimate the surveillance sensitivity of the spent hen surveys, a model based on the within-flock prevalence results shown in Table A-3 was developed. This model showed that the sample of 300 hens per flock used in the spent hen surveys had a sensitivity of 76%. This finding means that 76% of truly positive flocks were correctly classified as SE-positive in these surveys, while 24% of truly positive flocks were incorrectly classified as SE-negative. This estimate of sensitivity had a standard deviation of 2.5%.

The true national SE-flock prevalence is calculated by dividing the apparent national prevalence by 0.76.

Because the spent hen surveys did not identify flocks by their sizes, SE prevalence within each size stratum may actually vary over a considerable range. At one extreme, all flocks fitting within a certain stratum may have been SE-positive in these surveys. At the other extreme, none of the flocks in a stratum may have been positive, or even sampled. Therefore, an algorithm was developed to allow prevalence to range from 0% to 100% within a stratum while maintaining a constant national prevalence. This adjustment serves to increase the uncertainty in estimates of SE flock prevalence.

Table A-3. Within-flock prevalence levels based on 1991 and 1995 spent hen survey results.

Number of positive samples	Number of flocks	Freq	Within-flock prevalence[1]
1	77	31.2%	0.33%
2	39	15.8%	0.67%
3	23	9.3%	1.00%
4	18	7.3%	1.33%
5	9	3.6%	1.67%
6	6	2.4%	2.00%
7	8	3.2%	2.33%
8	7	2.8%	2.67%
9	8	3.2%	3.00%
10	4	1.6%	3.33%
11	6	2.4%	3.67%
12	4	1.6%	4.00%
13	4	1.6%	4.33%
14	2	0.8%	4.67%
15	2	0.8%	5.00%
16	6	2.4%	5.33%
17	1	0.4%	5.67%
18	3	1.2%	6.00%
19	3	1.2%	6.33%
21	2	0.8%	7.00%
22	3	1.2%	7.33%
23	1	0.4%	7.67%
24	1	0.4%	8.00%
25	1	0.4%	8.33%
26	2	0.8%	8.67%
27	2	0.8%	9.00%
28	1	0.4%	9.33%
36	1	0.4%	12.00%
39	1	0.4%	13.00%
42	1	0.4%	14.00%
44	1	0.4%	14.67%

[1] Within-flock prevalence calculated as number of positive samples divided by 300 hens sampled.

b. Value of the variable:

On average, we estimate 37% of egg-laying flocks are SE-positive.

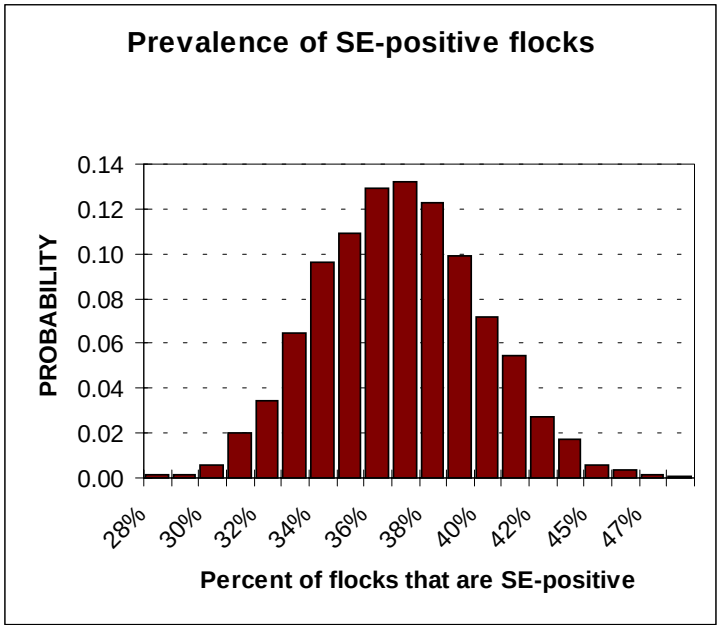
c. Distribution: Beta(267,443)

A Beta distribution is used to estimate the proportion of a population that is positive when positive/negative sampling data is available. The formula for this estimate is Beta (s+1, n-1+1) where s is the number of positive samples and n is the total number of samples collected (Vose, 1996)

The following histogram shows the distribution of the percent of egg-laying flocks which are SE-positive flocks. This graph reflects our uncertainty regarding true prevalence. It shows that we estimate with 90% confidence that the prevalence of SE positive flocks lies between 32% (5th percentile) and 43% (95th percentile).

Figure A-2

Mean	37%
Standard deviation	3%
5th percentile	32%
95th percentile	43%



2. Frequency of high prevalence flocks

a. Evidence

As explained earlier, a high prevalence flock is a flock which is SE-positive and produces SE-positive eggs at a higher rate than the average rate for all SE-positive flocks. The attribute (or factor) of prevalence among SE-positive flocks has been dichotomized in this module into high and low levels - i.e., high prevalence SE-positive flocks produce SE-positive eggs at high rates and low prevalence SE-positive flocks produce SE-positive eggs at low rates. This dichotomy is probably a simplification, as it is possible that a continuum from low to high prevalence SE-positive flocks exists in the population of all SE-positive flocks. It is advantageous to explicitly model at least two levels of SE-positive flocks based on SE-positive egg frequency so that the relative contribution of these different levels to the total number of SE-positive eggs produced per year can be evaluated.

The frequency of high prevalence SE-positive flocks is a conditional probability which predicts the proportion of flocks that are in the high prevalence category given that the flocks are SE-positive.

There is experimental and field evidence which supports the concept of variable expression of SE infection in flocks. Several researchers have experimentally demonstrated that there are differences between SE strains which make some strains of SE more capable of causing more severe manifestations of infection than others - e.g., higher rates of SE-positive eggs - (Gast et al., 1990; Gast et al., 1992; Guard-Petter et al., 1993, 1995, 1996, 1997a, 1997b; Gast et al., 1995; Gast et al., 1996: Thiagarajun et al., 1994). Other experimental research has shown that there exist host factors that might influence the severity of SE-infection (Lindell et al., 1994; Tellez et al., 1994; Qin et al., 1995; Manning et al., 1994; Phillips et al., 1995; Bumstead et al., 1993). Unfortunately, very little research is available concerning flock management or environmental risk factors which might explain increased severity of SE infection in flocks. Studies by Henzler (1992, 1998) have suggested that rodents play a role in the epidemiology of SE in the environment of egg-laying flocks. Poor control of rodent populations may allow greater transmission of SE into and throughout the flock in a layer house with consequent higher prevalence rates of SE-positive hens. Mallinson (1997) has suggested that environmental moisture levels are associated with *Salmonella* prevalence in manure drag swabs and on broiler (i.e. chicken) carcasses. The relationship of the prevalence of SE-positive hens within a flock and environmental factors such as temperature, ventilation, stocking density, caging, and feeding/watering systems are less well studied in the literature.

A study by Schlosser et al. (1995) provides one source of field based evidence regarding high prevalence flocks. In that study, 43 SE-positive flocks were

investigated as part of the Pennsylvania Pilot Project. Eight of the 43 flocks were characterized as having the highest rates of SE-positive eggs cultured from them. These flocks were also SE-positive in >50% of the environmental samples collected from them. Because of this apparent correlation between environmental and egg sampling, the designation of a SE-positive flock as a 'high prevalence flock' can be made based on either type of sampling. In this same study, 27 of these 43 SE-positive flocks had no SE-positive eggs - i.e. no SE was cultured from any of the eggs tested. Such findings provide strong evidence for low prevalence flocks.

In another field study of SE-positive flocks, Henzler et al. (1994) showed that the greatest rate of SE-positive eggs were found in two of four flocks investigated. In both of these high prevalence flocks, >50% of environmental samples were SE-positive.

Combining the data from Schlosser et al. (1995) and Henzler et al. (1994) implies that of 47 SE-positive flocks intensively investigated, 10 (21%) could be characterized as high prevalence flocks. However, just as with the national prevalence estimate, we must adjust this percentage by the surveillance sensitivity of testing used to determine these flocks' SE-positive status. In these two studies, environmental samples were collected and cultured. It is reported that environmental sampling is equivalent to sampling 50 hens' caeca from a flock at slaughter (Kingston, 1981). Therefore, environmental sampling is less sensitive at detecting positive flocks than the spent hen surveys (which sampled 300 hens).

A consequence of this lower surveillance sensitivity is that if we determined that 21% of all SE-positive flocks were high prevalence, we would be wrong. Based on a sample size of 50 hens, we calculated the sensitivity of environmental testing as 49%, using the same methodology as explained for the national prevalence adjustment. This means that 51% of SE-positive flocks would be incorrectly classified as negative (i.e., false negative) using environmental testing. Clearly, the SE-positive flocks incorrectly classified would not include those characterized as high prevalence flocks, since these flocks - by definition - are easily detected as positive using environmental testing. Therefore, the false negative flocks must be included in those flocks considered low prevalence. Consequently, we must reduce the frequency of high prevalence flocks calculated from Schlosser et al. (1995) and Henzler et al. (1994) by approximately one-half (i.e., 21% x 49% = 11%).

b. Value of the variable:

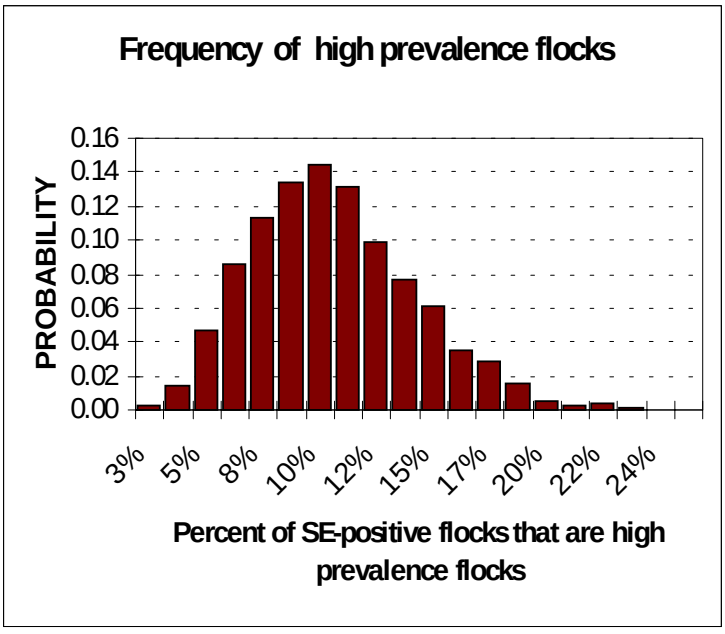
On average, we estimate that 11% of SE-positive flocks are high prevalence flocks.

c. Distribution: Beta(11,85)

The following histogram shows the distribution of the percent of SE-positive flocks that are high prevalence flocks. This graph reflects our uncertainty of the fraction of positive flocks that are high prevalence flocks. It can be seen from this graph that we are 90% confident that the true value for this variable lies between 6% (5th percentile) and 17% (95th percentile).

Mean	11%
Standard deviation	3%
5th percentile	6%
95th percentile	17%

Figure A-3



3. Frequency of SE-positive molted flocks

a. Evidence

Molting is a process used in commercial egg flocks to extend the period of egg production by rejuvenating the reproductive systems of hens. Flocks that are not molted typically only lay eggs for one year. Molting is the shedding of feathers followed by growth of new feathers. Layers that molt also cease egg production during the molt period. In commercial flocks, molting is induced by the restriction of light and feed. This process provides the necessary stimulus to urge the hens in a flock to undergo a molt. This period usually averages about 4 weeks during which the flock is essentially non-productive. Once molting is complete the birds are stimulated - primarily by light - to begin laying again. Although slightly fewer eggs are produced after molt, these eggs tend to be larger than eggs produced before molt.

There is epidemiologic evidence which associates molting with higher prevalence of SE in flocks. Molted SE-positive flocks also seem to produce SE-positive eggs more frequently than their non-molted counterparts. Experimentally, Holt et al. (1996,1995,1994,1993,1992) have demonstrated that molting is associated with increased numbers of SE in hens' intestinal tracts, and higher rates of SE-positive eggs are produced following molt. Schlosser et al. (1995) demonstrated similar results in a field study during the Pennsylvania Pilot Project. In that study, molted flocks produced SE-positive eggs twice as frequently as non-molted flocks for a period up to 140 days following molt.

The frequency distribution for SE-positive molted flocks is derived from statistics reported by the USDA - National Agricultural Statistics Service (USDA-NASS). These statistics state that approximately 22% of flocks in egg production - at any time of the year - are flocks that have molted.

b. Value of the variable:

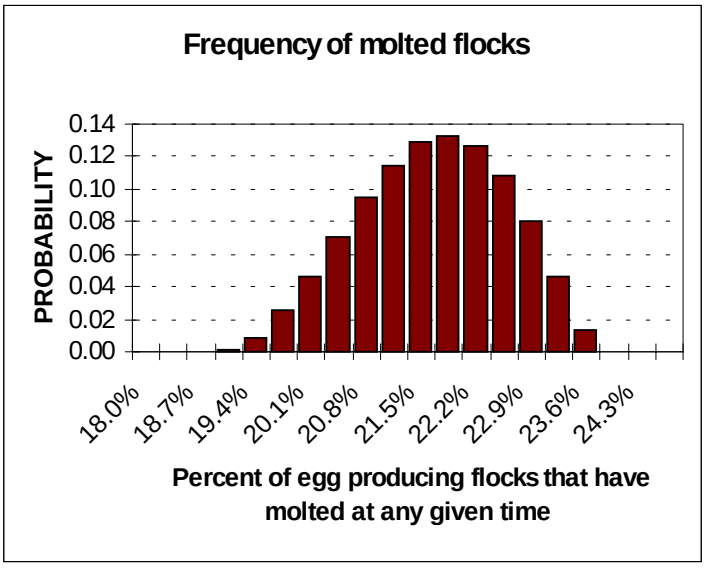
On average, we estimate that 22% of flocks producing eggs on any given day are flocks that were previously molted.

c. Distribution: Pert(19%,22%,24%)

The following histogram shows the distribution for the frequency of molted flocks variable. This graph reflects our uncertainty regarding the fraction of SE-positive flocks that were previously molted. It can be seen from this graph that we are 90% confident that the true value for this variable lies between 20% (5th percentile) and 23% (95th percentile).

Mean	22%
Standard deviation	0.9%
5th percentile	20%
95th percentile	23%

Figure A-4



4. Number of days of increased frequency of SE-positive eggs post-molt

   a. Evidence

      SE-positive flocks that are molted do not perpetually produce SE-positive eggs more frequently than flocks that are not molted. Instead, there appears to be a period immediately after molt when these flocks are at higher risk of producing more positive eggs.

      The frequency distribution for 'number of days of increased frequency of SE-positive eggs post-molt' is based on the data from the Pennsylvania Pilot Project (Schlosser et al, 1995). In that study, SE-positive molted flocks were sampled from 0 to 20 weeks (140 days) post-molt. During this time period, these molted flocks produced nearly twice as many SE-positive eggs as similarly studied SE-positive flocks that were not molted.

   b. Value of the variable:

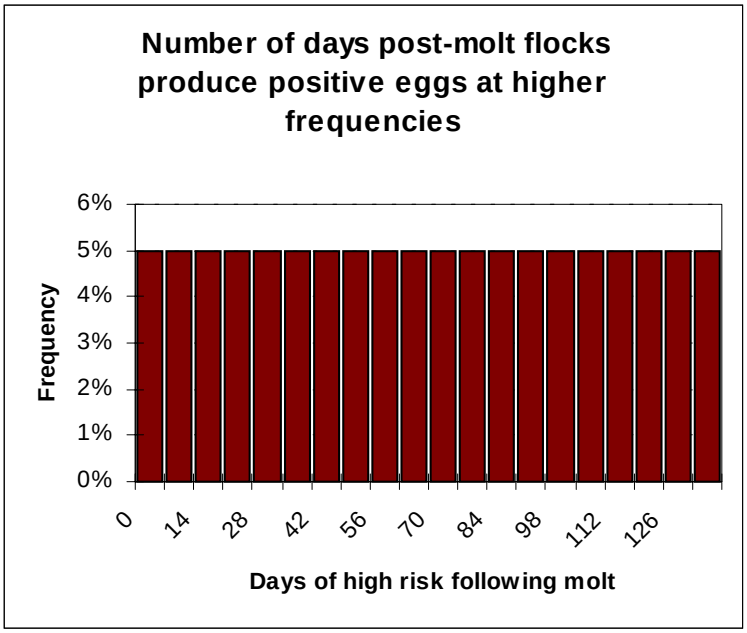
      On average, we estimate that SE-positive flocks will produce more positive eggs during the first 70 days following molt.

c. Distribution: Uniform(0,140 days)

A uniform distribution is used to model variables for which only a minimum and maximum value are available. The available evidence shows that flocks were between 0 (minimum) and 20 weeks (maximum) post-molt when they produced eggs at higher frequencies

The following histogram shows the frequency distribution for the number of days post-molt when SE-positive eggs are produced more frequently. This graph reflects the variability in this value for individual SE-positive molted flocks. It can be seen from this graph that 90% of such flocks will experience between 7 days (5th percentile) and 133 days (95th percentile) of increased SE-positive eggs following their molt.

Figure A-5



Mean	70
Standard deviation	40
5th percentile	7
95th percentile	133

5. Eggs per flock per day

a. Evidence

To estimate eggs produced per flock per day, we begin with the 1992 U.S. Agriculture Census data used to determine the number of flocks by size strata (Table A-1 on page 31). For each stratum, the average number of hens per flock is calculated as the total number of commercial laying hens, divided by the number of flocks, in the stratum. For example, the 1992 U.S. Agriculture Census reports the 10,000-19,000 flock size stratum comprised 21.7 million hens and 1892 flocks. Therefore, the average flock in this stratum consisted of 11,470 hens (21.7 million / 1892). Similar calculations for the 20-49K, 50-99K, and >100K flock size strata resulted in average flock sizes of 27,222, 68,691, and 110,00 hens per flock, respectively. The average flock size across all four strata is 50,154 hens per flock.

We assume the average hen in a flock produces 0.72 eggs per day (i.e., she will produce 72 eggs during a 100 day period). This average daily egg production was based on a published egg production curve (Rahn, 1977), which was adjusted for improved egg production - using annual USDA-NASS statistics - since that curve was derived.

b. Value of the variable

: The model assumes there are 5028 flocks in the U.S. (Table 1, page 2). The average flock size is 50,154 hens per flock. Each hen produces 72 eggs per 100 days. Therefore, the average flock produces 13 million eggs per year. Furthermore, the model predicts an average of 65 billion eggs produced per year (i.e., 5028 flocks x 50,154 hens/flock x 0.72 eggs/day x 365 days). This annual production estimate is consistent with 1995-1996 statistics published by USDA-NASS.

c. Distribution: Eggs produced per day is a constant in the model.

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6. Frequency of SE-positive eggs in high prevalence, SE-positive / not molted flocks

a. Evidence

As was discussed earlier, SE-positive flocks which are molted appear to produce more SE-positive eggs. For this reason, a distinction is made between SE-positive flocks which are molted and SE-positive flocks which are not molted.

Egg culturing results from the eight flocks identified as high prevalence, SE-positive flocks in the Pennsylvania Pilot Project (Schlosser et al., 1995) are incorporated into this estimate (see pp. 37). Of 113,000 eggs collected from these flocks, 56 were found SE-positive. These flocks had the greatest average SE-positive egg frequency of the 43 flocks uniformly studied. The ages of flocks in this cohort ranged from 20 weeks to 72 weeks old. None of these flocks were molted.

Egg sampling results from two flocks identified through traceback procedures from human SE outbreaks showed that 41 of 15,980 eggs collected were SE-positive (Henzler, et al., 1994). These two flocks demonstrated particularly high rates of SE-positive eggs and SE-positive environmental samples, and for this reason meet the definition of high prevalence, SE-positive flocks.

Egg culture results from 8 flocks in California which were SE-positive with phage type 4 variety of SE (Kinde et al., 1996) are similar to the other results for high prevalence, SE-positive / not molted flocks. Of 85,360 eggs collected from these flocks, 58 eggs were SE-positive.

From egg sampling completed in these three studies, we find that a total of 214,340 eggs have been sampled from flocks we would characterize as high prevalence/not molted. From these samples, 155 eggs were found SE-positive. Therefore, these results suggest that high prevalence/not molted flocks produce 7 SE-positive eggs in every 10,000 eggs they lay (i.e., 155/214,340 = 0.07%). This rate is equivalent to 1 SE-positive egg in every 1383 eggs produced, or 2 SE-positive eggs in every 2766 eggs produced. We use the latter estimate to form our distribution for this variable.

b. Value of the variable:

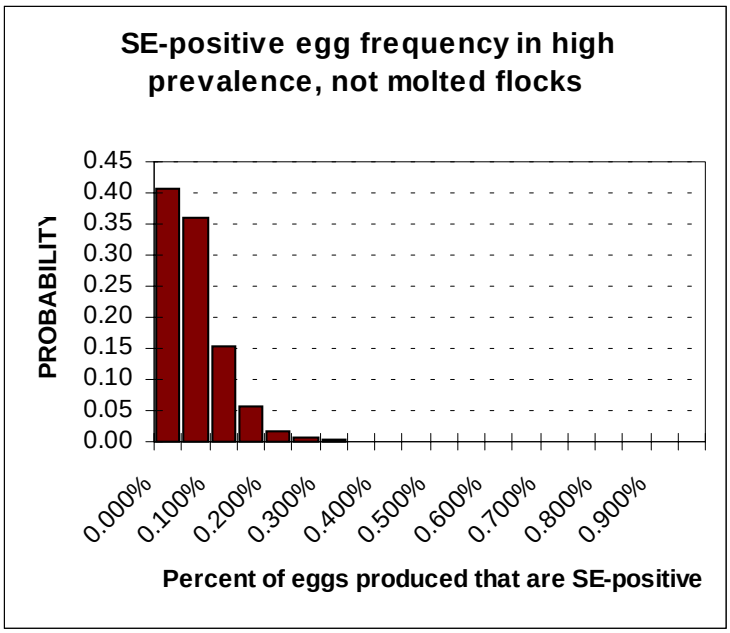
On average, we estimate that high prevalence / not molted flocks will produce 7 SE-positive eggs in every 10,000 eggs they produce.

c. Distribution: Gamma(2,$(2766)^{-1}$)

The gamma distribution is used to estimate low frequency events (Vose, 1996). The formula for this estimate is gamma (s, 1/n), where s is the number of positive samples and n is the total number of samples collected. Because the egg sampling results we used were from just a few flocks, we wanted to model our estimate of positive egg frequency with the greatest degree of uncertainty possible based on the available evidence. Setting s equal to 2 and proportionally adjusting n provides the greatest variance for a gamma distribution variable.

The following histogram shows the distribution for the frequency of SE-positive eggs in high prevalence / not molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by high prevalence / not molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 1 SE-positive egg in every 10,000 eggs produced (5^{th} percentile) and 17 SE-positive eggs in every 10,000 produced (95^{th} percentile). These percentile values are equivalent to 0.01% (5^{th} percentile) and 0.17% (95^{th} percentile).

Figure A-6



Mean	0.07%
Standard deviation	0.05%
5^{th} percentile	0.01%
95^{th} percentile	0.17%

7. Frequency of SE-positive eggs in high prevalence, SE-positive / molted flocks

a. Evidence

The frequency at which SE-positive eggs are produced by high prevalence, SE-positive / molted flocks is used to calculate the number of SE-positive eggs produced by high prevalence, SE-positive flocks during the high risk period following molt (as explained on pp. 42). For flocks in this category, the rate of SE-positive eggs during other times of the egg production year is modeled in the same way as for high prevalence, SE-positive / not molted flocks.

The distribution for the frequency of SE-positive eggs in high prevalence, SE-positive / molted flocks is calculated using analysis of the data from the Pennsylvania Pilot Project (Schlosser et al., 1995). In that analysis, the aggregate frequency of SE-positive eggs was compared for flocks that were in egg production during the 20-week time frame before molting and for flocks that were in egg production during the 20-week time frame after molting. This approach controlled for confounding variables in the data due to the effect of the age of the hen. Based on these findings, it appears that the average effect of molting is to double the frequency of SE-positive eggs in SE-positive flocks after the molting process.

Data Source		s	n	Number of SE-positive eggs per 10,000 eggs
Schlosser et al., 1995	Post-molt (0-20 wks)	31	74,000	4.2
	Pre-molt (0-20 wks)	14	67,000	2.1

s = the number of SE-positive eggs
n = the number of eggs sampled in high prevalence, SE-positive / molted or not molted flocks

The frequency of SE-positive eggs in high prevalence, SE-positive / molted flocks was modeled by adjusting the frequency calculated for high prevalence, SE-positive / not molted flocks. The adjustment is based on a risk ratio developed from the data of the Pennsylvania Pilot Project. The risk ratio associated with molting equals the frequency of SE-positive eggs detected in post-molt flocks, divided by the frequency of SE-positive eggs detected in pre-molt flocks.

Multiplying the positive egg frequency for high prevalence / not molted flocks (i.e., 0.07%) by the relative risk associated with molting (i.e., 2) equals 0.14%. Therefore, applying the effect of molting to high prevalence flocks implies that these flocks produce 14 SE-positive eggs per 10,000 eggs they lay during the high risk period following molt. Alternatively, this estimate equals 1 SE-positive egg in every 714 eggs produced, or 2 SE-positive eggs in every 1429 eggs produced. We use this latter estimate to form our distribution for this variable.

b. Value of the variable:

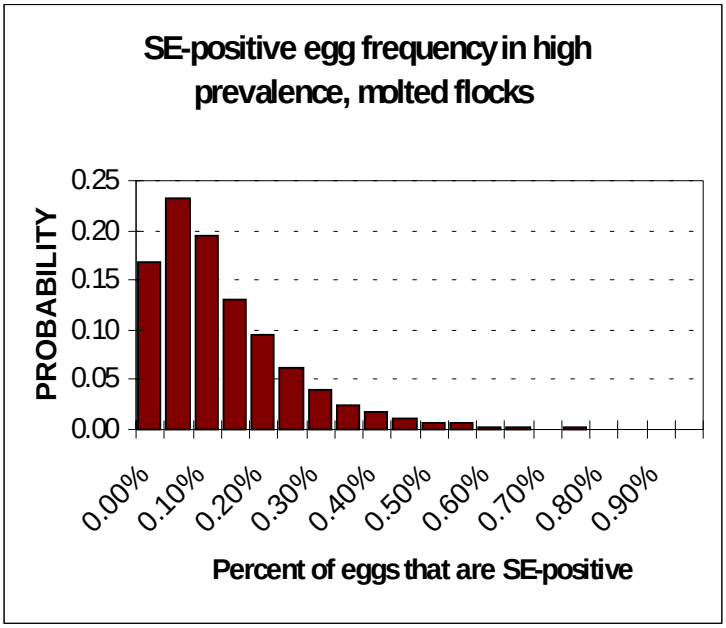
On average, we estimate that high prevalence / molted flocks produce 14 (0.14%) SE-positive eggs in every 10,000 eggs they lay during the high risk post-molt period (which averages about 70 days). To validate this estimate, we analyzed data from 13 SE-positive flocks that were molted during the Pennsylvania Pilot Project. There were four flocks with above average frequencies of SE-positive eggs which we classified as high prevalence / molted. The remaining nine flocks were classified as low prevalence / molted. We found that 76 (0.167%) of 46,000 eggs cultured from the four high prevalence flocks were SE-positive for a rate of 16.7 SE-positive eggs per 10,000 eggs. This result closely compares to the mean frequency of SE-positive eggs (0.14% or 14 SE-positive eggs per 10,000 eggs) which was calculated using the methods outlined above.

c. Distribution: Gamma(2,$(1429)^{-1}$)

The following histogram shows the distribution for the frequency of SE-positive eggs in high prevalence / molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by high prevalence / molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 2 SE-positive eggs in every 10,000 eggs produced (5th percentile) and 41 SE-positive eggs in every 10,000 produced (95th percentile). These percentile values are equivalent to 0.02% (5th percentile) and 0.41% (95th percentile).

Figure A-7

Mean	0.16%
Standard deviation	0.13%
5th percentile	0.02%
95th percentile	0.41%



8. Frequency of SE-positive eggs in low prevalence, SE-positive / not molted flocks

a. Evidence

Just as the available evidence supports the existence of high prevalence, SE-positive flocks, such evidence also supports the concept that a greater proportion of SE-positive flocks are low prevalence, SE-positive flocks.

The frequency of SE-positive eggs in low prevalence, SE-positive / not molted flocks is calculated using the following data:

Data Sources	s	n	Frequency of SE-positive eggs per 10,000 eggs
Schlosser et al., 1995	22	381,000	0.6
Henzler et al, 1994	2	10,140	2.0

s = the number of SE-positive eggs
n = the number of eggs sampled in SE-positive, low prevalence/not molted flocks.

The data from 43 unmolted flocks in the Pennsylvania Pilot Project cited previously (Schlosser et al., 1995) was used to determine the frequency of SE-positive eggs in low prevalence, SE-positive flocks. Those SE-positive flocks not classified as high prevalence (n=8) in that study were classified as low prevalence (n=35), and the aggregate egg culture results from the low prevalence, SE-positive flocks are represented in the table above. In a study by Henzler et al., (1994) of four flocks, two flocks showed low frequencies of SE-positive egg cultures and SE-positive environmental samples. Combining the results of these two studies, we find that 24 SE-positive eggs were detected in 391,140 eggs sampled from low prevalence / not molted flocks.

Therefore, these results suggest that low prevalence / not molted flocks produce 6 SE-positive eggs in every 100,000 eggs they lay. However, this estimate only applies to flocks that were found SE-positive using environmental testing since flocks in these studies were detected using environmental sampling. Because within-flock prevalence levels in low prevalence, SE-positive flocks can be very low, it is not reasonable to apply a frequency of SE-positive eggs which is derived from data collected in flocks found to be SE-positive on the basis of environmental testing. We expect there are SE-positive flocks that would not be detected using environmental testing (i.e., false negative flocks), but would be producing SE-positive eggs. However, these false negative flocks would not be expected to produce SE-positive eggs at a lower frequency than flocks whose level of infection was sufficient to be detected via environmental sampling.

In the national spent hen surveys, nearly 50% of the SE-positive flocks detected had within-flock prevalence levels between 0.33% and 0.66% (Table A-2, page 32). Within-flock prevalence measures the proportion of hens that have SE in

their intestinal tract. However, infected hens typically produce SE-positive eggs only during the first week of their four week infection (Leslie, 1996). In other words, one-quarter of infected hens at any given time are capable of producing SE positive eggs. Furthermore, it is estimated that a positive hen in her first week of infection only produces SE-positive eggs 8% of the time during that week (Leslie, 1996).

A within-flock prevalence of 0.33% means that 33 hens are SE-positive in a flock of 10,000 hens. One-quarter of these hens - or eight hens in a flock of 10,000 - are assumed to be in their first week of infection. These eight hens will produce 3 SE-positive eggs in one week (8 hens x 7 days x 0.72 eggs/day x 8% SE-positive eggs). The flock of 10,000 hens will produce a total of 50,400 eggs in a week (10,000 hens x 7 days x 0.72 eggs/day). Therefore, we estimate that an SE-positive egg frequency of approximately 0.005% (i.e. 3 / 50,400)) corresponds to a within-flock prevalence of 0.33%. For a within-flock prevalence of 0.66%, the corresponding positive egg frequency is 0.0096% (i.e. 9.6 SE-positive eggs per 100,000 eggs). These frequencies of SE-positive eggs closely agree with the mean frequency of SE-positive eggs (0.006% or 6 SE-positive eggs per 100,000 eggs produced) developed from the data in the table above. Therefore, these findings support using a frequency of 6 SE-positive eggs per 100,000 eggs produced in flocks detected via environmental testing or the spent hen survey methods. However, these findings also support the need to develop another frequency distribution for SE-positive eggs which applies to flocks whose within-flock prevalence levels are below the detection threshold of the spent hen surveys.

Low prevalence, SE-positive flocks are further subdivided into two categories. Category 1 low prevalence, SE-positive flocks are those low prevalence, SE-positive flocks found to be SE-positive through the national spent hen surveys. Category 2 low prevalence, SE-positive flocks are those low prevalence, SE-positive flocks which were not detected by the spent hen surveys.

To determine the frequency of SE-positive eggs for Category 2 low prevalence flocks, the within-flock prevalence levels of SE-positive hens for flocks not detected to be SE-positive flocks by the spent hen surveys must first be determined. Bayes theorem is used to calculate P(prev | test-), which is a mathematical expression which states 'the probability of the within-flock prevalence of SE-positive hens given that the flocks tested SE-negative in the spent hen surveys'. Bayes theorem states;

P(prev | test -) = P(test - | prev) * P (prev) / ∑[P(test - | prev) * P(prev)]

The probability of a flock testing SE-negative given different within-flock prevalence levels - i.e. P(test - | prev) - was calculated by determining the probability of no SE-positive results in a sample of 300 hens when a flock had a within-flock prevalence which ranged from 0.001% to 1% (i.e. 1 SE-positive hen per 100,000 hens to 1 SE-positive hen per 100 hens). The probability of

different within-flock prevalence levels - i.e. P(prev) - was determined by fitting a distribution to the national spent hen data. From our calculations of **P(prev | test -),** we developed a distribution for SE-positive eggs by assuming that one-fourth of positive hens in a flock were at risk of producing SE-positive eggs, and these at-risk hens produced positive eggs 8% of the time (i.e., as we estimated above). This analysis estimated that the average Category 2 low prevalence / not molted flock produced 5 SE-positive eggs in every 1 million eggs they laid.

b. Value of the variable:

(1) Frequency of SE-positive eggs in Category 1 low prevalence, SE-positive / not molted flocks.

On average, we estimate that Category 1 low prevalence / not molted flocks produce 6 SE-positive eggs in every 100,000 eggs they lay.

(2) Frequency of SE-positive eggs in Category 2 low prevalence, SE-positive / not molted flocks.

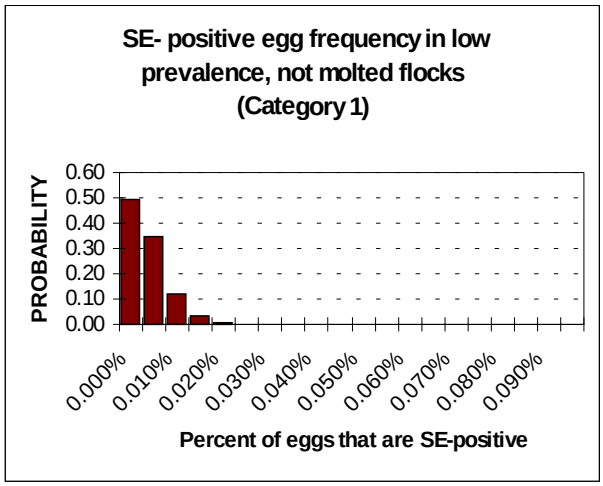
On average, we estimate that Category 2 low prevalence / not molted flocks produce 5 SE-positive eggs in every 1 million eggs they lay.

c. Distribution:

(1) Category 1: Gamma(2,$(33{,}333)^{-1}$)

The following histogram shows the distribution for the frequency of SE-positive eggs in Category 1 low prevalence / not molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by Category 1 low prevalence / not molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 1 SE-positive egg in every 100,000 eggs produced (5th percentile) and 14 SE-positive eggs in every 100,000 produced (95th percentile). These percentile values are equivalent to 0.001% (5th percentile) and 0.014% (95th percentile).

Figure A-8



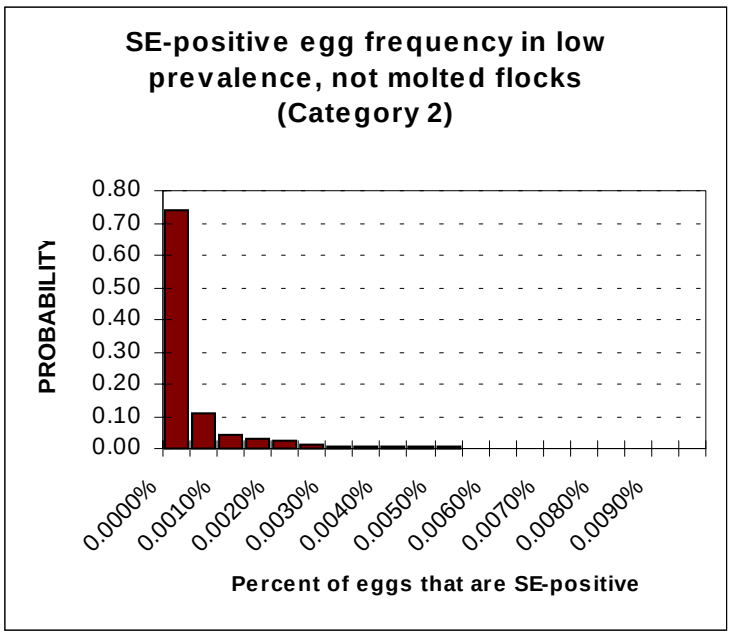
Mean	0.006%
Standard deviation	0.004%
5th percentile	0.001%
95th percentile	0.014%

(2) Category 2: Cumulative(0%,0.06%,0.00001%::0.01%,0.04::0.99)

This distribution is defined such that the minimum value is zero, and the maximum value is 6 per 10,000 (0.06%). Furthermore, the distribution is based on a range of values extending from 1 in 10 million (0.00001%) to 1 in 10,000 (0.01%), which occur with cumulative probabilities beginning with 0.04 and ending with 0.99. These cumulative probabilities ensure that extreme values (i.e., maximum and minimum) only occur about 5% of the time.

The following histogram shows the distribution for the frequency of SE-positive eggs in Category 2 low prevalence / not molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by Category 2 low prevalence / not molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 1 SE-positive egg in every 1 million eggs produced (5^{th} percentile) and 2 SE-positive eggs in every 100,000 produced (95^{th} percentile). These percentile values are equivalent to 0.0001% (5^{th} percentile) and 0.002% (95^{th} percentile).

Figure A-9



Mean	0.0005%
Standard deviation	0.001%
5^{th} percentile	0.0001%
95^{th} percentile	0.002%

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9. Frequency of SE-positive eggs in low prevalence, SE-positive / molted flocks

a. Evidence

The frequency at which SE-positive eggs are produced by low prevalence, SE-positive / molted flocks is used to calculate the number of SE-positive eggs produced by low prevalence, SE-positive flocks during the time period following the molting process of the hens when the rate of SE-positive eggs increases. For flocks in this category, the frequency of SE-positive eggs during the remainder of the year, when the flock is not molting, is modeled in the same way as for low prevalence, SE-positive / not molted flocks.

The frequency of SE-positive eggs in low prevalence, SE-positive / molted flocks is calculated by adjusting the frequency of SE-positive eggs of low prevalence, SE-positive / not molted flocks. This method uses the same data for molted flocks as was presented for the frequency of SE-positive egg from high prevalence, SE-positive / molted flocks (pp. 48).

Value of the variable:

(1) Frequency of SE-positive eggs in Category 1 low prevalence, SE-positive / molted flocks.

On average, we estimate Category 1 low prevalence / molted flocks produce 1.3 SE-positive eggs in every 10,000 eggs they lay. This frequency is essentially twice the frequency we estimated for Category 1 low prevalence / not molted flocks.

Analysis of the data from the 13 molted flocks in the Pennsylvania Pilot Project validates our estimate of the frequency of SE-positive eggs for low prevalence, SE-positive / molted flocks. By classifying the nine SE-positive flocks with below-average frequencies of SE- positive eggs as low prevalence, SE-positive flocks, it was found that 16 eggs (0.019%) of 83,000 eggs cultured from this cohort of nine flocks were SE-positive eggs. This result closely compares to the mean positive egg frequency (0.013%) calculated for Category 1 - low prevalence, SE-positive / molted flocks.

(2) Frequency of SE-positive eggs in Category 2 low prevalence, SE-positive / molted flocks.

On average, we estimate that Category 2 low prevalence / molted flocks produce 1 SE-positive egg in every 100,000 eggs they lay. Again, this is essentially double the rate estimated for Category 2 flocks that were not molted.

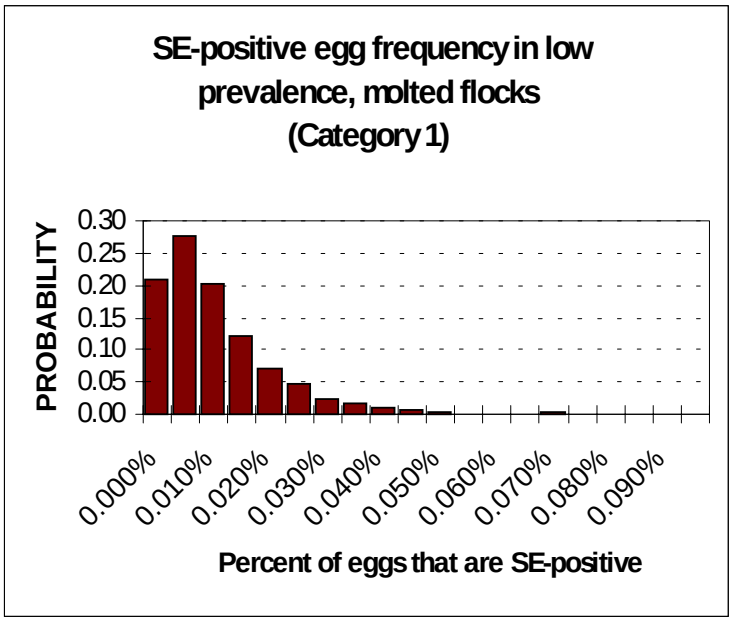
b. Distribution of the variable:

(1) Category 1: Gamma(2,$(16{,}500)^{-1}$)

The following histogram shows the distribution for the frequency of SE-positive eggs in Category 1 low prevalence / molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by Category 1 low prevalence / molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 1 SE-positive egg in every 100,000 eggs produced (5th percentile) and 3 SE-positive egg in every 10,000 produced (95th percentile). These percentile values are equivalent to 0.001% (5th percentile) and 0.03% (95th percentile).

Mean	0.013%
Standard deviation	0.01%
5th percentile	0.001%
95th percentile	0.03%

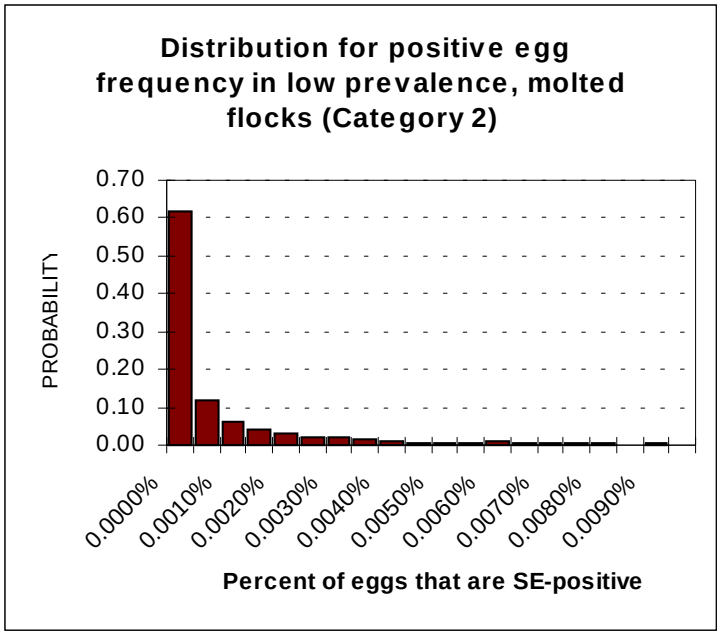
Figure A-10



(2) Category 2: Cumulative distribution for Category 2 not molted flocks times the relative risk of molting (approximately 2).

The following histogram shows the distribution for the frequency of SE-positive eggs in Category 2 low prevalence / molted flocks. This graph reflects our uncertainty regarding the fraction of eggs produced by Category 2 low prevalence / molted flocks that are SE-positive. It can be seen from this graph that we are 90% confident that this frequency is between 1 SE-positive egg in every 1 million eggs produced (5th percentile) and 5 SE-positive eggs in every 100,000 produced (95th percentile). These percentile values are equivalent to 0.0001% (5th percentile) and 0.005% (95th percentile).

Figure A-11



Mean	0.001%
Standard deviation	0.002%
5th percentile	0.0001%
95th percentile	0.005%

Production Module

10. Destination of SE-positive eggs post-production

The physical distribution of SE-positive eggs to plants for further processing as shell eggs or into liquid egg products after egg production determines the total number SE-positive eggs which will be modeled in the Shell Egg Processing/Distribution module and the Egg Products Processing/Distribution module. These modules - Shell Egg Processing/Distribution module and Egg Products Processing/Distribution module - actually simulate the growth of SE in a single egg.

The likelihood that any egg is distributed to the shell egg processor or to the egg products processor is based on USDA-NASS and Agricultural Marketing Service (AMS) statistics. Every year 76.1% of all eggs are marketed through shell egg processing, while 23.9% of all eggs are marketed through egg products. After processing and grading, 5% of all shell eggs are determined to be restricted eggs because these eggs have checks (i.e. cracks in the shell detected during candling of the egg) in the shell or are dirty, and these restricted eggs are diverted to plants which make egg products. However, 10% of restricted eggs are determined to be inedible, and these inedible eggs are either destroyed or labeled and handled as either for animal food or for industrial use.

We calculate the number of SE-positive eggs per year that are destined for egg products and shell egg markets based on the following percentages.

Shell eggs	72.3%
Egg Products	23.9%
Shell eggs diverted to egg products	3.4%
Inedible eggs	0.4%
	======
	100%

D. Output of Production Module

The output of the production module consists of;

1) the number of SE-positive eggs produced annually by commercial U.S. layer flocks (which are divided into four different types of flocks),

2) the percent of SE-positive eggs in all eggs produced annually by these four different types of flocks, and

3) the number of SE-positive eggs distributed to the processors of shell eggs for distribution and to the processors of egg products for distribution.

To calculate these outputs, the module first calculates the number of SE-positive flocks, then categorizes these SE-positive flocks by prevalence (i.e., high or low) and molting status. For each of the four types of flocks, the module calculates the annual number of eggs produced, then applies the appropriate frequency of SE-positive eggs for the type of flock in order to calculate the number of SE-positive eggs produced per annum by each flock type and by all flock types together. The module outputs also include the number of SE-positive flocks, the number of high prevalence SE-positive flocks, the number of high prevalence SE-positive /molted flocks, the number of SE-positive eggs produced per year by high prevalence SE-positive / molted flocks, etc.

To calculate total eggs produced by one of the four types of SE-positive flocks (e.g., high prevalence, SE-positive / not molted flock), the daily egg production of each of the four types of SE-positive flocks is multiplied by the number of days each type of flock is in production. This product is then multiplied by the number of flocks of each type. This calculation is done for each size stratum within each of the four types of SE-positive flock.

The number of SE-positive eggs produced by each of the four types of SE-positive flocks is calculated as Normal($n\lambda$, $(\lambda n)^{1/2}$) distribution, where n is the number of eggs produced per year by a specific SE-positive flock type, and λ is the frequency of SE-positive eggs of each type of flock. The Central Limit Theorem states that the sum of a group of random variables will have a Normal($n\mu$,$\sigma n^{1/2}$) distribution, where n is the number of random variables in the group and μ and σ are the mean and standard deviation of the variables. In this case, n is the number of eggs produced per year and each egg has some likelihood of being an SE-positive egg based on the frequency of SE-positive eggs associated with the type of flock that produced the egg.

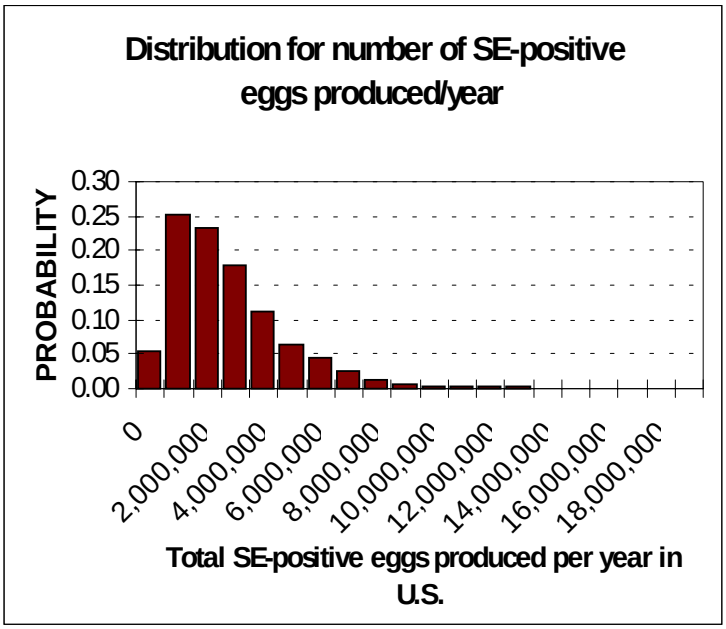
From the total number of SE-positive eggs, the number of SE-positive eggs sent to shell egg processors/distributors and to egg products processors/distributors is calculated. Also calculated are the number of SE-positive eggs initially sent to shell egg processing/distribution, but later diverted to egg products processing/distribution. Finally, the number of SE-positive eggs which are treated as inedible is calculated. Inedible eggs are not considered further in the model.

The following histogram depicts the distribution for the total number of SE-positive eggs produced per year, as predicted by the Production module. On average, we estimate that about

Production Module

3.3 million SE-positive eggs are produced from the 65 billion eggs laid per year. It can be seen from this graph that we are 90% confident that the total number of SE-positive eggs produced per year is between 974,303 (5th percentile) and 7,386,495 (95th percentile).

Figure A-12

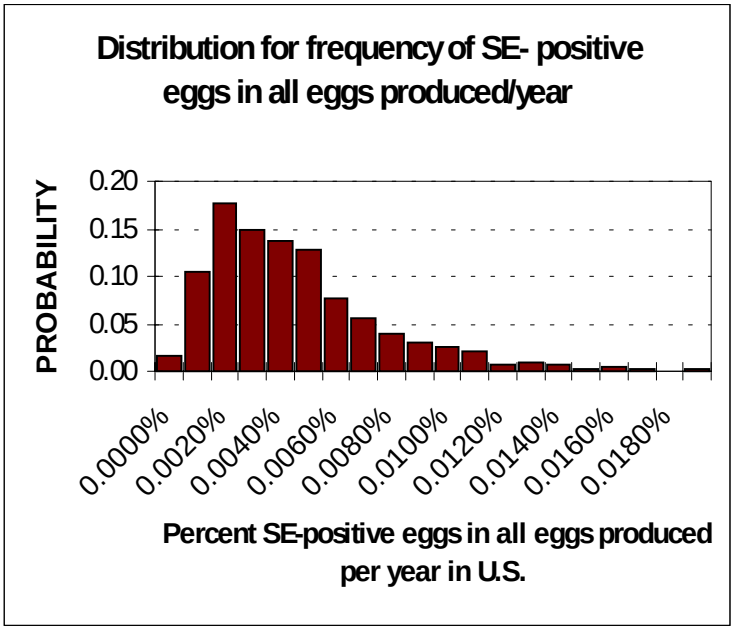


Mean	3,312,064
Standard deviation	2,164,706
5th percentile	974,303
95th percentile	7,386,495

Production Module

The following histogram depicts the distribution for the overall frequency of SE-positive eggs produced per year in the U.S. Overall frequency of SE-positive eggs is calculated by dividing the total number of SE-positive eggs produced per year (on average, 3.3 million) by the total number of eggs produced per year (on average, 65 billion). We estimate there is an average of 5 SE-positive eggs produced per 100,000 eggs laid by U.S. hens. It can be seen from this histogram that we are 90% confident that the frequency of SE-positive eggs produced per year is between 1 SE-positive egg per 100,000 eggs produced (5th percentile) and 11 SE-positive eggs per 100,000 eggs produced (95th percentile). These percentile values are equivalent to 0.001% (5th percentile) and 0.011% (95th percentile).

Figure A-13



Mean	0.005%
Standard deviation	0.003%
5th percentile	0.001%
95th percentile	0.011%

Table A-4. Mean percentage contribution to total SE-positive eggs by type of SE-positive flocks and by stratum within a type of flock

Type of Flock		Total	10-19K hens per Flock	20-49K hens per Flock	50-99K hens per Flock	>100K hens per Flock
High prevalence, SE-+ / molted		15.44%	1.28%	1.79%	2.26%	10.12%
High prevalence, SE-+ / not molted		50.94%	4.43%	6.34%	7.15%	33.02%
Low prevalence, SE-+ / molted	Cat. 1	7.49%	0.64%	0.91%	1.05%	4.88%
	Cat. 2	0.25%	0.02%	0.03%	0.04%	0.17%
Low prevalence, SE-+ / not molted	Cat. 1	25.02%	2.15%	3.03%	3.52%	16.31%
	Cat. 2	0.85%	0.07%	0.10%	0.12%	0.55%
		100%				

The results depicted in Table A-4 above demonstrate the relative contribution of each of the four types of SE-positive flocks to the total number of SE-positive eggs produced per year in the production module. The percentage attributed to each of the four types of SE-positive flocks by the production module is located in the column labeled 'Total'. Note that two of the types of flocks are each further subdivided into two categories, as discussed earlier in the text. The contribution of each of the four types of SE-positive flocks to the total production of SE-positive eggs based on the size of a flock (i.e. stratum) is shown in the four columns on the right hand side of Table A-4.

High prevalence, SE-positive / not molted flocks produce a slight majority of the positive eggs (50.9%). On average, 11% of SE-positive flocks are high prevalence flocks. Furthermore, an average of 22% of these high prevalence flocks are molted. Therefore, only 9% of all SE-positive flocks are high prevalence / not molted flocks. Yet, these flocks are estimated to produced over one-half the SE-positive eggs per year.

On average, high prevalence flocks are responsible for about two-thirds of all positive eggs (i.e. 15.44% + 50.94%). Low prevalence flocks account for the remaining one-third. However, Category 2 low prevalence flocks' contribution to total SE-positive eggs per year is minimal. Molted flocks contribute roughly one-quarter of all positive eggs (i.e 15.44% + 7.49%). This proportion is essentially the same as the proportion of SE positive flocks that are molted. By flock size strata, the largest stratum (i.e. $\geq$100,000 hens per flock) contributes almost two-thirds of the positive eggs (i.e. 10% + 33% + 4.8% + 16%), while the remaining one-third of positive eggs are distributed among the other three strata in nearly equivalent proportions.

Table A-5. Number of SE-positive eggs per year distributed to shell egg and egg products markets.

Marketing option	Number of SE-positive eggs/year		
	Mean	5th percentile	95th percentile
Direct to shell egg processing	2,242,526	704,373	5,340,066
Diverted from shell egg market to egg products	106,225	33,365	252,950
Inedible eggs	11,803	3,707	28,106
Direct to egg products processing	741,356	232,859	1,765,372

Table A-5 demonstrates the distribution of SE-positive eggs to shell egg processing and egg products processing predicted by the Production module. On average, we estimate that 2.2 million SE-positive eggs per year are processed and distributed as shell eggs. Furthermore, we estimate that an average of 847,581 SE-positive eggs (741,356 + 106,225) per year are processed and distributed as egg products. We estimate that about 11,803 SE-positive eggs are disposed of as inedible before further processing. For all eggs produced per year (65 billion), 47 billion are processed and distributed as shell eggs, 18 billion are processed and distributed as egg products, and 0.26 billion are inedible.

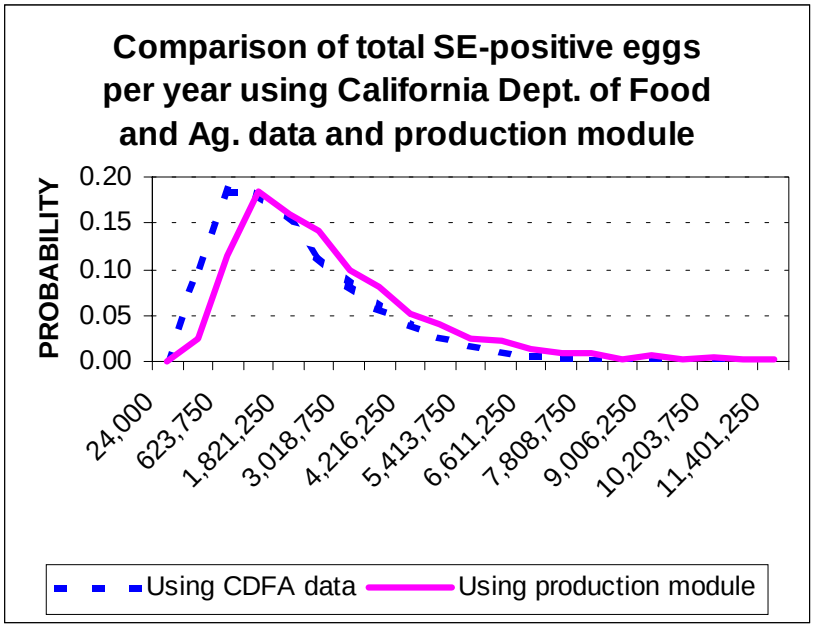
E. Module Validation

A comparison of the output distribution of SE-positive eggs from the production module with a distribution of SE-positive eggs developed from survey data provided by the California Department of Food and Agriculture (CDFA) (Ian Gardner, personal communication) shows good correspondence. A random survey conducted in California found 1 SE-positive pooled egg sample in 1416 pooled egg samples, where 20 eggs were pooled per sample. This result is equivalent to finding 1 SE-positive egg in 28,320 eggs. Applying our methodology to this data results in a Gamma $(2,(14,160)^{-1})$ distribution with a mean of 0.35 SE-positive eggs per 10,000 eggs. Because eggs in this survey were sampled without knowledge of the SE status of the flock, this distribution is applicable to all eggs produced per year.

To compare the survey findings of the CDFA to the production module's predictions, the national prevalence of SE-positive flocks used in the production module was adjusted to only reflect the results of the national spent hen surveys from the Western region. Because the production module is designed to model national levels, this adjustment is necessary to compare California's data to the production module results. California is the largest egg producing state in the U.S.. Therefore, data generated from that state is reasonably expected to reflect the Western U.S.. For the sake of simplicity, the prevalence of SE-positive flocks in the western region was applied to all U.S. flocks, and the distribution for total number of SE-positive eggs produced per year is demonstrated. Figure A-14 compares the two distributions (one based on the data from CDFA and one based on the production module). Figure A-14 shows that the output of the production module is very similar to the distribution of SE-positive eggs independently derived from the CDFA data. This CDFA data was not used in the development

of the production module. Therefore, this comparison of the CDFA data and the production module output is a demonstration of this module's validity. The actual numbers of SE-positive eggs predicted by the production module are not relevant to this discussion. Instead, the intention of the Figure A-14 is to demonstrate the robustness of the production module. Such agreement is reassuring. The mean frequencies of SE-positive eggs among all eggs produced for the California data and the production module are 0.35 per 10,000 eggs and 0.5 per 10,000 eggs, respectively. These frequencies predict the mean numbers of SE-positive eggs per year of 2.2 million SE-positive eggs from the California validation output and 2.7 million SE-positive eggs from the output of the production module.

Figure A-14



F. Sensitivity Analysis

A sensitivity analysis of the production module was completed to determine the degree to which the input variables were correlated with this module's output. When an input variable is highly correlated with the output variable, it is expected that adjustments in the input distribution will result in substantial changes in the output distribution and may be a control point for intervention.

This sensitivity analysis examined the degree to which input variables were correlated with the total number of SE-positive eggs produced per year in the U.S. All input variables were evaluated. Specifically, these input variables included;

- ♦ Prevalence of SE-positive flocks
- ♦ Frequency of high prevalence flocks
- ♦ Frequency of molted flocks
- ♦ Days of high risk post-molt
- ♦ Positive egg frequency variables for high/low prevalence, molted/not molted flocks.

Our sensitivity analysis of the production module indicates the following variables are most correlated with the number of SE-positive eggs produced per year (Table 6):

- positive egg frequency in unmolted high and low prevalence flocks,
- frequency of SE-positive flocks (especially in the largest flocks),
- frequency of high prevalence flocks.

Because high prevalence flocks contribute a disproportionately large number of positive eggs to the total SE-positive eggs per year (as demonstrated in Table A-4, see page 63), it is not surprising that variables that serve to estimate the role of high prevalence flocks should be correlated with the output of the production module. For example, when the module predicts a lower than average percent of flocks are high prevalence flocks, the total number of SE-positive eggs per year calculated by the module is reduced. Similarly, when the module predicts a lower than average frequency of SE-positive eggs in high prevalence flocks, total positive eggs per year declines.

Because molted flocks only contribute a proportional number of positive eggs to the total SE-positive eggs per year (Table A-4, see page 63), the variables associated with molting are not correlated with the output of the production module. Such results are somewhat surprising given the much higher frequencies at which molted flocks produce SE-positive eggs. However, these flocks experience high positive egg frequencies for a limited time - typically 70 days in the module. Furthermore, molted flocks do not produce any eggs for an average of 30 days because

they cease production during molt. Consequently, when the frequency of molted flocks, or the positive egg frequencies in molted flocks, is varied in the module, there is less effect on the predicted total number of SE-positive eggs per year than other variables.

Strategies to mitigate the likelihood of SE-positive eggs at the production level include mechanisms to prevent the entry of SE into commercial flocks, remove SE from the poultry house environment, and reduce within-flock transmission. Effects of these strategies can be incorporated into the production module through the variables listed above. For example, mechanisms to prevent entry of SE into flocks include the testing of replacement pullets before the introduction of replacement pullets into the layer house, using SE-free feedstuffs, and other biosecurity practices. These mechanisms could be modeled through their reduction in the frequency of SE-positive flocks. Similarly, the effect of improved rodent control on reducing an important reservoir of SE in poultry environments could be modeled as a reduction in frequency of SE-positive flocks. Improved rodent control might also reduce within-flock transmission of SE, thereby causing a reduction in the frequency of high prevalence flocks.

Table A-6. Correlation between input variables and SE-positive eggs produced/year.

Name of input variable	Correlation Coefficient
Positive egg frequency in high prevalence, SE-positive / not molted flocks	0.62
Prevalence of SE-positive flocks in >100K hens per flock size stratum	0.54
Positive egg frequency in low prevalence, SE-positive / not molted flocks - Cat. 1	0.34
Frequency of high prevalence, SE-positive flocks	0.26
Apparent SE-positive flock prevalence in >100K flock size stratum	0.24
Apparent SE-positive flock prevalence calculated from spent hen surveys	0.10
Sensitivity of environmental testing	0.09
Days of high risk post-molt	0.08
SE-positive egg frequency in high prevalence, SE-positive / molted flocks	0.06
Apparent within-flock prevalence for test-negative flocks	0.03

G. Production Module Limitations

The limitations of the production module stem from the data used to estimate its variables and the scope of the risk assessment.

Data used to estimate the frequency of high/low prevalence flocks was generated from a large industry-government project conducted in Pennsylvania (Schlosser et al., 1995). Although this data is extremely valuable because of its uniqueness (i.e., it is the only such data published concerning U.S. commercial flocks), it can only be expected to have direct relevance to the Pennsylvania industry. Similar limitations also apply for the positive egg frequency data generated by this project.

Another limitation is the lack of temporal data to provide information regarding patterns of flock prevalence and within-flock prevalence over time. Estimates of positive egg frequencies in Category 2 low prevalence flocks, for example, were developed based on theoretically static within-flock prevalence levels because empiric evidence was lacking. Furthermore, estimates of positive eggs were restricted to an annual basis because monthly or quarterly estimates could not be supported by the available data.

The scope of this risk assessment also applied limitations for the production module. This assessment was designed to model the number of human illnesses resulting from internally SE-positive eggs, then evaluate the effectiveness of various mitigations in reducing these illnesses. Therefore, we developed a baseline model which reflects the status quo regarding SE occurrence. The model does not attempt to reflect changes in SE occurrence over time.

In Europe, the emergence of a particularly virulent strain of SE has resulted in a persistent and pervasive SE problem. While the current situation in the U.S. is not as severe as Europe's, research by Guard-Petter (1997) suggests that the U.S. situation may yet evolve to the level of the European experience. Specifically, Guard-Petter et al. (1997) argue that SE populations on farms can undergo differentiation and result in growth to higher cell densities, expression of virulence factors, and overall higher penetrance within flocks. Such developments could result in greater frequencies of high prevalence flocks in the U.S. over time. The recent detection of Phage type 4 SE - the SE type currently affecting Europe - in U.S. commercial egg flocks (Kinde et al., 1996 and Hogue et al., 1997) suggests the need for heightened surveillance for SE in this country. However, this assessment does not currently address a hypothetically increasing prevalence of severe SE infections in the U.S. Nevertheless, as more epidemiologic data becomes available, the model can be adapted to evaluate such changes.

H. Mathematics of the Production Module

1. Definitions of Constants

$N_i \equiv$ number of flocks in size stratum I, (I=1,2,3,4)

$B_i \equiv$ number of hens per flock in stratum I, (I=1,2,3,4)

$E \equiv$ frequency of eggs per hen per day (0.72)

$Z_1 \equiv$ percent of eggs only marketed to the shell egg market per year

$Z_2 \equiv$ percent of eggs marketed to the shell egg market then diverted to egg products market per year

$Z_3 \equiv$ percent of eggs marketed directly to the egg products market per year

$Z_4 \equiv$ percent of eggs that are inedible per year

2. Variables

a. Input variables

$p_i \equiv$ prevalence (percent) of SE-positive flocks in stratum$_i$

$h \equiv$ frequency (percent) of high prevalence flocks among SE-positive flocks

$m \equiv$ frequency (percent) of flocks that have molted

$f_j \equiv$ frequency (percent) of SE-positive eggs produced by SE-positive flocks in category j, (j=1,2,3,4,5,6)

$k \equiv$ number of days a flock is out of production due to molting

$d \equiv$ number of days post-molt that molted flocks experience increased positive egg frequencies

$s \equiv$ percent of SE-positive flocks detected when sampling 300 hens per flock

3. Calculations

a. Intermediate variables

(1) **Number of positive flocks**

HPM_i ≡ number of SE-positive, high prevalence, molted flocks in stratum I

$HPM_i = N_i * p_i * h * m$

$HPUM_i$ ≡ number of SE-positive, high prevalence, unmolted flocks in stratum I

$HPUM = N_i * p_i * h * (1-m)$

$LPM1_i$ ≡ number of Category 1, SE-positive, low prevalence, molted flocks in stratum I

$LPM1_i = N_i * p_i * (1- h) * s * m$

$LPM2_i$ ≡ number of Category 2, SE-positive, low prevalence, molted flocks in stratum I

$LPM2_i = N_i * p_i * (1- h) * (1-s) * m$

$LPUM1_i$ ≡ number of Category 1, SE-positive, low prevalence, unmolted flocks in stratum I

$LPUM1_i = N_i * p_i * (1- h) * s * (1-m)$

$LPUM2_i$ ≡ number of Category 2, SE-positive, low prevalence, unmolted flocks in stratum I

$LPUM2_i = N_i * p_i * (1- h) * (1-s) * (1-m)$

(2) **Total eggs per year produced by positive flocks**

$EHPM_i$ ≡ total eggs produced per year by HPM_i flocks

$EHPM_i = HPM_i * B_i * E * (365 \text{ days} - k)$

$DEHPM_i$ ≡ total eggs produced by HPM_i flocks during d days following molt,

$DEHPM_i = Normal(HPM_i * B_i * E * \mu_d , (HPM_i * B_i * E * \sigma_d)^{0.5})$

$YEHPM_i$ ≡ total eggs produced by HPM_i flocks during the rest of the year,

$YEHPM_i = EHPM_i - DEHPM_i$

$EHPUM_i$ ≡ total eggs produced per year by HPUMi flocks

$EHPUM_i = HPUM_i * B_i * E * 365$ days

$ELPM1_i$ ≡ total eggs produced per year by $LPM1_i$ flocks

$ELPM1_i = LPM1_i * B_i * E * (365 \text{ days} - k)$

$DELPM1_i$ ≡ total eggs produced by $LPM1_i$ flocks during d days following molt,

$DELPM1_i = Normal(LPM1_i * B_i * E * \mu_d , (LPM1_i * B_i * E * \sigma_d)^{0.5})$

$YELPM1_i$ ≡ total eggs produced by $LPM1_i$ flocks during the rest of the year,

$YELPM1_i = ELPM1_i - DELPM1_i$

$ELPM2_i$ ≡ total eggs produced per year by $LPM2_i$ flocks

$ELPM2_i = LPM2_i * B_i * E * (365 \text{ days} - k)$

$DELPM2_i$ ≡ total eggs produced by $LPM2_i$ flocks during d days following molt,

$DELPM2_i = Normal(LPM2_i * B_i * E * \mu_d , (LPM2_i * B_i * E * \sigma_d)^{0.5})$

$YELPM2_i$ ≡ total eggs produced by $LPM2_i$ flocks during the rest of the year,

$YELPM2_i = ELPM2_i - DELPM2_i$

$ELPUM1_i$ ≡ total eggs produced per year by $LPUM1_i$ flocks

$ELPUM1_i = LPUM1_i * B_i * E * 365$ days

$ELPUM2_i$ ≡ total eggs produced per year by $LPUM2_i$ flocks

$ELPUM2_i = LPUM2_i * B_i * E * 365$ days

(3) **SE-positive eggs per year produced by positive flocks**

$SEHPM_i$ ≡ SE-positive eggs produced per year by HPMi flocks

$SEHPM_i =$

$Normal[(YEHPM_i * f_1), (YEHPM_i * f_1)^{0.5}] + Normal[(DEHPM_i * f_2), (DEHPM_i * f_2)^{0.5}]$

where f_1 is the positive egg frequency for high prevalence, unmolted flocks and f_2 is the positive egg frequency for high prevalence, molted flocks.

$SEHPUM_i$- SE-positive eggs produced per year by HPUMi flocks

$SEHPUM_i = Normal[(EHPUM_i * f_1), (EHPUM_i * f_1)^{0.5}]$

$SELPM1_i \equiv$ SE-positive eggs produced per year by $LPM1_i$ flocks

$SELPM1_i =$

$Normal[(YELPM1_i * f_3), (YELPM1_i * f_3)^{0.5}] + Normal[(DELPM1_i * f_4), (DELPM1_i * f_4)^{0.5}]$

where f_3 is the positive egg frequency for Category 1 low prevalence, unmolted flocks and f_4 is the positive egg frequency for Category 1 low prevalence, molted flocks.

$SELPM2_i \equiv$ SE-positive eggs produced per year by $LPM2_i$ flocks

$SELPM2_i =$

$Normal[(YELPM2_i * f_5), (YELPM2_i * f_5)^{0.5}] + Normal[(DELPM2_i * f_6), (DELPM2_i * f_6)^{0.5}]$

where f_5 is the positive egg frequency for Category 2 low prevalence, unmolted flocks and f_6 is the positive egg frequency for Category 2 low prevalence, molted flocks.

$SELPUM1_i \equiv$ SE-positive eggs produced per year by $LPUM1_i$ flocks

$SELPUM1_i = Normal[(ELPUM1_i * f_3), (ELPUM1_i * f_3)^{0.5}]$

$SELPUM2_i \equiv$ total eggs produced per year by $LPUM2_i$ flocks

$SELPUM2_i = Normal[(ELPUM2_i * f_5), (ELPUM2_i * f_5)^{0.5}]$

b. <u>Output variables</u>

$Y \equiv$ total number of SE-positive eggs produced per year

$$Y = \sum_I [SEHPM_i + SEHPUM_i + SELPM1_i + SELPM2_i + SELPUM1_i + SELPUM2_i]$$

$Y_1 \equiv$ total number of SE-positive eggs marketed to shell eggs per year

$$Y_1 = Y * Z_1$$

$Y_2 \equiv$ total number of SE-positive eggs marketed as egg products per year

$$Y_2 = Y * (Z_2 + Z_3)$$

$Y_3 \equiv$ total number of SE-positive eggs that are inedible per year

$$Y_3 = Y * Z_4$$

Production Module

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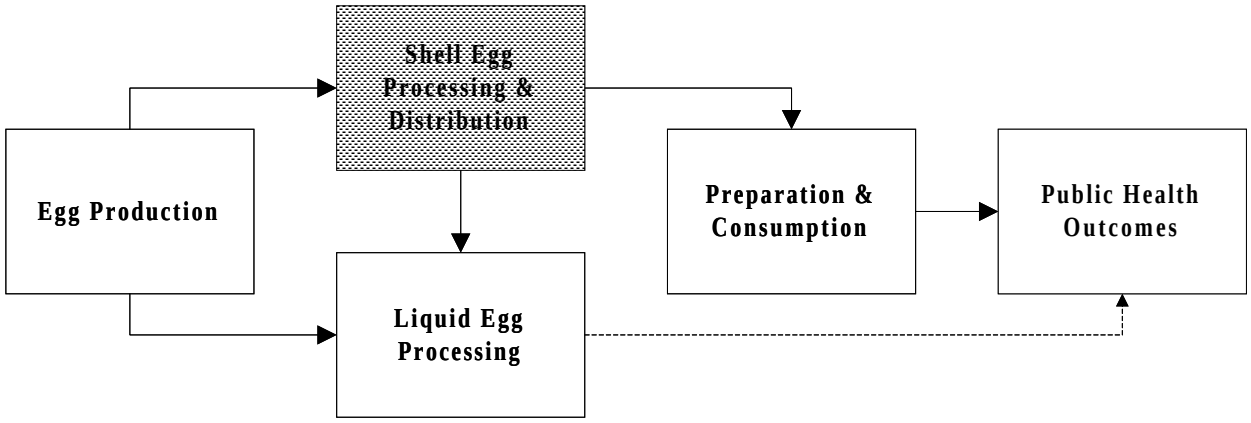
Shell Eggs Processing and Distribution Module



A. Summary of Shell Eggs Processing and Distribution Module

The purpose of the shell egg processing and distribution module is to simulate the processing, storage, and distribution of shell eggs from the farm to egg products processing/distribution, or preparation and consumption. Eggs remain intact throughout this process. Therefore, the primary factors affecting SE are the cumulative effects of temperatures and times of the various processing, transportation, and storage stages. The two important modeling components in this module are the time until the yolk membrane loses its integrity, and the growth rate of SE in eggs. These components are dependent on the distributions for time and temperature for various stages. The assumption is made that there is no die-off of SE once it has been deposited inside the egg.

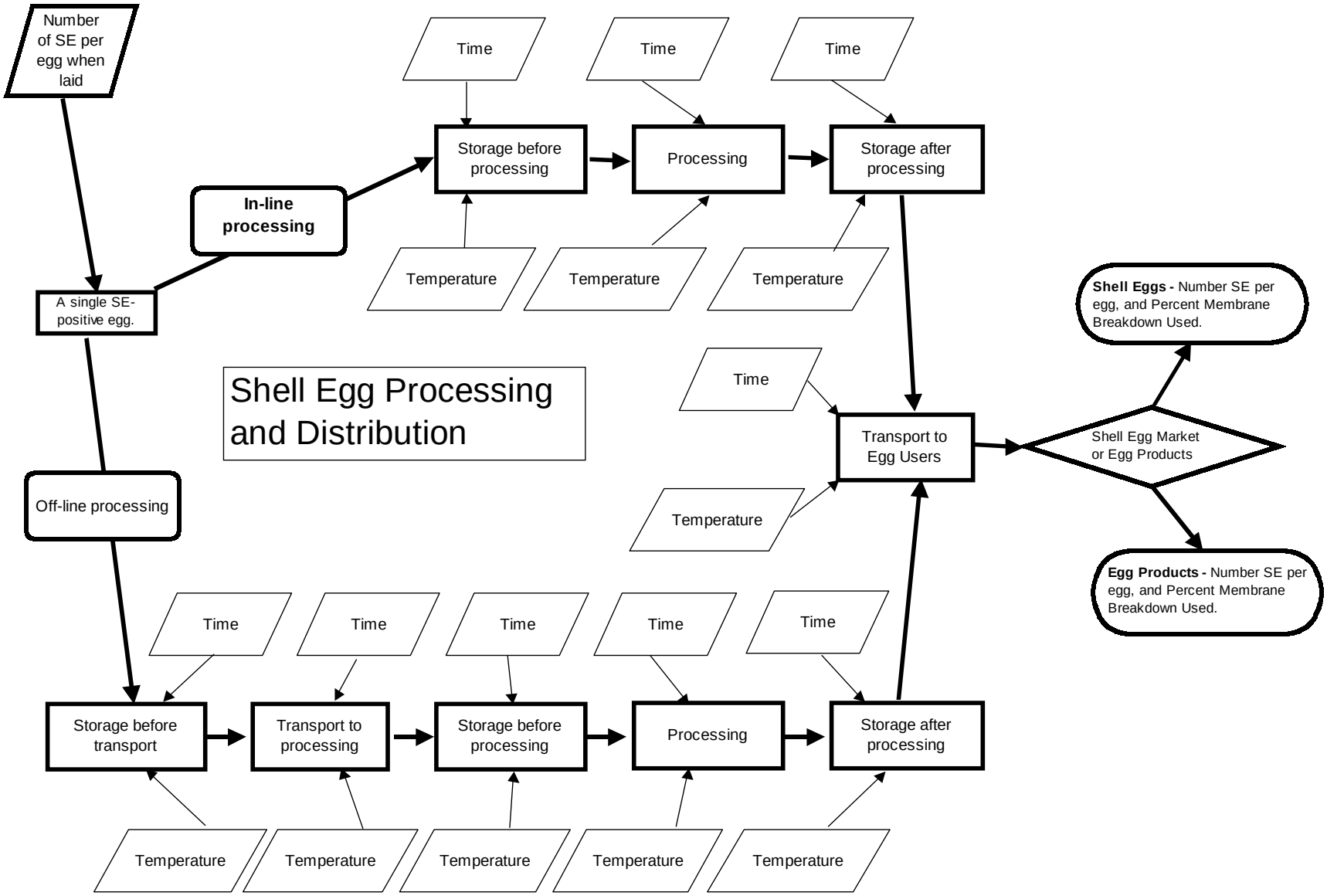
The shell egg processing and distribution module is the next stage, following egg production, in a farm-to-table quantitative risk assessment. While the egg production module simulates the number of SE-positive eggs produced by a population of commercial flocks, this processing and distribution module calculates the likelihood of various numbers of SE bacteria for a single SE-positive egg.

An egg in this module can either follow an in-line or off-line process. An off-line processed egg is subjected to additional transportation and storage stages relative to an in-line processed egg. For either process, an egg is washed, graded, candled, and stored at the egg processing plant. An egg is then transported to either the shell egg market or to the egg products market.

At each stage of this module, time and temperature variables are used to determine the yolk membrane breakdown time of the egg. Yolk membrane breakdown time measures the time (in days) necessary before the antibacterial properties of the egg are compromised, thereby allowing replication of SE bacteria within the egg. For a stored egg, the temperature at any time is

calculated from the beginning internal temperature of the egg, the ambient air temperature, and the type of packaging and environment that the egg is in. The extent of yolk membrane breakdown time is calculated as a function of temperature. The number of days in storage is then compared with the calculated membrane breakdown time to determine the percent of membrane breakdown time remaining for a specific egg. Once this percentage reaches zero, SE growth in the egg is calculated based on the time remaining and temperatures, in storage.

Salmonella on the surface of the shell is not represented in this module. The possibility of *Salmonella*, including *S.* Enteritidis migrating from the shell surface at the time of lay through the shell and two shell membranes was considered. In his review, Humphrey (1994) states that organisms die rapidly on the egg shell unless the egg is stored in high humidity and low temperatures. Little data exist on the prevalence of egg shell contamination or migration. Schoeni et al. (1995) and Chen et al. (1996) demonstrated that penetration is possible. However, if outbreaks of Salmonellosis originated from external shell contamination, outbreaks in undercooked egg products from non-Enteritidis strains would be frequent. Epidemiologic data does not indicate this occurs (Tauxe, 1997) and outbreaks are predominantly *S.* Enteritidis. Therefore, this risk assessment will consider only *S.* Enteritidis which are inside the freshly-laid egg.


Number of SE per egg when laid
Time
Time
Time
Storage before processing
Processing
Storage after processing
In-line processing
Temperature
Temperature
Temperature
A single SE-positive egg.
Shell Egg Processing and Distribution
Shell Eggs - Number SE per egg, and Percent Membrane Breakdown Used.
Time
Transport to Egg Users
Shell Egg Market or Egg Products
Temperature
Off-line processing
Egg Products - Number SE per egg, and Percent Membrane Breakdown Used.
Time
Time
Time
Time
Time
Storage before transport
Transport to processing
Storage before processing
Processing
Storage after processing
Temperature
Temperature
Temperature
Temperature
Temperature

B. Inputs to the Shell Egg Module

1. Number of SE bacteria per positive egg at lay

The number of SE bacteria per positive egg at lay variable is used to calculate growth of SE once an egg's membrane breakdown is complete. Until then, the number of SE bacteria is modeled as unchanged through the different stages of the shell egg processing and distribution module. The assumption is made that there is no die-off of SE once it has been deposited inside the egg.

a. Evidence

Table B-1. Evidence for the number of SE organisms per egg at lay

Reference	Mean[2]	min.	mode	max.
Gast and Beard[1], 1992 **(Artificially infected hens)**	200	60	180	420
Humphrey et al., 1991 **(naturally infected hens)**	7	1	5	20

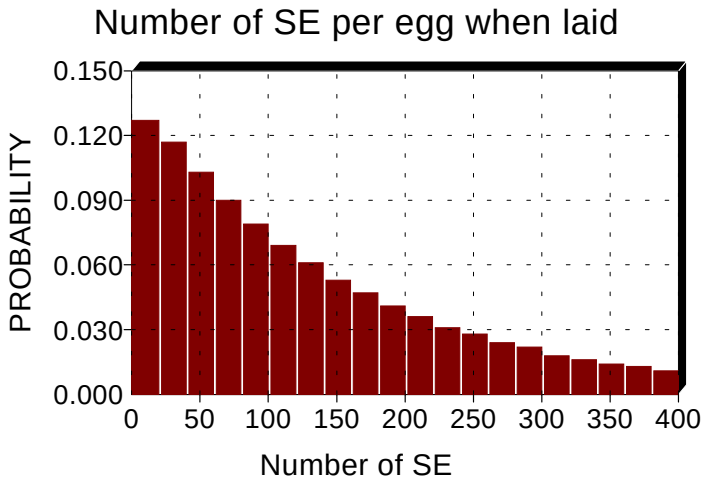
[1] Values are extrapolated from published values based on 60 ml per egg.
[2] The mean value is the calculated expected value of a Pert(min, mode, max) distribution.

b. Mean – 122 SE bacteria

c. Distribution – Truncated Exponential (152,1,400)

This distribution incorporates the high levels of SE fond by Gast and Beard with artificially infected hens while allowing for the low values found by Humphrey in naturally infected hens. This distribution also attempts to include the growth of SE up to 1 log that can occur initially after laying before the pH increases (Humphrey, 1993).

Figure B-2



C. Shell Egg Module Variables

1. Probability that an egg is processed in-line

The probability of an egg being processed at an in-line facility is used in this module to determine whether an egg avoids transportation from the farm to a processing facility. The probability that an egg is processed off-line – thereby subjected to additional time in storage and transportation prior to processing – is equal to (1- p) where p is the probability of an egg processed in-line. Other egg handling scenarios such as cryogenic cooling are possible but occur in low frequencies in the U.S. They can be incorporated into the model for comparison purposes or for testing mitigation strategies.

a. Evidence –

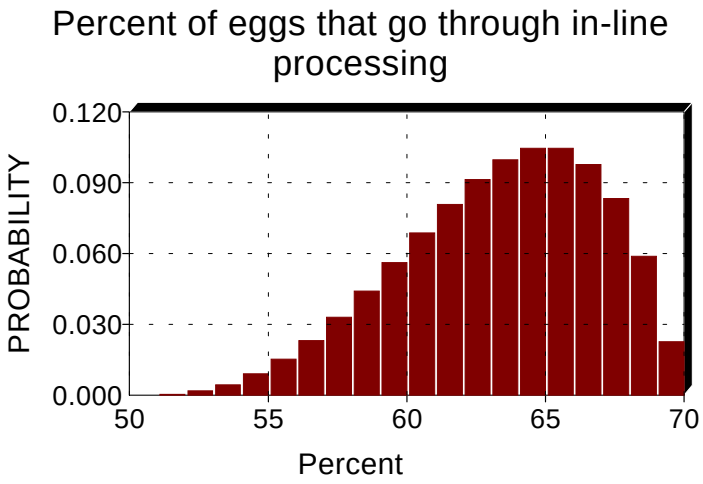
Personal communication Dr. P. Curtis, NC State University.

b. Mean – 0.63

c. Distribution – Pert(0.50,0.65,0.70)

This distribution reflects the survey and experience with the egg industry in the Southeast. In the past, over half of the eggs went to in-line processing and the new and larger facilities being constructed are usually in-line. This mean represents an estimate of the current ratio.

Figure B-3



Shell Egg Processing and Distribution Module

Time and temperature for processing and transport

Time and temperature variables are used in the shell egg processing and distribution module at the following stages;

- pre-processing storage/transportation for off-line processed eggs,

- storage at processing (for in-line or off-line eggs),

- storage during transport to shell egg markets or egg products processors.

At each stage of this module, time and temperature variables are used to calculate the yolk membrane breakdown time, percent membrane breakdown time remaining, and growth of SE in an egg. Time and temperature for each stage are independent, but these variables' distributions are basically similar.

The distributions for time and temperature in storage or transport are developed based on studies by Anderson et al. (1992), Bell & Curley (1966), Czarick and Savage (1992), and Stadelman & Rhorer, 1987.

Off-line processing

Eggs are collected on farms, where some eggs may also be washed, and stored in 13-16 C (55-60° F) pre-processing cooler. Internal eggs temperature declines from 37 to 20° C (99 to 68° F).

Eggs are transported to processors at a mean ambient temperature of 59.2° C (45-90° F)

Eggs arrive at processor at 16-20° C (60-68° F).

Washing-candling raise temperatures to 24-27° C (76-80° F) internal temperature followed by an increase of 2° C (5-6° F) in first 6 hours if palletized in processing room (processing room 22-28° C (72-82° F)). Post processing coolers were 7- 13° C (45 - 55° F), palletized eggs declined to 18° C (65° F) in 50 hours and to 14° C (57° F) in 100 hours (Anderson et al., 1992).

2. Storage temperature before transportation for off-line eggs (F)

   a. Evidence –

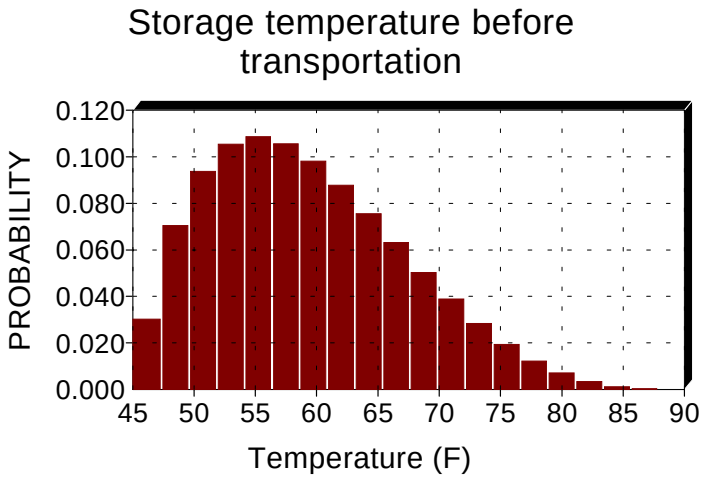
      Eggs decline in temperature after lay from 99 to 68° F. Eggs arrive at processor at 60-68° F (Anderson et al.,1992). Personal communication from egg industry (UEP, Atlanta, 1998).

   b. Mean – 59° F.

   c. Distribution – Pert(45,55,90)

      Evidence suggests it most likely that eggs stored prior to off-line processing will be kept at room temperature. Some eggs may be refrigerated at ambient temperatures as low as 45° F. A few eggs may remain at ambient temperatures as high as 90° F.

Figure B-4



3. Storage time before transportation for off-line eggs (hours)

   a. Evidence –

      Eggs are collected on farms, where some eggs may also be washed, and stored 0.5 to 7 days before transportation from the farm to an off-line processing facility (Anderson et al.,1992). Personal communication from egg industry (UEP, Atlanta, 1998).

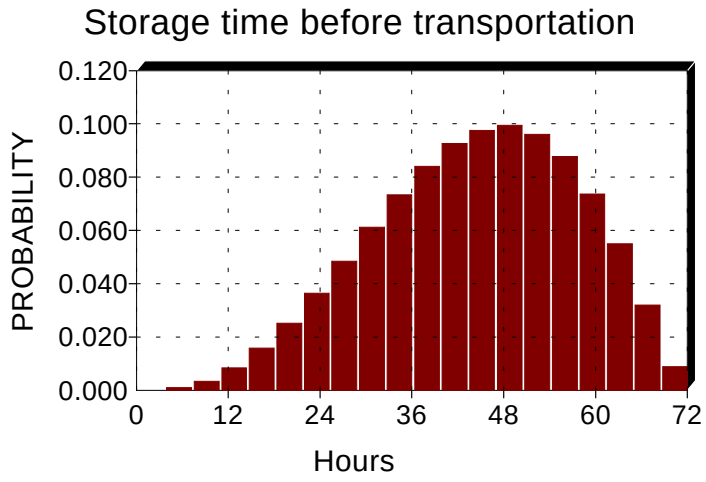
   b. Value – 44 hours

   c. Distribution – Pert(1, 48, 72)

      Some eggs may be transported within 1 hour of being laid. However, some houses may have pickups only every 2 days. It would be possible in this case to have an egg that stays in the house 3 days before transporting. Therefore, this relatively broad distribution has the most frequent time for eggs to reach the processor as 48 hours.

      Cooling rate for before transportation has a mean k parameter of 0.08 for eggs in individual flats (boxes) or plastic baskets. Pert(0.0053,0.08,0.107)

Figure B-5



4. Ambient temperature during transportation of off-line eggs (F)

   a. Evidence –

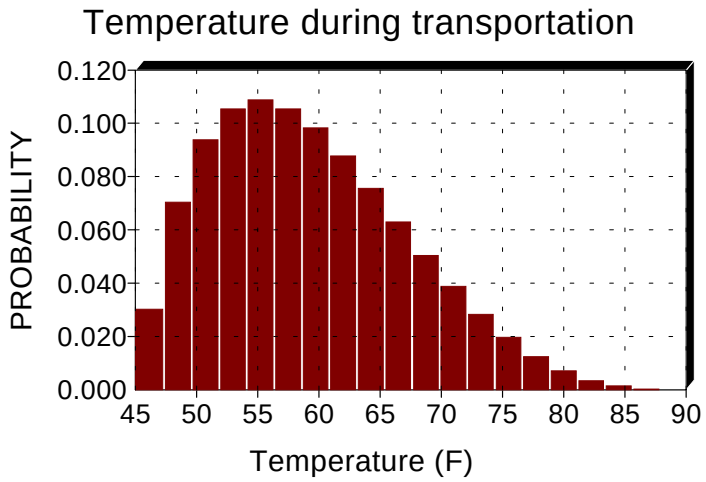
      Personal communication from egg industry (UEP, Atlanta, 1998).

   b. Mean – 59° F

   c. Distribution – Pert(45,55,90)

      Current information suggests that the ambient temperature of eggs transported from the farm to an off-line processor encompasses a wide range. The lowest possible ambient temperature is modeled as 45° F and the most likely ambient temperature is 55° F. Despite widespread refrigeration it is assumed that the highest ambient air temperature during transportation is 90° F.

Figure B-6



5. Time for transportation for off-line eggs (hours)

   a. Evidence –

      Personal communication from egg industry (UEP, Atlanta, 1998).

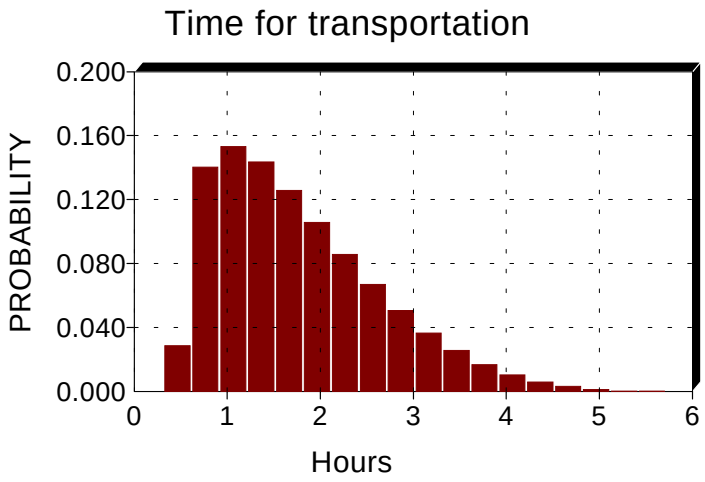
   b. Mean – 1.8 hours

   c. Distribution – Pert(0.5,1,6)

      According to personal communication from UEP, all off-line processed eggs will take no more than 6 hours to get to a processing facility, with the minimum amount of time to be 0.5 hour and the most likely value to be 1 hour.

      Cooling rate parameter for eggs during transportation is k = 0.25 for eggs in individual boxes. However, the range is relatively broad to reflect the differences in packaging, air circulation rates and other factors during this stage, Pert(0.0165,0.25,0.335) .

Figure B-7



6. Storage temperature before processing at off-line processor (F)

   a. Evidence –

      Personal communication from egg industry (UEP, Atlanta, 1998).

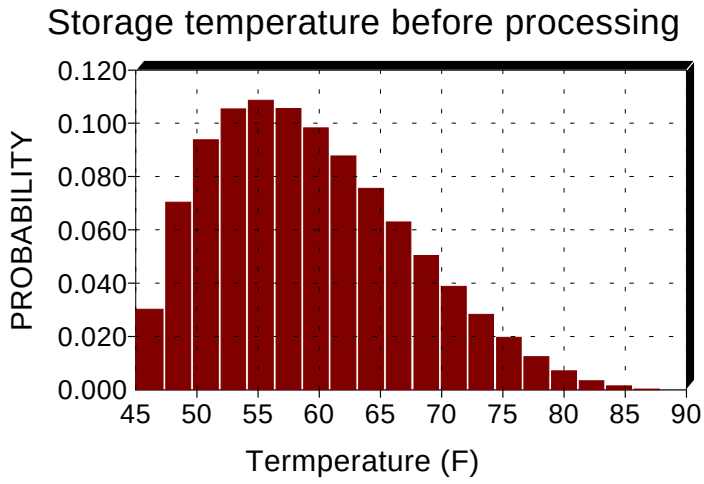
   b. Mean – 59° F.

   c. Distribution – Pert(45, 55, 90)

      The ambient temperature of storage at an off-line processor prior to processing may encompass a wide range.

      The lowest possible ambient temperature is modeled as 45° F., and the most likely ambient temperature is 55° F., however, the highest possible ambient temperature is 90° F.

Figure B-8



7. Storage time before processing at off-line processor (hours)

   a. Evidence –

      Personal communication from egg industry (UEP, Atlanta, 1998).

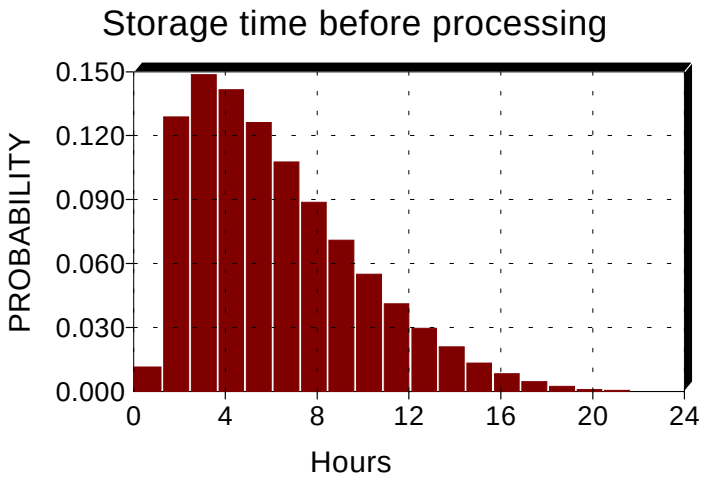
   b. Mean – 6 hours

   c. Distribution – Pert(1,3,24)

      Available information suggests off-line processed eggs will seldom be stored longer than 24 hours at an off-line facility before processing. The minimum storage time is 1 hour and the most likely time is 3 hours.

      Cooling rate parameter for before processing is k = 0.08 for eggs in individual flats (boxes). Pert(0.0053,0.08,0.107)

Figure B-9



8. Ambient temperature at processing at off-line processor (F)

   a. Evidence –

      Personal communication from egg industry (UEP, Atlanta, 1998). Washing and candling of eggs at processing raises temperatures to 76-80° F internal temperature (Anderson et al., 1992).

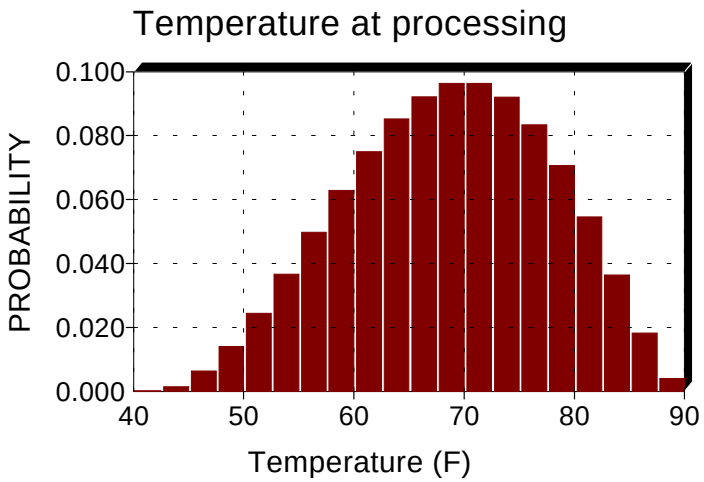
   b. Mean – 69° F.

   c. Distribution – Pert(41,70,90)

      Available information suggests that the ambient temperature for eggs during processing encompasses a wide range. The lowest possible ambient temperature is modeled as 41° F., the most likely ambient temperature is 70° F., and the highest possible ambient temperature is 90° F.

      The egg temperature begins this phase with a 10 degree F increase described as Normal(10,1).

Figure B-10



9. Time for processing at off-line processor (hours)

   a. Evidence –

      Personal communication from egg industry (UEP, Atlanta, 1998).

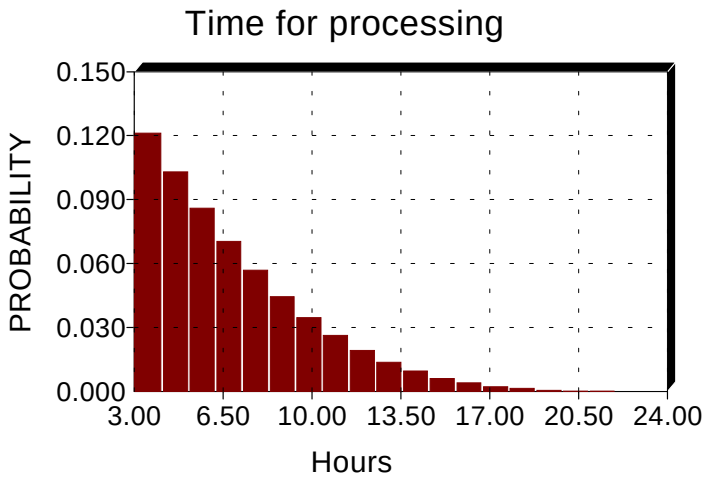
   b. Mean – 4.7 hours

   c. Distribution – Pert(0.5, 1, 24)

      Available information suggests the time for actual processing of eggs will normally be 1 hour and no less than ½ hour. Times may extend up to 24 hours. Processing includes all the time between removing the eggs from storage until they are placed back into storage.

      Cooling rate parameter for processing is k = 0.50 for eggs that are individually exposed to air and water. Pert(0.033,0.50,0.67)

Figure B-11



10. Storage temperature after processing at off-line processor (F)

    a. Evidence –

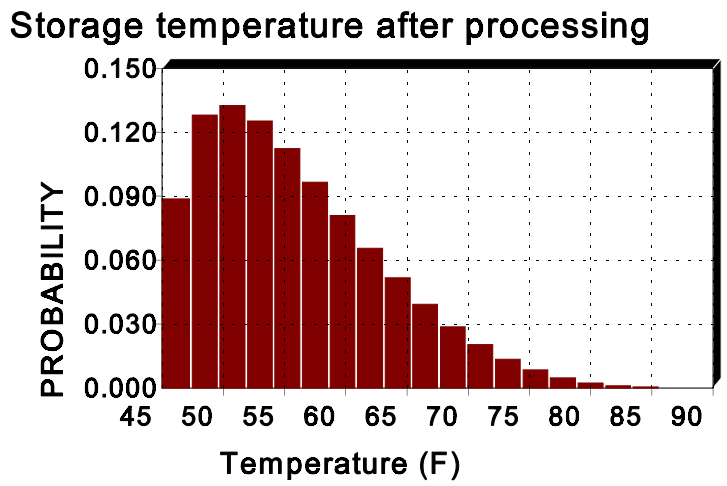
    Personal communication from egg industry (UEP, Atlanta, 1998).

    b. Mean – 56° F.

    c. Distribution – Pert(45,50,90)

    Available information suggests the ambient temperature of eggs after processing while in storage at an off-line processor is usually refrigerated, but temperatures encompass a wide range. The lowest possible ambient temperature is modeled as 45° F., the most likely ambient temperature is 50° F., and the highest possible ambient temperature is 90° F.

Figure B-12



11. Storage time after processing at off-line processor (hours)

    a. Evidence –

    Personal communication from egg industry (UEP, Atlanta, 1998).

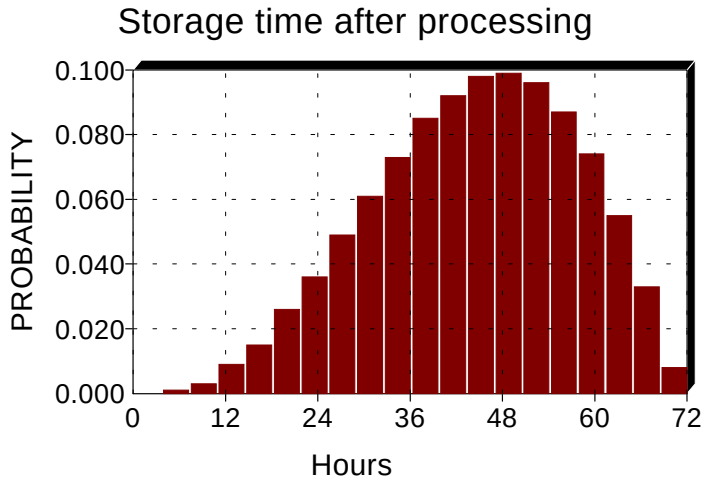
    b. Mean – 44 hours

    c. Distribution – Pert(1,48,72)

    Available information suggests off-line processed eggs will seldom be stored longer than 72 hours after processing. The minimum storage time is 1 hour and the most likely time is 48 hours.

    Cooling rate parameter after processing is k = 0.008 Pert(0.0005,0.008,0.0107) for eggs in the interior of flats that are stacked in pallets.

Figure B-13



In-line processing

Eggs are conveyed from the laying house directly to the processing area where they are washed, candled, cartoned or cased, palletized, and placed under refrigeration. Cooling data (from figure 4 in Anderson et al., 1992). Eggs leave washing at 27-34° C (80-94° F) and cool to 27° C (80° F) internal temperature in 48 hours in a 10° C (50° F) cooler.

12. Ambient storage temperature before processing at in-line processor (F)

a. Evidence –

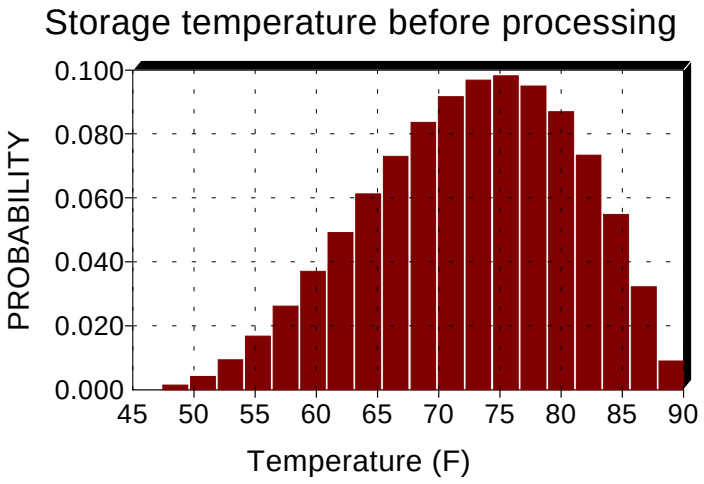
Personal communication from egg industry (UEP, Atlanta, 1998).

b. Mean – 73° F.

c. Distribution – Pert(45,75,90)

Available information suggests that the ambient temperature of eggs prior to processing while in storage at an in-line processor encompasses a wide range. The lowest possible ambient temperature is modeled as 45° F., the most likely ambient temperature is 75° F., and the highest possible ambient temperature is 90° F.

Figure B-14



13. Storage time before processing at in-line processor (hours)

    a. Evidence –

    Personal communication from egg industry (UEP, Atlanta, 1998).

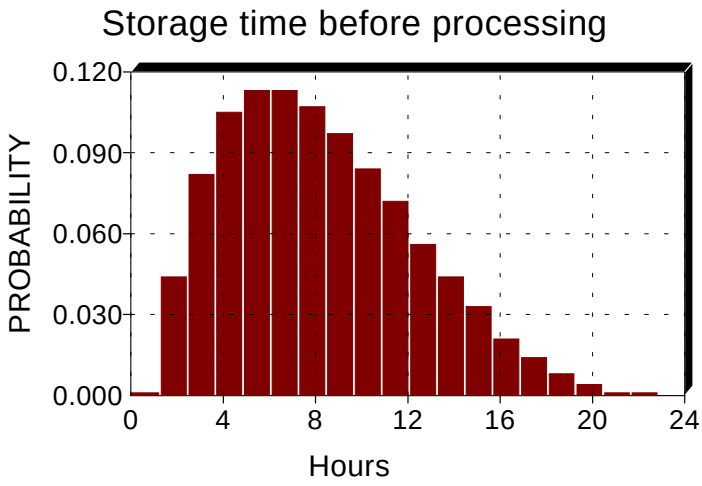
    b. Mean – 8 hours

    c. Distribution – Pert(1,6,24)

    Available information suggests all in-line processed eggs will be stored no longer than 24 hours at an in-line facility before processing. The minimum storage time is 1 hour and the most likely time is 6 hours.

    Cooling rate parameter before processing is k = 0.08 for eggs in individual boxes. Pert(0.0053,0.08,0.107).

Figure B-15



14. Ambient temperature during processing at in-line processor (F)

    a. Evidence –

    Personal communication from egg industry (UEP, Atlanta, 1998). Washing and candling of eggs at processing raises temperatures to 76-80°F internal temperature (Anderson et al., 1992).

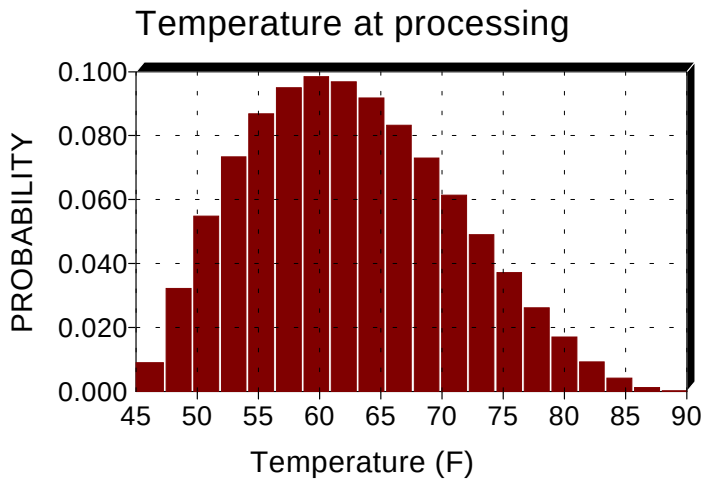
    b. Mean – 63° F.

    c. Distribution – Pert(45,60,90)

    Available information suggests that the ambient temperature for eggs during processing encompasses a wide range. The lowest possible ambient temperature is modeled as 45° F., the most likely ambient temperature is 60° F., and the highest possible ambient temperature is 90° F.

    The egg temperature begins this phase with an 8 degree Fahrenheit increase described as Normal(8,1).

Figure B-16



15. Time for processing at in-line processor (hours)

    a. Evidence –

       Personal communication from egg industry (UEP, Atlanta, 1998).

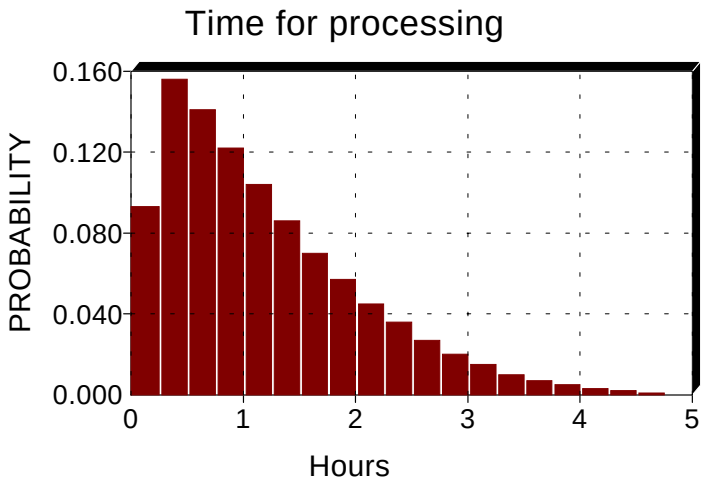
    b. Mean – 1.2 hours

    c. Distribution – Pert(0.1, 0.25, 6)

       Available information suggests the time for actual processing of eggs is seldom more than 6 and no less than 0.1 hour. Processing includes all the time between removing the eggs from storage until they are placed back into storage.

       Cooling rate parameter for processing is k = 0.50 Pert(0.033,0.50,0.67) for individual eggs.

Figure B-17



16. Ambient storage temperature after processing at in-line processor (F)

    a. Evidence –

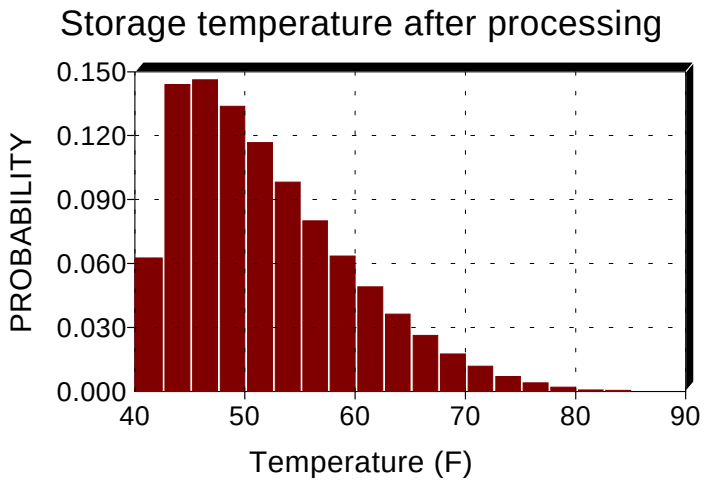
    Personal communication from egg industry (UEP, Atlanta, 1998).

    b. Mean – 52° F.

    c. Distribution – Pert(41,45,90)

    Available information suggests that the ambient temperature of eggs after processing while in storage at an in-line processor encompasses a wide range. The lowest possible ambient temperature is modeled as 41° F., the most likely ambient temperature is 45° F., and the highest possible ambient temperature is 90° F.

Figure B-18



17. Storage time after processing at in-line processor (hours)

    a. Evidence –

    Personal communication from egg industry (UEP, Atlanta, 1998).

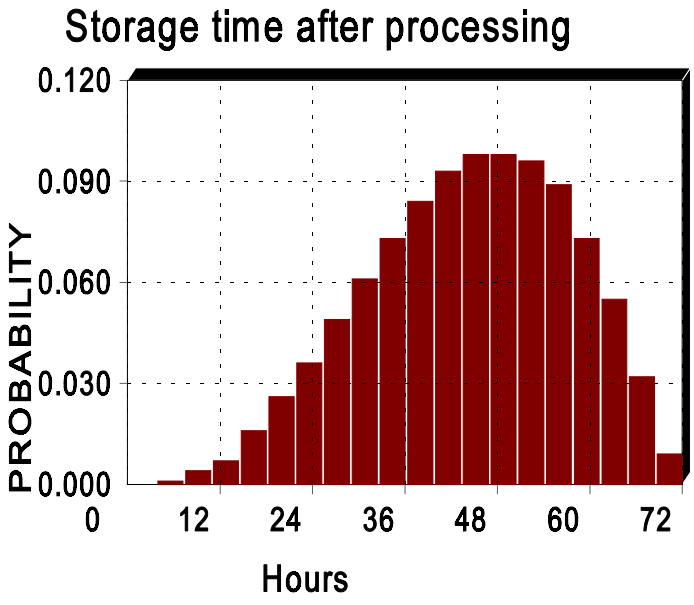
    b. Mean – 44 hours

    c. Distribution – Pert(1,48,72)

    Available information suggests all off-line processed eggs will be stored no longer than 72 hours at an in-line facility after processing. The minimum storage time is 1 hour and the most likely time is 48 hours.

    Cooling rate parameter for after processing is k = 0.008 for eggs in the interior of boxes and stacked pallets. Pert(0.0005,0.008,0.0107)

Figure B-19



Transportation to Egg Users

18. Transportation temperature

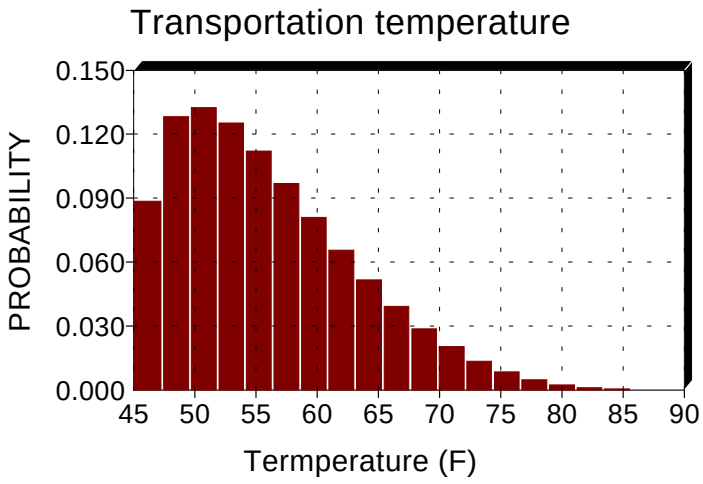
    a. Evidence –

       None

    b. Mean – 56° F.

    c. Distribution – Pert(45,50,90)

Figure B-20



19. Transportation time

a. Evidence –

None

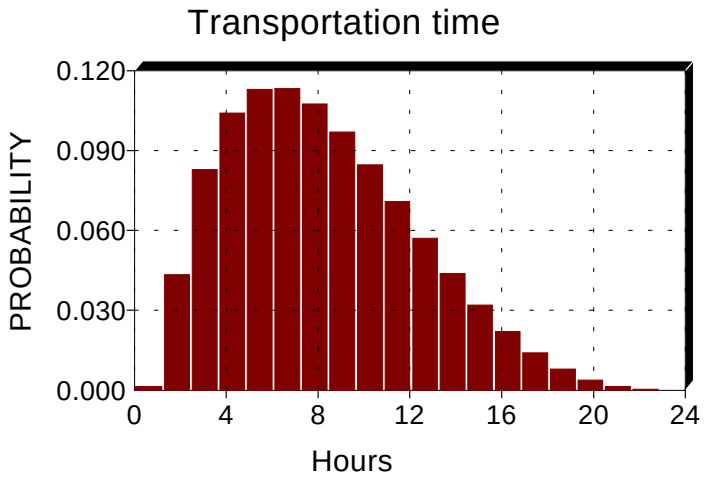
b. Mean – 8 hours

c. Distribution – Pert(1,6,24)

Egg production is regional and truck transportation has eggs reaching their markets within 24 hours.

Cooling rate parameter for transportation is k = 0.32 for eggs in individual boxes. However, the range is relatively broad to reflect the differences in packaging, air circulation rates and other factors during this stage, Pert(0.0231,0.35,0.469)

Figure B-21



D. Modeling Periods and Elements

Each of the storage, processing, and transportation periods will comprise a unit composed of the three models for cooling, yolk membrane survival and *Salmonella* growth. Each period will take the internal egg temperature, fraction of yolk membrane time remaining and number of *Salmonella* from the previous unit and using the time and ambient temperature of that period calculate the internal egg temperature, fraction of yolk membrane time and *Salmonella* numbers that are passed on to the next period.

Model Elements

1. Cooling of eggs

The interactions of initial egg internal temperature, air temperature, packaging and other variables on the temperature cooling is modeled by a simplified non-steady state heat transfer. The relationship is

$$\log [(T - To)/(Ti - To)] = -kt$$

where T is the temperature (F) at a specific time t (hours) in the interior of the egg (i.e. center egg within box or pallet), Ti is the initial egg temperature at the beginning of the cooling period and To is the air temperature. The estimated temperature (T) is the internal temperature of an egg in the center of the box or pallet. This assigns to all eggs in the pallet the temperature of the warmest egg in the pallet, which is thought to be in the center of the pallet. This assumption overestimates the temperature of most eggs in the pallet and provides a conservative (i.e. over estimate) of the risk of SE growth.

The parameter k depends on the combination of thermal characteristics of the egg, packaging and air circulation around the packaging.

Values for k were determined by fitting this equation to published graphs showing egg cooling. The following table lists these fits.

Table B - 3. K Values determined by fitting an equation to published egg cooling graphs

Situation	k	Reference
Pallet, cardboard & fiber flats, In-line	0.0075	Anderson et al., 1992
Pallet, cardboard boxes	0.008	Czarick & Savage, 1992
Pallet, cardboard boxes, Styrofoam	0.013	Czarick & Savage, 1992
Pallet, cardboard, Off-line	0.035	Anderson et al., 1992
Single cardboard case	0.052	Czarick & Savage, 1992
Flats, closed	0.07	Bell & Curley, 1966
Flats, folded shut	0.08 to 0.14	Bell & Curley, 1966
Pallet, plastic baskets, Styrofoam	0.11	Czarick & Savage, 1992
Open stack	0.2 to 0.4	Bell & Curley, 1966
Fiber case, foam cartons with & without slots, moving air	0.24	Stadelman & Rhorer, 1987
Open stack, forced air	0.4 to 1.0	Bell & Curley, 1966
Cryogenic cooling	11	Curtis et al., 1995

Four replicate cooling curves provided by Dr. Anderson, NC State Univ., were used to estimate the likely ranges for the k values. The mean of the ranges divided by their averages was 0.51. This value was used for all the pert distributions.

2. Yolk membrane breakdown

The yolk membrane breakdown variable is used to calculate the number of days an egg is resistant to internal SE replication at a given temperature.

Table B-3 shows the results of a study in which a group of 9-11 eggs was artificially infected with a known number of SE bacteria and was incubated at a known temperature. In a similar manner other groups of 9-11 eggs were also artificially infected with a known number of SE and were incubated at a known temperature (i.e. 12° C, 16° C, 20° C, etc.). The groups of eggs were monitored to detect the growth of SE within the artificially infected eggs being incubated at known temperatures. During the incubation period the yolk membrane begins to deteriorate at the molecular level, but appears to be normal to visual inspection. This molecular breakdown of the yolk membrane permits the nutrients within the yolk to be available to the SE for growth within the artificially infected eggs. Therefore, growth in the number of SE within the infected egg is an indicator of the breakdown of the yolk membrane at the molecular level, and this breakdown is sufficient to make the nutrients within the yolk available to the SE for growth. The time from artificial infection of the eggs with a known number of SE and incubation at a known temperature to the detection of growth of SE in 25% of the eggs within a group of 9-11 eggs is measured in days and is the time required for breakdown of the yolk membrane at a specific temperature. For example, at an incubation temperature of 12° C, growth of SE in an artificially infected group of eggs will be present in 25% of the eggs at 35 days. Similarly, at an incubation temperature of 25° C, growth of SE in an artificially infected group of eggs will be present in 25% of the eggs at 6 days. This entire set of experiments was repeated a number of times, and each replication is represented by a row in Table B-3.The data was obtained from Dr. T. Humphrey, Exeter, UK.

Table B-3. Time before growth of *S*. Enteritidis in eggs stored at various temperatures

	Temperature in degrees centigrade								
	12° C	**16° C**	**20° C**	**23° C**	**24° C**	**25° C**	**27° C**	**30° C**	**37° C**
Replicates (Days)	35*	21	17	18	7	6	6	6	3
	28	28	42		10	12	12	7	
	42	28	14		7		7	6	
	42	28	27		10		6	13	
	28		28		12				
	28		28						

*Time for more than 25% of the eggs in a group of 9-11 eggs to permit SE growth

The logarithm of time before growth linearly decreased with increasing temperature. The fitted regression equation and 95% confidence intervals are (in days and degrees C) (Steel and Torrie, 1960):

$\log_{10}$ YM =

{(2.0872 - 0.04257 T) ± (2.042*0.15245)[(1/32) + ((T -21.6)^2/(32*43.2))]^0.5}

At each of the stages (previously defined) of the shell egg processing/distribution module, the yolk membrane breakdown is calculated. If storage time of the egg at a particular stage is less than the yolk membrane breakdown calculated for that stage, then the percent of yolk membrane breakdown time used in that stage is calculated. This percent of yolk membrane used is cumulative from stage to stage. If the cumulative percent membrane breakdown used equals or exceeds 100% at any stage of this module, then growth of SE in that stage is calculated for the time remaining in that stage and all subsequent stages.

3. SE growth rate

The SE growth rate variable is used in this module to calculate the number of SE bacteria in an egg once yolk membrane breakdown is complete. This variable is calculated using the following linear regression equation:

Growth rate (log(cfu/h) = μ = -0.143 + 0.026T

where μ is the square root of the growth rate, T is the internal egg temperature (^{o}C). The logs of growth in a stage of this module is calculated by multiplying the growth rate by the number of hours available for growth. The number of SE bacteria in an egg at the end of a module stage is then calculated as the cumulative number of log SE bacteria in the egg from the preceding stages.

The equation for SE growth rate was estimated using data from Bradshaw et al. (1990) and Schoeni et al. (1995).

Temperature	Generation Times (h)	
Centigrade	Bradshaw et al.	Schoeni et al.
4°		No Growth
7°	No Growth	
10°		10.3
15.5°	3.5	
25°		1.7
37°	0.41	

SqRt EGR = { (-0.1434 + 0.026012 T) ± (3.182)(0.02124)[(1/5)+(T -18.9)^2/(5*149.30)]}

This equation calculates the mean and 95% confidence intervals (Steel and Torrie, 1960).

4. Probability of egg marketed to egg products

The probability of marketing an egg to an egg products processor is used in this module to determine the distribution of yolk membrane breakdown time and number of SE bacteria per egg for SE-positive eggs sent to breaking plants. The likelihood of an egg marketed to shell egg users (e.g., retail, institutions) is simply (1-p), where p is the probability of an egg marketed to egg products.

The distribution for this variable is developed using USDA-AMS data which shows that 4.5% of graded/processed eggs are restricted and diverted to egg products processors. Data from the Pennsylvania Pilot Project (Schlosser et al., 1995) demonstrated that blood spot eggs were more frequently SE-positive than eggs without blood spots. This study also demonstrated a similar increase in washed, dirty eggs. Therefore, the probability that an SE-positive egg is diverted is modeled as 4.5% times Pert (min, mode, max). The Pert distribution parameters are taken from the calculated odds ratio for blood spot eggs (Schlosser et al, 1995) and equals Pert (0.89, 1.79, 3.55).

E. Results

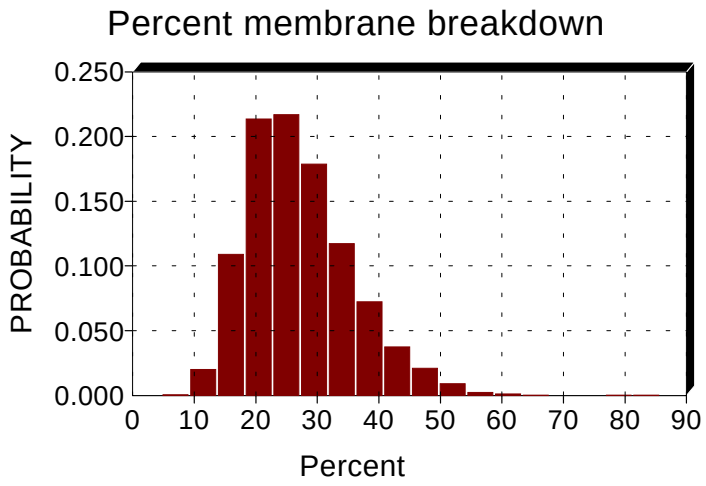
Summary

The most significant output of the Shell Egg Processing and Distribution module is the percent yolk membrane breakdown that occurs because no microbial growth occurs until membrane breakdown is complete. Membrane breakdown is a function of time and temperature. This output is summarized in the table and graph below.

Table B-5. Percent Yolk Membrane Breakdown Resulting from the Shell Egg Processing and Distribution Module

	% yolk membrane breakdown
Mean	26.9
Standard deviation	8.5
5th percentile	15.2
95th percentile	42.6

Figure B-22



F. Sensitivity Analysis

The percent yolk membrane was most sensitive to storage times and temperatures before and after processing where the variables allowed for extreme values. There was not sufficient time and temperature abuse modeled to allow for complete yolk membrane breakdown and rapid growth of bacteria. The percent yolk membrane breakdown that does occur, however, lessens the time needed for complete breakdown to occur in the preparation and consumption module.

Table B-6. Sensitivity Analysis of In-Line Processing Variables

In Line Processing Variable	Correlation Coefficient
Storage time after processing	0.46
Temperature at processing	0.315
Storage temperature before processing	0.311
Storage temperature after processing	0.134

Table B-7. Sensitivity Analysis of Off-Line Processing Variables

Off Line Processing Variables	Correlation Coefficient
Storage time after processing	0.278
Storage temperature before processing	0.198
Temperature at processing	0.177
Temperature at processing	0.172
Time for transportation	0.167
Storage time after processing	0.123
Temperature during transportation	0.104
Transportation time	0.093

G. Mathematics of the Shell Egg Processing and Distribution Module

1. Definition of subscript notation.

Shell eggs undergo processing in either an 'in-line' mode or in an 'off-line' mode. The subscript 'i' is used with many of the variables in the Shell Egg Processing and Distribution Module to designate whether the shell egg is being processed in either an 'in-line' mode or in an 'off-line' mode. If the value of 'i' is equal to 1, then the egg is being processed in an 'in-line' mode. If the value of 'i' is equal to 2, then the egg is being processed in an 'off-line' mode. Hence, the subscript 'i' may have the value of either 1 or 2.

Shell eggs may be exposed to a maximum of 6 different storage periods before sale at retail. The subscript 'j' is used with many of the variables in the Shell Egg Processing and Distribution Module to designate a specific storage period to which the shell egg may be exposed. The following table describes each of the values which the subscript 'j' may have for eggs which are processed in either an 'in-line' mode or in an 'off-line' mode.

Many of the variables in the Shell Egg Processing and Distribution Module will have both the 'i' and 'j' subscripts. The value of the 'i' subscript is written first, and the value of the 'j' subscript is written second. For example if the variable t_{ij} is written as t_{13} (or more explicitly $t_{i=1, j=3}$), then this indicates the time an egg undergoing in-line processing (i=1) spends in storage after processing (j=3).

	In-line processing **i = 1**	Off - line processing **i = 2**
Value of 'j' subscript	Description of storage period	
j = 1	Storage before processing	Storage before transportation
j = 2	Processing	transportation before processing
j = 3	Storage after processing	Storage before processing
j = 4	Transportation to retail	Processing
j = 5		Storage after processing
j = 6		Transportation to retail

2. Definition of Constants

T_0 Initial temperature of egg = 99° F

tYM_o Initial yolk membrane integrity time used = 0

FYM_0 Initial fraction yolk membrane time used = 0

3. Input Variables

$SE_0 \equiv Log_{10}$ initial number of S. Enteritidis bacteria in an egg

$P_i \equiv$ probability of an egg being processed in-line (where i=1) or off line (where i=2)

4. Calculations

In-line process vs. off-line process:

P_1 = probability of eggs being processed in-line pert(0.50,0.65,0.70) distribution

$P_2 = (1 - P_1)$ = probability of eggs being processed off-line

Times:

t_{ij} = Time period for a step (d) = User input

tYM_o = Initial yolk membrane integrity time used = 0.0

tYM_{ij} = Yolk membrane integrity time for a step (h) $= 10^{(2.0872 - 0.04258\, AT_{ij})}$

tG_{ij} = Time period within step available for growth $= t_{ij} (1 - (EYM_{ij}/(t_{ij} / tYM_{ij})))$

tGS_{ij} = Time growth started $= t_{ij} - tG_{ij}$

Temperatures:

$T_{i0} = T_0$ = Initial temperature of egg = 99° F

TA_{ij} = Air temperature for a step (F) = User input

k_{ij} = Cooling parameter (h^{-1}) = User input

T_{ij} = Egg temperature at end of a step $= e^{(-k_{ij} * t_{ij})} (T_{i(j-1)} - TA_{ij}) + TA_{ij}$

AT_{ij} = Average egg temperature of a step = $e^{((-k_{ij} * t_{ij})/2)} (T_{i(j-1)} - TA_{ij}) + TA_{ij}$

TG_{ij} = Temperature at start of growth = $e^{(-k_{ij} * tGS_{ij})} (T_{i(j-1)} - TA_{ij}) + TA_{ij}$

ATG_{ij} = Average temperature in growth period = $e^{((-k_{ij} * tGS_{ij})/2)} (T_{i(j-1)} - TG_{ij}) + TG_{ij}$

Yolk membrane integrity status - intact vs compromised:

FYM_0 = Initial fraction yolk membrane time used = 0.0

FYM_{ij} = Summed fraction yolk membrane time used = $(t_{ij}/tYM_{ij}) + FYM_{I(j-1)}$

EYM_{ij} = Excess yolk membrane fraction = 1 - FYM_{ij}

If $FYM_{ij} < 1.0$ then EGR_{ij} = Exponential growth rate = 0.0

If $FYM_{ij} \geq 1.0$ then EYM_{ij} = Excess yolk membrane fraction = 1 - FYM_{ij}

EGR_{ij} = Exponential growth rate = $(-0.143 + 0.026\ ATG_{ij})^2$

S. Enteritidis populations:

SE_0 = Log_{10} initial number of S. Enteritidis = log (truncated exponential(152,1,400))

SE_{ij} = Log_{10} S. Enteritidis at end of a step = $SE_{i(j-1)} + (ERG_{ij} * tG_{ij})$

If $SE_{ij} > 10.0$, then set $Se_{ij} = 10.0$

Growth of SE stops at log_{10} 10.0

Note: °F to°C and hour to day conversions are not detailed

H. References

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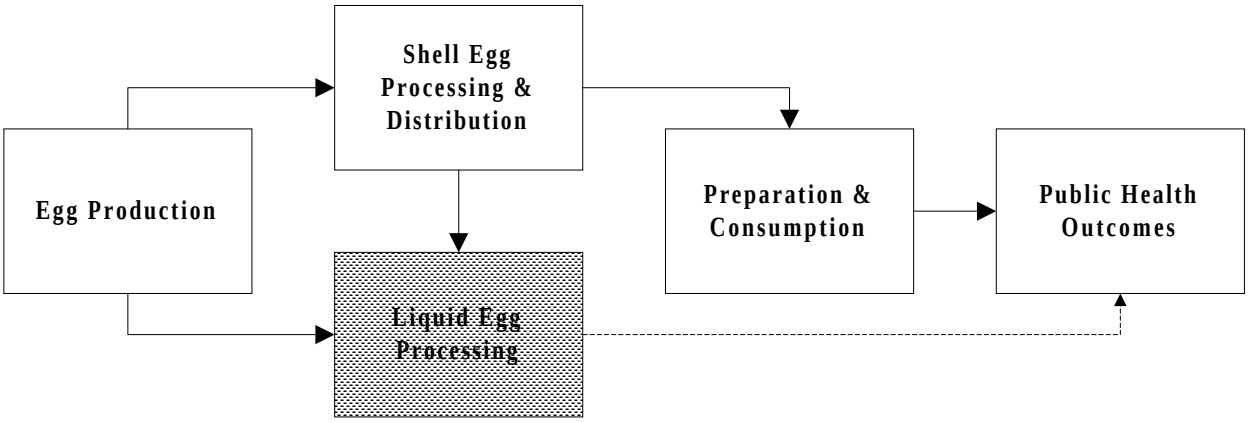
Egg Products Processing and Distribution Module



A. Summary of Egg Products Processing and Distribution Module

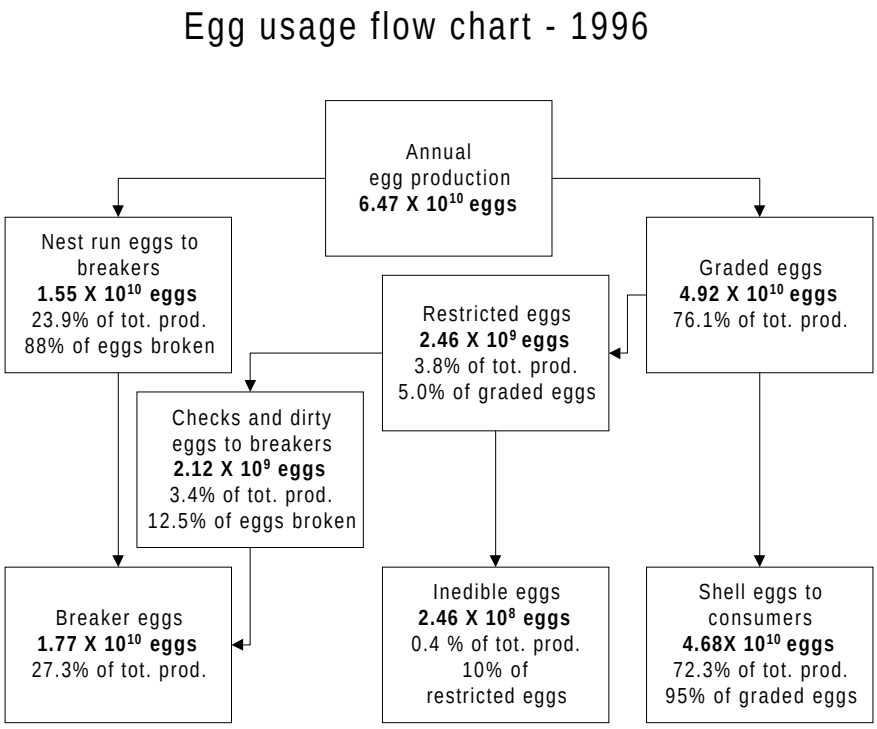
The purpose of this module is to calculate the number of *Salmonella* Enteritidis bacteria in six different egg products: liquid whole egg, liquid yolk, liquid albumen, frozen whole egg, frozen yolk, and frozen albumen. This is done by tracking the change in numbers of *Salmonella* Enteritidis through the production processes of egg products plants.

The egg products industry processed 17 billion eggs or 27% of the U.S. production of eggs in 1996 (Figure C-1). Eggs arriving at egg products plants originate from two sources. Nest run eggs from poultry layer flocks constituted 88% of all eggs processed in 1996. Restricted eggs sent from egg grading plants constituted 12% of all eggs processed in 1996 (Figure C-1). The six products modeled here (liquid and frozen forms of whole egg, albumen, and yolk) constitute about 44% (32% + 12%) of the egg products produced (Table C-1). The remaining 56% of egg products shown in Table C-1 are not simulated in this module. The estimates of the amounts of product in Table C-1 are based on data collected by the Egg Products Inspection Division, Food Safety and Inspection Service for 1996. The amount and type of egg product formulations change significantly from year to year.

Figure C-2 illustrates the processes simulated in this module. In modeling frozen products the assumption is made that freezing does not change the number of SE bacteria present. A simulation result for a liquid egg product is directly applied to the frozen product counterpart. We did not simulate SE in blended, dried, or blended and dried egg products (Figure C-3).

Although many *Salmonella* serotypes are found in egg products prior to pasteurization, this module considers only *Salmonella* Enteritidis. *Salmonella* Enteritidis from **egg contents** is modeled independently from *Salmonella* Enteritidis from **all sources**. The prevalence and level of SE contamination of egg contents is an input to this module from the production module. SE from all sources is modeled as a variable that begins at the breaking process (Figure C-2). SE from all sources includes SE from cross contamination as well as SE from egg contents. Cross

Figure C-1



contamination from equipment, egg shells, machine operators, and airborne spread during breaking are significant sources of SE in liquid egg prior to pasteurization. This contamination of liquid egg is incorporated into the variable "SE in liquid egg" (see page 126).

Restricted eggs (i.e. cracked or dirty eggs) are not modeled independently, but the contribution of SE from restricted eggs to the load of SE is reflected in the estimates of SE in liquid egg prior to pasteurization. Restricted eggs are at increased risk to have *Salmonella* of different species (Humphrey, 1989).

The per cent of U.S. egg production used by the egg products industry has risen steadily in recent years. Consequently, the percent of eggs that come from grading operations as restricted eggs has declined. Restricted eggs are checked (cracked shell but intact shell membrane) and dirty eggs that are diverted from the shell egg market during grading. An estimated 2 billion eggs (12.5% of eggs broken) received at egg product plants were restricted in 1996 (figure C-1). The remaining 15.5 billion eggs (87.5% of eggs broken) came directly from production as nest run eggs.

Specialty egg products are not included in this module. In the last few years there has been an increase in the usage of convenience products and products for immediate consumption. This includes ready-to-eat scrambled eggs; hard-cooked eggs in the shell; hard-cooked and peeled eggs (plain or pickled); omelets; and frozen, fried eggs. Egg substitute and low-cholesterol products are perhaps the newest of these convenience products and their formulation includes a number of added ingredients such as vegetable oil, non-fat milk powder, soy protein, gums, food coloring, minerals and vitamins. Some specialty egg products present a potential risk in that they may be eaten with little or no additional heat treatment. Each of these products should be modeled individually because the processing steps involved are unique.

Egg Products Processing and Distribution Module

The number of SE bacteria in a lot (a lot is composed of 10,000 pounds of egg product) is determined for SE from egg contents and SE from all sources. Ten thousand pound lots of liquid whole egg, albumen, and yolk are modeled through pasteurization (Figure C-2). Results reported for this module are the number of SE bacteria from **all sources** for pasteurized liquid whole egg, albumen and yolk (Figure C-2).

FSIS regulates the minimum time and temperature requirements for pasteurization of egg products. Our model assumes that all egg products plants meet but do not exceed the FSIS time and temperature requirements for pasteurization. We determined the reduction in the number of SE bacteria from pasteurization by combining the data from all recent publications on experimental studies of SE reduction from pasteurization of egg products. A single regression equation was formulated based on this combined data, and an estimated log D-value with associated uncertainty was calculated.

The pH of albumen has a significant effect on the reduction of SE, when liquid egg white is pasteurized. Pasteurization is more effective at higher pH levels. Egg albumen has a bicarbonate buffer system which allows the pH to rise very rapidly. The pH of a freshly laid egg is about pH 7.8 and rises to pH 8.7 or 8.8 over 3 days of storage. After that, the pH increases much more slowly over time to a maximum pH of 9.3 to 9.4 (Froning). The time and temperature requirements of the pasteurization regulations were based on a pH of about 9 for egg white which was the case in 1969 when the regulations were written and eggs did not arrive at the egg processing plant before 3 - 5 days. Since that time conditions have changed. Eggs reach the egg processing plant sooner now than in 1969, and the pH of the albumen is lower in eggs. For these reasons pasteurization today may be less effective than in 1969 because of the lower pH of eggs at the time of processing in 1998.

Several processes are used to pasteurize egg white but a hydrogen peroxide process and pasteurization without the use of added chemicals are the most commonly used. We modeled only pasteurization without chemicals. About 60% of albumen in the U.S. is pasteurized in this manner.

Egg Products Processing and Distribution Module

Figure C-2

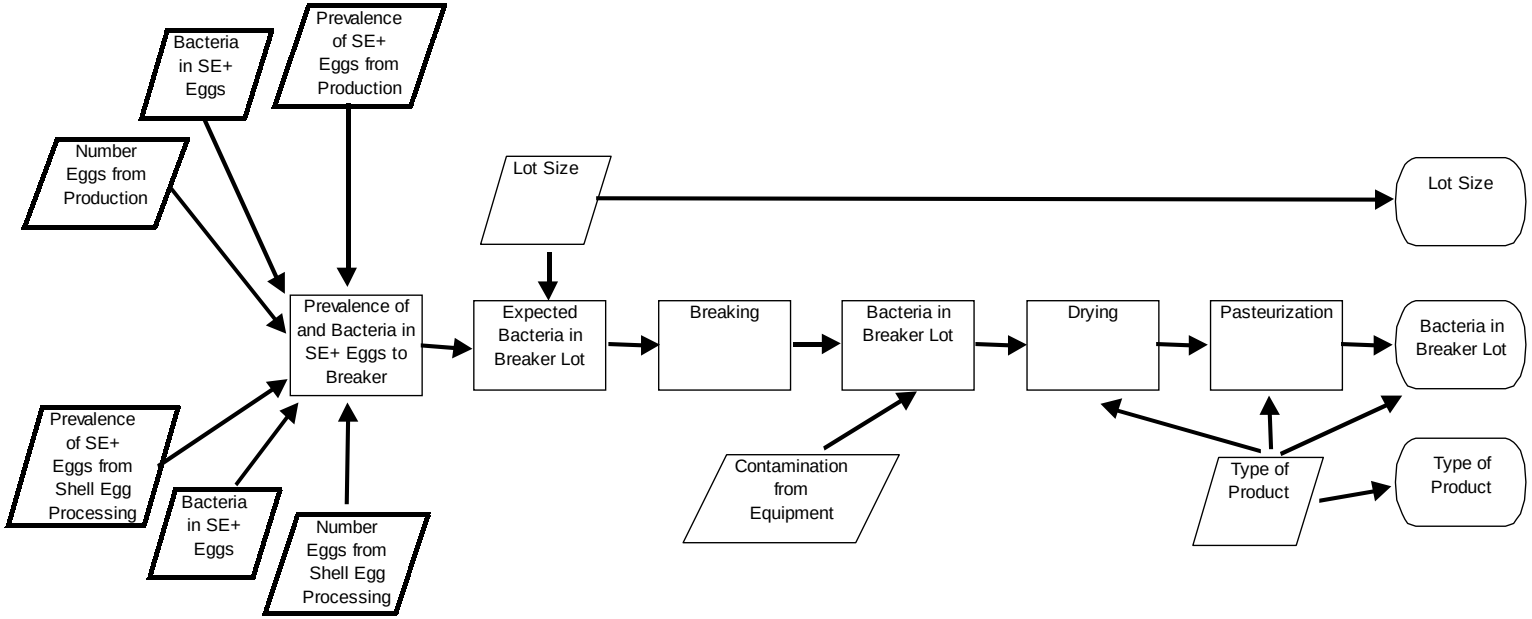


Figure C-3

Liquid egg product flow FY 1996

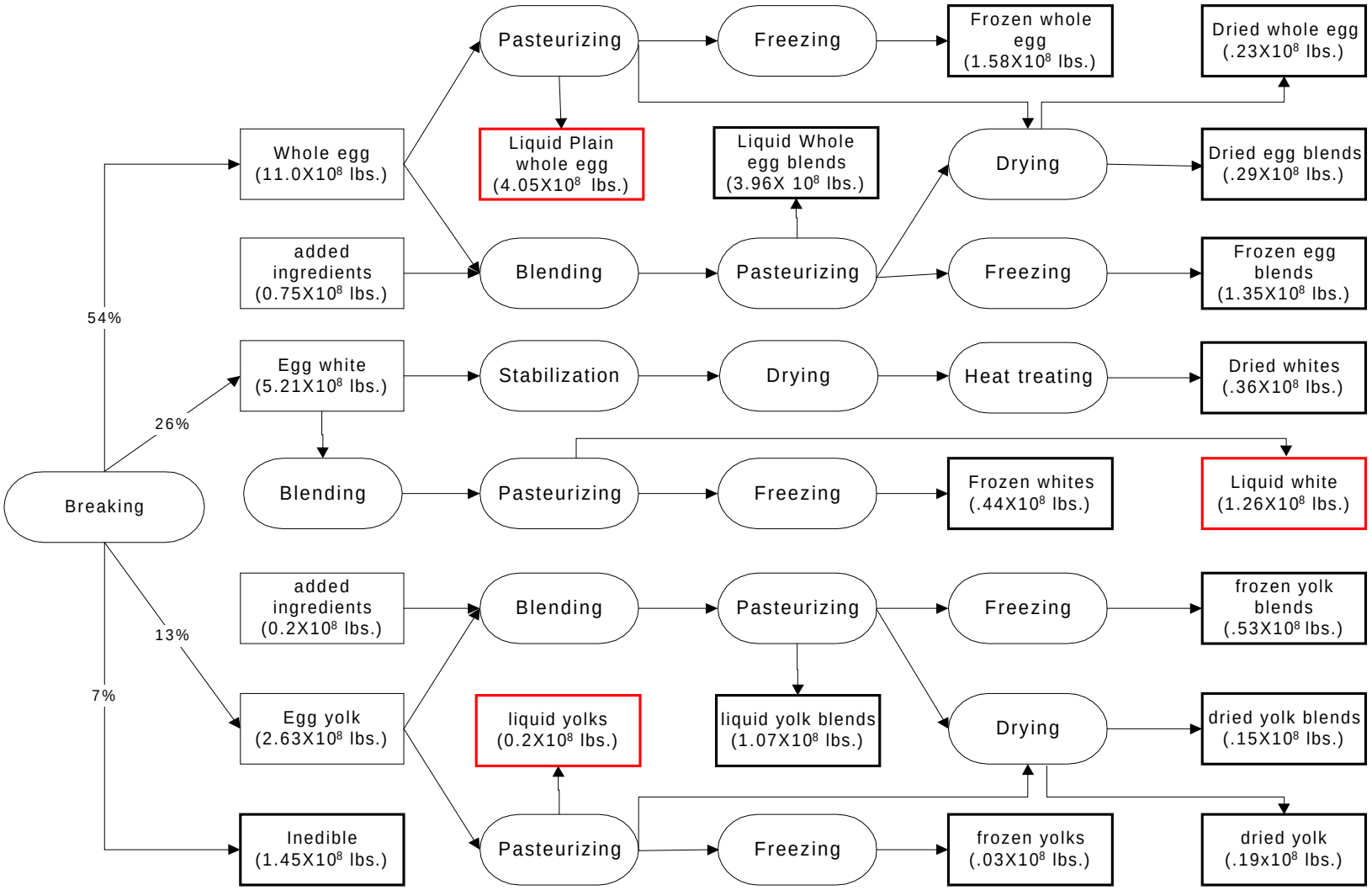


Table C-1. Amount of Egg Products Produced in the US in 1996

	Product	Pounds	Percent	Percent
liquid	whole egg	405,000,000	24%	32%
	albumen	126,000,000	7%	
	yolk	20,000,000	1%	
frozen	whole egg	158,000,000	9%	12%
	albumen	44,000,000	3%	
	yolk	3,000,000	0%	
blended	whole egg	396,000,000	23%	29%
	yolk	107,000,000	6%	
blended and frozen	whole egg	135,000,000	8%	11%
	yolk	53,000,000	3%	
dried	whole egg	23,000,000	1%	5%
	albumen	36,000,000	2%	
	yolk	19,000,000	1%	
blended and dried	whole egg	29,000,000	2%	3%
	yolk	15,000,000	1%	
inedible		145,000,000	8%	8%
Total		**1,714,000,000**	**100%**	**100%**

Conversions

Number of milliliters per pound of liquid egg = 438.25

To convert from pounds into milliliters of liquid egg multiply the number of pounds by 453.59 (equivalent in grams of 1 avoirdupois pound); then divide the product by 1.035 (the specific gravity of whole egg, albumen, and yolk) (Siegmund, 1979).

Ounces of egg to milliliters of egg

Multiply the number of ounces by 28.35 (equivalent in grams of 1 avoirdupois ounce): then divide the product by the specific gravity of the substance, to obtain its volume in milliliters (Siegmund, 1979).

B. Inputs to the Egg Products Processing and Distribution Module

1. Number of birds in a flock

Flocks are stratified by size to account for variability in egg production between flock size strata. The number of birds in a flock that contributes eggs to a lot (10,000 lbs.) of liquid egg is estimated from the distribution of birds per flock in the U.S. (See page 31 in production module).

a. Evidence

Table C-2. Number of egg-type laying birds per flock

Number of flocks	Birds per flock	frequency
1,892	11,470	0.38
1,134	27,222	0.23
519	68,691	0.10
1,483	110,000	0.30
5,028		1.0

Census of Agriculture, 1992

b. Distribution

Discrete (11,470, 27,222, 68,691, 110,000, .38, .23, .1, .3)

2. Frequency of *S*. Enteritidis positive flocks

The frequency of *S*. Enteritidis positive flocks is determined in the Production Module (see page 32). This module uses the Production Module calculations to determine the number of positive eggs in a lot (10,000 pounds of liquid).

3. Positive eggs per infected flock (see outputs of the Production Module page 60).

4. Number of SE bacteria per positive egg at lay (see page 80 in the Shell Egg Module)

C. Egg Products Module Variables

1. Number of eggs produced per bird per day

   a. Evidence

      The average hen in a flock produces 0.72 eggs per day (i.e., a hen will produce 72 eggs during a 100 day period). This average daily egg production is based on a published egg production curve (Rahn, 1997), which was adjusted for improved egg production - using annual USDA-NASS statistics.

   b. Value: 0.72 eggs per bird per day

   c. Distribution: Eggs produced per day is a constant in the model.

2. Proportion yolk and proportion albumen

   a. Evidence

   b. Value: An egg is 55% albumen and 45% yolk by volume or weight.

   c. Distribution: Proportion yolk and proportion albumen are constants in the model.

3. Weight of eggs in ounces

a. Evidence

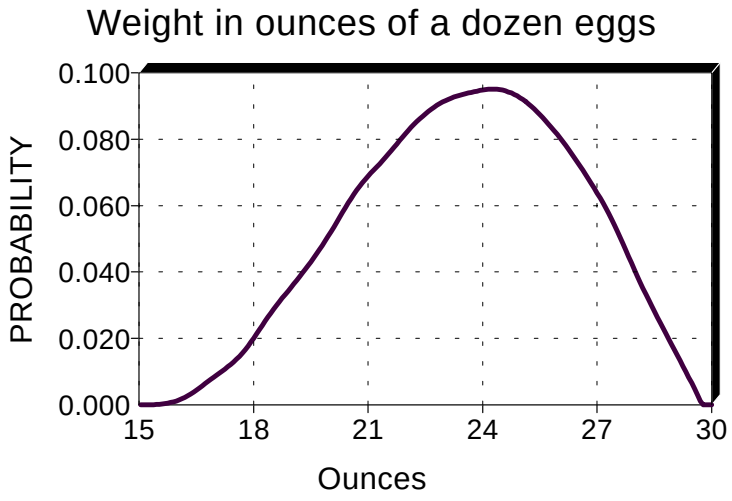
Table C-3. U.S. Weight Classes for Consumer Grades for Shell Eggs 7 CFR 56.218

Size or weight class	Minimum net weight per dozen (ounces)	Minimum net weight for individual eggs at rate per dozen (ounces)
Jumbo	30	29
Extra large	27	26
Large	24	23
Medium	21	20
Small	18	17
Peewee	15	--

b. Distribution - Pert(30,24,15)

This distribution assumes 15 ounces is the minimum weight of a dozen eggs, 24 ounces is the most likely and 30 ounces is the maximum. The value selected from this distribution is applied to all eggs from a flock.

Figure C-4



4. SE bacteria (from egg contents) in albumen and yolk

The mechanism of infection in birds determines the site of contamination within eggs. Research suggests *S.* Enteritidis colonizes the pre-ovulatory follicles of infected birds. SE can attach to granulosa cells resulting in the organisms becoming closely attached to the outside of the yolk membrane (Thiagarajan D., 1994). However, the isolation of *S.* Enteritidis from white of some eggs suggests that contamination can also occur after the ovulation process. This could occur through colonization of the oviduct or reverse peristalsis from the cloaca.

a. Evidence

SE was never isolate from aseptically collected yolk contents (Gast, 1990) but SE is frequently isolated from the yolk portion when the yolk is mechanically separated from the albumen. In a study of naturally infected eggs from two flocks SE was cultured from the yolk of 4 eggs and the albumen of 2 (Humphrey, 1989). In a second study on naturally infected eggs Humphrey found 2 of 14 yolks positive and 12 of 14 albumens positive (Humphrey, 1991). In experimentally infected laying hens, SE was cultured from the albumen of 153 of 855 (17.9%) eggs laid over a period of a month. SE was cultured from the yolk of 143 of 835 (17.1%) eggs (Gast, 1990). In a number of eggs *S.* Enteritidis was cultured from both the yolk and albumen of an egg. From this information it appears that although SE is rarely found in yolk contents, the probability of S. Enteritidis organisms being located in the albumen when eggs are separated is about the same as the probability of them being in the yolk portion.

When eggs are separated after breaking *Salmonella* Enteritidis organisms are distributed between yolks and albumens. This occurs only for SE from the internal contents of the eggs. After breaking an additional load of *Salmonella* is added to the egg. We assume that contamination added after breaking is equally likely to affect the yolks as the albumens.

b. Distribution:

The SE bacteria within an egg at the time of breaking are assigned to one of the following three outcomes: (1) all of the SE bacteria within the egg are associated with the yolk, or (2) all of the SE bacteria within the egg are associated with the albumen, or (3) 50% of the SE bacteria within the egg are associated with the yolk and 50% are associated with the albumen. Each of these three outcomes is assigned the same probability of 0.33. This assignment is used to calculate the level of SE in a lot (i.e. 10,000 pounds) of liquid egg product.

5. Pasteurization times, temperatures, and scenarios

The USDA currently regulates the minimum temperature and holding time for pasteurization of egg products. We used these values as constants and assumed that all breaker plants meet but do not exceed the requirements of the regulation. For the three products modeled, the regulation specifies two scenarios for albumen and yolk, and one for whole egg (Table C-4).

a. Evidence

Table C-4. USDA minimum time and temperature requirements for three egg products.

Liquid egg product	Minimum temperature requirements (° F)	Minimum holding time requirements (Minutes)
Albumen	134	3.5
	132	6.2
Whole egg	140	3.5
Plain yolk	142	3.5
	140	6.2

From: Regulations Governing the Inspection of Eggs and Egg Products (7 CFR Part 59). May 1, 1991, USDA, FSIS, Washington, D.C. 20250.

b. Distribution

We assumed the probability of pasteurization by the higher temperature shorter time scenario is the same as the lower temperature longer time scenario. Thus, a discrete distribution of 0 and 1 are used with a probability of 0.5 for both outcomes (discrete {0,1},{0.5,0.5}). If the result is 0 the log reduction from pasteurization is based on the lower temperature longer time scenario. If the result is 1 the log reduction is based on the higher temperature shorter time scenario.

6. Number of *Salmonella* Enteritidis in a lot (10,000 lbs.) of unpasteurized liquid egg

A number is selected by simulated sampling from the distribution of organisms per ml. shown below and multiplied by the number of ml. in a lot (10,000 lbs.) of liquid egg.

a. Evidence

The distribution of *Salmonella* Enteritidis in unpasteurized liquid egg across breaker plants nationwide was estimated from two surveys (table C-6). The first is an APHIS survey of 10 plants conducted in 1991 and repeated in 1995. Ten ml. of liquid whole egg were cultured for the presence or absence of *Salmonella* Enteritidis and other *Salmonella* serotypes. The second is a 1969 survey by Garibaldi that quantifies the level of *Salmonella* in liquid egg (Garibaldi, 1969).

Table C-6. *Salmonella* in unpasteurized liquid eggs

Reference	*Salmonella* species			*Salmonella* Enteritidis		
	pos.	samples	percent	pos.	samples	percent
Garibaldi, 1969	100	287	35%			
Ebel, 1993	524	1002	52%	132	1002	13%
Hogue, 1997	451	935	48%	179	937	21%

Comparison of results from the two surveys is problematic because of differences in methodology. Garibaldi used a Most Probable Number method and reported the number of *Salmonella* (all serotypes) per ml. of liquid egg while the APHIS surveys cultured 10 ml. of liquid egg for the presence or absence of *Salmonella* Enteritidis and all other *Salmonella* serotypes.

Evidence suggests that the use of data from Garibaldi's 1969 survey overestimates the number of organisms in a lot (10,000 lbs.) of liquid egg: 1) Garibaldi's survey reported the number of *Salmonella* species but *Salmonella* Enteritidis is one of many serotypes present in unpasteurized liquid egg (Hogue, 1997). 2) The highest level of *Salmonella* found in Garibaldi's survey was 100 organisms per ml. Controls over sanitation have improved since passage of the Egg Products Inspection Act of 1970 and its unlikely that levels in raw product today are as high as the highest level found in 1969.

b. Distribution

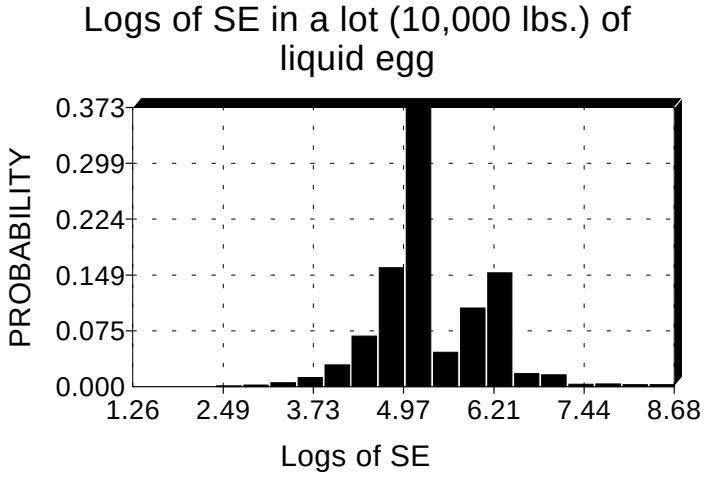
The data in Table C-7 was used to develop a distribution. A maximum value of 150 and a minimum value of 0.000001 were specified.

Table C-7. Number of *Salmonella* in Commercially Broken Eggs before Pasteurization

Number of Samples	MPN *Salmonella*	Frequency
187	0	0.6538
85	0.5	0.0411
10	2.25	0.0050
1	5.3	0.0005
2	24	0.0010
1	110	0.0005

Garibaldi, 1969

Mean	5.3
Standard Deviation	0.7
5th Percentile	4.2
95th Percentile	6.3



7. Pounds of liquid egg in a bulk egg holding tank

The bulk egg holding tank volume is the unit used in the liquid egg products module. The distribution of SE is calculated per tank and reductions in bacteria during pasteurization are applied to the entire tank.

a. Value

10,000 pounds

b. Evidence

unpublished data from the 1995 liquid egg survey

c. Distribution - none

The pounds of egg in holding tanks vary from 1,000 pounds to 100,000 pounds but we assumed a constant value of 10,000 pounds per tank.

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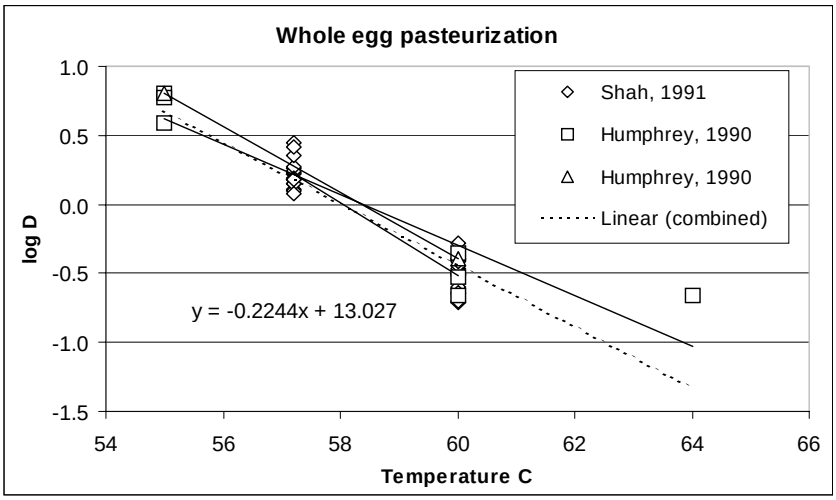
8. Log_{10} reduction of *Salmonella* Enteritidis in liquid whole eggs from pasteurization at 60° C (140° F) for 3.5 minutes.

a. Assumptions

All whole egg is pasteurized at the time and temperature combinations specified in the Egg Products Regulation (60° C [140° F] for 3.5 minutes).

All egg products plants meet but do not exceed the pasteurization requirements of the Egg Products Regulation (USDA, 1991).

Figure C-6



b. Evidence

Data from recent experimental studies by Shah and Humphrey were combined to calculate a single least squared regression equation to estimate log-D = 13.03 + (-0.22 × T) + E, where T is temperature in degrees Centigrade and E is the variability of the estimate: E = normal(μ = 0, σ = 0.16) (Figure C-6).

The log of D for *Salmonella* Enteritidis from pasteurization according to FSIS regulation (60° C for 3.5 minutes) is determined as follows:
First, determine the log-D from pasteurization at 60°C for one minute, by solving the regression equation (13.03 + (-0.22 × T) + E for T = 60°C:
$Log\text{-}D_{60}$ = 13.03 + (-0.22 × 60) = -0.44.
Then, determine the log of D for pasteurization at 60°C for 3.5 minutes:
$Log\text{-}D_{60\text{-}3.5}$ = log(3.5) - (-0.44) + E = 0.544 + 0.44 + E = 0.983 + E

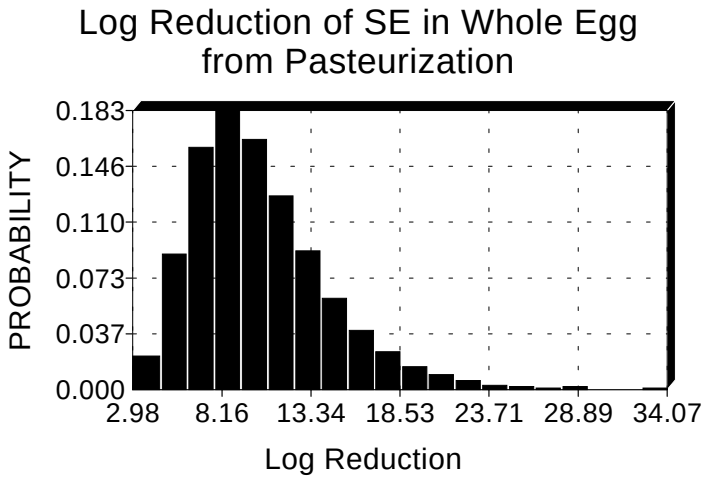
The log of the decimal reduction (log-D) for *Salmonella* Enteritidis from pasteurization according to FSIS regulation (60° C for 3.5 minutes) can be represented by a log normal distribution with a mean of 0.983 and a standard deviation of 0.16. The log reduction (D) is the antilog of log-D: $10^{log\text{-}D} = D$.

c. Distribution - $10^{\text{log normal } (\mu = 0.983,\ \sigma = 0.16)}$

Figure C-7 is a distribution for the log reduction of *Salmonella* Enteritidis in whole egg pasteurized at the minimum time and temperature requirements of the egg products regulation (60° C [140° F] for 3.5 minutes).

Figure C-7

Mean	10.3
Standard Deviation	4.0
5th Percentile	5.2
95th Percentile	17.8



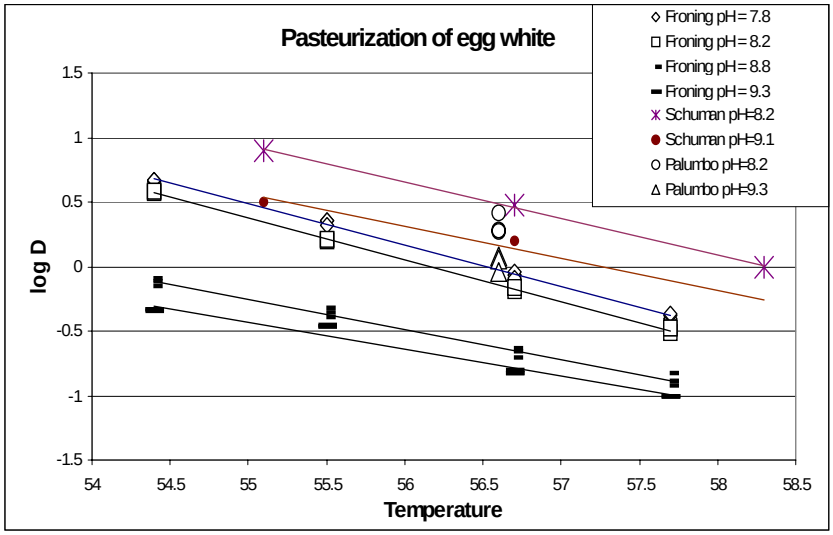
9. Log reduction of *Salmonella* Enteritidis in liquid egg white from pasteurization.

a. Assumptions

All liquid egg white is pasteurized at one of the two time and temperature combinations specified in the Egg Products Regulation (56.7° C [134° F.] for 3.5 minutes or 55.6° C [132° F.] for 6.2 minutes) and either time-temperature scenario is equally likely to occur.

All egg products plants meet but do not exceed the pasteurization requirements of the Egg Products Regulation (USDA, 1991).

Figure C-8



b. Evidence

Data from experimental studies by Froning (1997), Schuman (1997), and Palumbo (1996) were combined to calculate a single least squared regression equation: log-D = 64.0 + (-1.1 × T) + (-6.1 × pH) + (0.1 × T × pH) + E, where T is temperature in degrees Centigrade, E is the variability of the estimate: E = normal(μ = 0, σ = 0.16) and pH is a pert distribution with a minimum value of 7.8, most likely value of 8.2 and a maximum of 9.1 (see page 135). pH is inversely correlated with the reduction of bacteria during pasteurization and there is a significant interaction between pH and temperature.

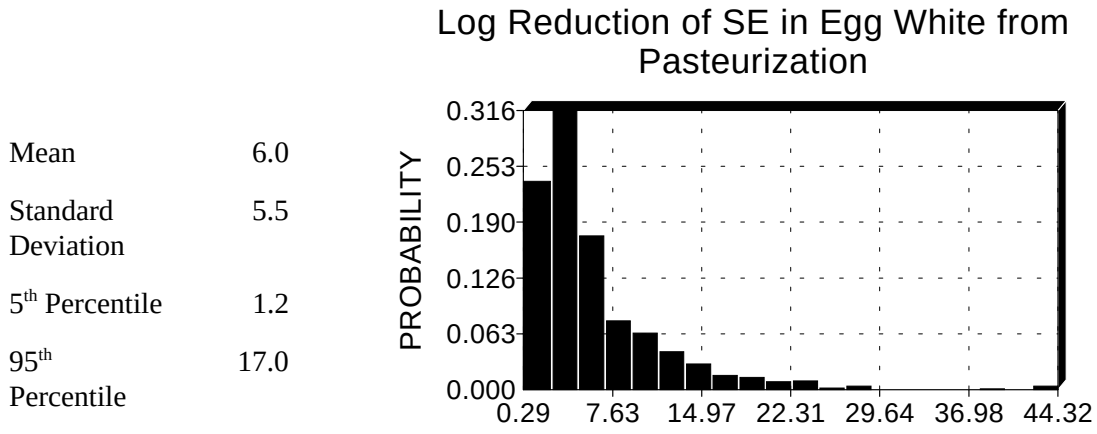
Variation of the estimate for the log of D within an experimental study, at a specified pH, is small (Figure C-8). However, there is a large variation in the results of experimental pasteurization studies by different investigators (Figure C-8). The reduction of bacteria calculated from a least squared regression

formula from data collected by Schuman for egg white pasteurized at 56.67 C for 3.5 minutes at a pH of 8.2 is 1.2 logs (Schuman, 1997). Under the same conditions Froning's data indicates a 5.1 log reduction; a difference of nearly 4 logs. The standard error of the Y estimate (log-D) calculated by combining the current data is large (0.33) because of this discrepancy in experimental results. This standard error is larger than that calculated by combining the data available for yolk (0.18) or whole egg (0.16). Possible explanations for the discrepancy are that Froning used a selective media which may have reduced the recovery of bacteria following pasteurization. A second explanation is that another confounding variable may be present.

c. Distribution - Log Normal

Figure C-9 is a distribution for the log reduction of *Salmonella* Enteritidis in egg white pasteurized at the minimum time and temperature requirements specified in the Egg Products Regulation (56.7° C [134° F.] for 3.5 minutes or 55.6° C [132° F.] for 6.2 minutes). Data from experimental studies by Froning, Palumbo, and Schuman were combined to calculate the regression equation used.

Figure C-9



Mean	6.0
Standard Deviation	5.5
5th Percentile	1.2
95th Percentile	17.0

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10. pH of liquid egg white at breaker plants

pH has a significant effect on the D-value when liquid egg white is pasteurized. The time and temperature requirements of the pasteurization regulations were based on a pH of about 9 for egg white which was the case in 1969 when the regulations were written. Since that time conditions have changed. Egg reach the market faster now than in 1969 and the pH of albumen is lower in fresher eggs. Pasteurization however is less effective at lower pH levels.

The effort here is to describe the distribution of pH in liquid egg white at breaker plants across the United States.

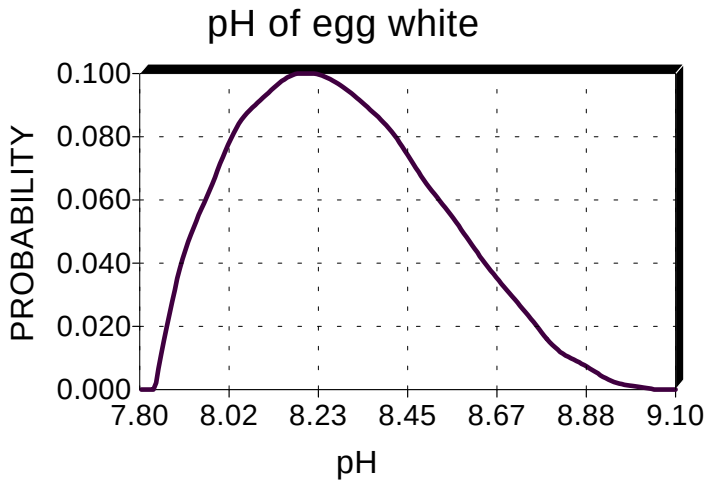
a. Evidence

Egg albumen has a bicarbonate buffer system which allows the pH to rise very rapidly. The pH of a freshly laid egg is about 7.8 and rises to 8.7 or 8.8 in about 3 days storage. After that, the pH increases much more slowly over time to a maximum of 9.3 to 9.4 (Froning).

In-line processed eggs reach the breaker plant within 24 hours of lay. Eggs that are broken in one plant and transported to another for processing are usually pasteurized within three days of lay. Eggs that are diverted from the shell egg market to breaking spend additional time in transport and storage before they are processed. The pH of eggs will reflect the time spent in transportation and storage.

b. Distribution - pert(7.8, 8.2, 9.1)

Figure C-10



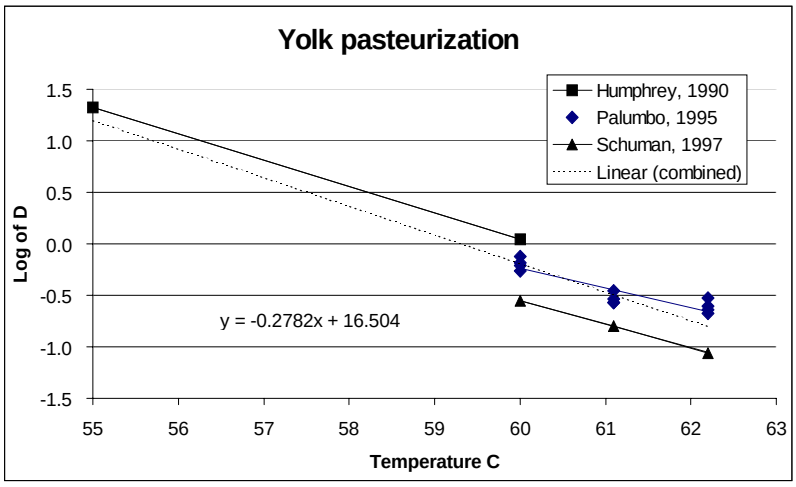
11. Log reduction of *Salmonella* Enteritidis in liquid egg yolk from pasteurization.

a. Assumptions

All liquid egg yolk is pasteurized at one of the two time and temperature combinations specified in the Egg Products Regulation (61.1° C [142° F] for 3.5 minutes or 60° C [140° F] for 6.2 minutes) and that either time-temperature scenario is equally likely to occur.

All egg products plants meet but do not exceed the pasteurization requirements of the Egg Products Regulation (USDA, 1991).

Figure C-11



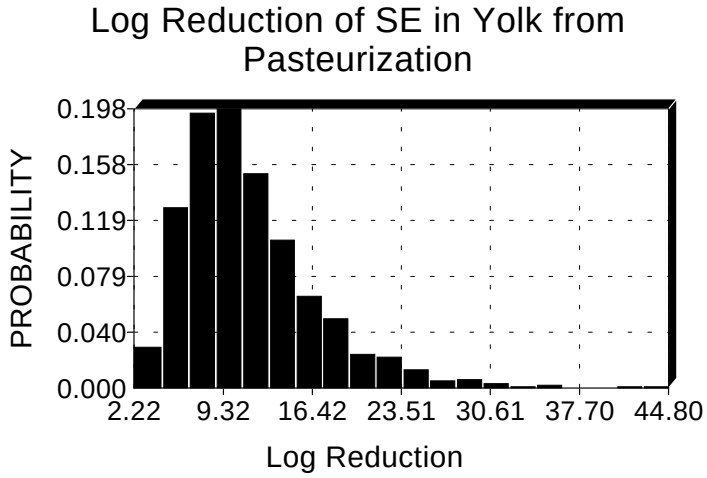
b. Evidence

Data from recent experimental studies (Humphrey, 1990; Palumbo, 1995; and Schuman, 1997) were combined to calculate a single least squared regression equation: log D = 16.50 - (0.28 × T), where T is temperature in degrees Centigrade (Figure C-12).

c. Distribution -

Figure C-12

Mean	11.3
Standard Deviation	5.3
5th Percentile	4.8
95th Percentile	21.6



D. Sensitivity Analysis

Table C-8. Correlation of input variables with *Salmonella* Enteritidis from all sources in product after pasteurization

Product	Input variable	Correlation Coefficient
Yolk	Number of SE before pasteurization	0.63
	Log reduction of SE (60 ° C)	0.34
	Log reduction of SE (61.1° C)	0.31
Whole egg	Number of SE before pasteurization	0.66
	Log reduction of SE (60° C)	0.65
Albumen	Number of SE before pasteurization	0.57
	Log reduction of SE (56.7° C)	0.41
	Log reduction of SE (55.6° C)	0.40
	pH	-0.19

The number of *Salmonella* Enteritidis bacteria remaining after pasteurization is more closely associated with the number of SE bacteria before pasteurization than with any other variable in the model. This relationship is true for yolk, whole egg, and albumen. Control of the bacterial load that goes into the pasteurizer is important in assuring the final product is free of SE. Knowledge of the distribution of SE in liquid egg across egg product plants in the U.S. is essential to predicting the number of bacteria that will remain after pasteurization.

The log reduction achieved through pasteurization according to FSIS time and temperature requirements is the second most strongly associated variable with the number of bacteria remaining after pasteurization. There is a great deal of uncertainty in the actual reduction achieved depending on the experimental study used to determine the D-value.

pH is inversely correlated with the final number of SE in pasteurized egg white. When time and temperature of pasteurization are held constant the number of bacteria decreases as the pH of albumen increases. This association is the weakest of those compared.

E. Module Validation

The FSIS monitoring program detected *Salmonella* species in 0.6% (25/4064) of the samples of egg product tested from January 1996 through December 1977 (Table C-9). Whole eggs with added yolk (88 samples), is the only product category in which no *Salmonella* species were detected. The FSIS monitoring program for egg products is not random. The skip lot program used by FSIS targets plants with a history of positive results for increased testing. Blended egg products had a greater proportion of samples positive for *Salmonella* species (1.0% or 13/1336), than dried (0.5% or 3/661), or liquid non-blended products (0.5% or 9/1979). An analysis of variance indicates that the proportion of *Salmonella* species positive blended samples is significantly higher than the proportion of *Salmonella* species positive liquid unblended products (at $p<0.05$). *Salmonella* Enteritidis was the most frequently isolated serotype (5 isolates); Typhimurium, Braenderup, Give, and Heidelberg were second (2 isolates each); Infantis, Agona, Hadar, and Montevideo were third (one isolate each). Serotyping was not done on six isolates and one isolate was untypable (Table C-9). All five *S*. Enteritidis isolates were cultured from blended egg products: four from yolk with more than 2% added salt or sugar and one from whole egg with more than 2.0% added salt or sugar (Table C-9).

The FSIS monitoring program detected five *Salmonella* Enteritidis isolates in pasteurized egg products from 1996 to 1997. *Salmonella* Enteritidis was not detected in any of the unblended liquid products modeled (yolk, whole egg, or albumen). Simulated testing was done to produce results from the model comparable with results from the FSIS monitoring program. Simulated testing of liquid whole egg and liquid yolk using FSIS methods (100 mls. of product tested with a detection sensitivity of 0.5 organisms per ml.) did not predict any SE-positive samples. These simulation results are consistent with the results of FSIS monitoring.

Simulated testing of albumen predicts that 5% of liquid albumen samples would be positive but the FSIS monitoring program did not find any *Salmonella* Enteritidis positive albumen samples. The discrepancy between the results of the FSIS monitoring program and the results of the simulation for liquid albumen may result from one or more of the following: 1) About 60% of the liquid albumen is produced without the use of added chemicals; the process modeled. The other 40% is produced with a process that uses peroxide to provide a greater reduction of bacteria at a lower temperature. The simulated results do not reflect the level of *Salmonella* Enteritidis in the 40% of albumen pasteurized using the peroxide process. 2) The pH of 8.3 which was used in the modeling of albumen may not accurate reflect conditions in the industry. 3) The model is incorrect in some other assumption.

Table C-9. Results of FSIS monitoring for *Salmonella* in pasteurized liquid egg products from 1996 and 1997

	year	pos	samples	percent	serotypes
egg whites - with or without added ingredients	1996	1	414	0.2%	Typhimurium
	1997	1	408	0.2%	Not serotyped*
whole eggs (<2% added ingredients)	1996	2	557	0.4%	Give Typhimurium
	1997	4	541	0.7%	Agona Hadar*
yolks (<2% added ingredients)	1996	1	36	2.8%	Braenderup
	1997	0	23	0%	
whole eggs with added yolks	1996	0	29	0%	
	1997	0	30	0%	
blended whole egg (>2% added ingredients)	1996	2	121	1.7%	Enteritidis
	1997	0	111	0%	
blended yolk (>2% added ingredients)	1996	4	331	1.2%	Enteritidis (2) Heidelberg*
	1997	5	338	1.5%	Enteritidis (2) Braenderup Heidelberg*
blended whole eggs with added yolks	1996	1	242	0.4%	Infantis
	1997	1	223	0.4%	Not serotyped*
Dried yolk and whole egg	1996	1	153	0.7%	Untypable
	1997	1	145	0.7%	Montevideo
Dried white	1996	1	186	0.5%	Give
	1997	0	176	0	

Serotyping was not done for all *Salmonella* species isolated

Table C- 10. Rank Order Comparison of *Salmonella* Serotypes Found in Liquid Egg Products Before and After Pasteurization

***Salmonella* serotypes in liquid egg before pasteurization - 1989 testing**		
Serotype	**number**	**percent**
Cerro	23	20%
Heidelberg	18	16%
Enteritidis	12	10%
Infantis	9	8%
Braenderup	8	7%
Mbandaka	7	6%
Montevideo	7	6%
Ohio	7	6%
Kentucky	4	3%
Thompson	3	3%
Agona	3	3%
Hadar	3	3%
Havana	2	2%
Typhimurium	2	2%
Livingstone	2	2%
London	1	1%
Oranienburg	1	1%
Poona	1	1%
Brandenburg	1	1%
Albany	1	1%
Haardt	1	1%
Total	116	100%

***Salmonella* serotypes in pasteurized liquid egg - 1996 to 1997 testing**		
Serotype	**number**	**percent**
Enteritidis	5	21%
Typhimurium	2	8%
Braenderup	2	8%
Give	2	8%
Heidelberg	2	8%
Infantis	1	4%
Agona	1	4%
Hadar	1	4%
Montevideo	1	4%
Untypable	1	4%
not serotyped	6	25%
Total	24	100%

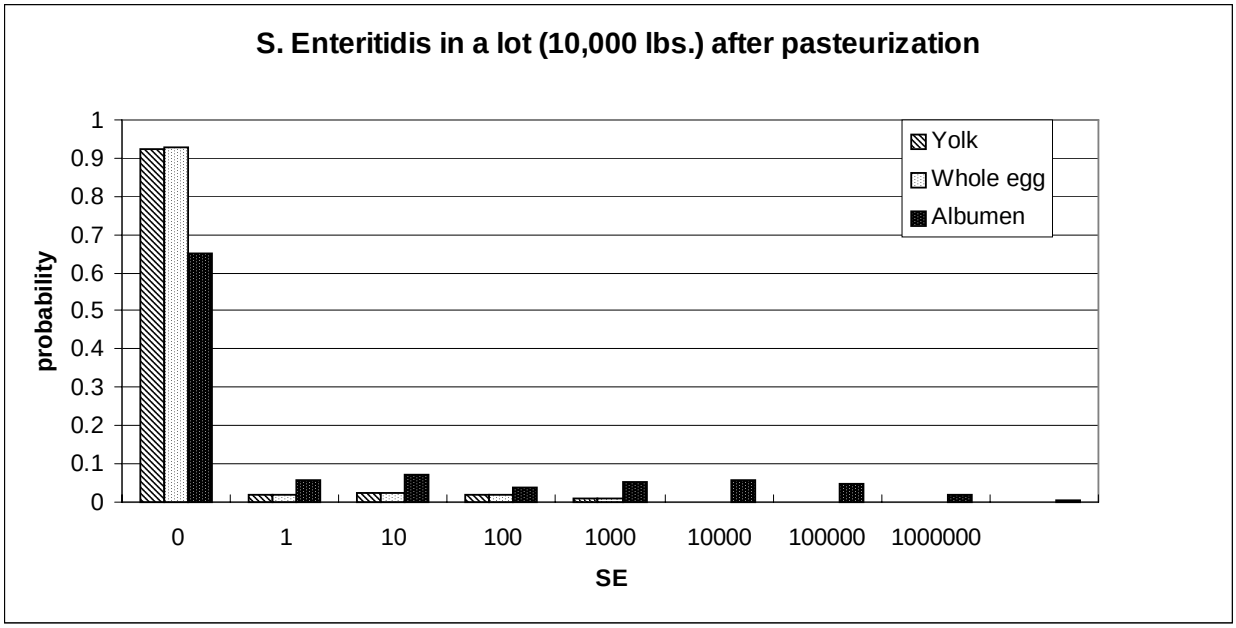
F. Results and Conclusions

The results of simulation of the module are shown in Figure C-13. The module predicts the probability that a single lot (a lot is composed of 10,000 lbs. of product) of liquid yolk or whole egg will not contain any *Salmonella* Enteritidis is larger than 0.9. The probability that liquid albumen will not contain any *Salmonella* Enteritidis in about 0.65.

The scope of this risk assessment for egg products is to evaluate the risk from a single *Salmonella* serotype (*Salmonella* Enteritidis) in a portion of the egg products produced in the U.S. annually. This module does not consider the possibility of post-pasteurization contamination of liquid egg products with *Salmonella* species but there is anecdotal evidence that this may occur. This module also does not consider the risk from out-of-date eggs returned to egg processing plants from grocery stores or from shell egg grading operations. Although this module is not a comprehensive coverage of the risk to human health from egg products it does provide insight into ways that FSIS can improve the controls in egg products processing.

Salmonella species are occasionally detected in pasteurized egg products (see Table C-10), but outbreaks of SE from egg products have not been reported since the Egg Productions Inspection Act was passed in early 1970. Two explanations may account for the lack of reported *Salmonella* outbreaks from pasteurized egg products: 1) Much of the egg product produced is used in further processing, either in an institution setting or in a consumer's home. Often this involves an additional heating process which kills any remaining *Salmonella*. 2) The number of *Salmonella* Enteritidis remaining after pasteurization is below the dose required to cause disease. If the egg product remains refrigerated, then *Salmonella* species will not multiply and the few remaining bacteria are diluted in a large volume of product. The exposure hazard for an

Figure C-13



individual under these circumstances is very small.

This baseline Egg Products Processing and Distribution Module describes the usual situation in the egg products processing industry and does not account for the possibility of process failure. Process failure can occur if the eggs used by breaker plants have very high levels of *Salmonella* or if equipment failure results in inadequate pasteurization. If current process controls fail, then a large number of people may be exposed to SE as a result. It is expected that failure in the pasteurization process is a rare event, but such an event has the potential to produce a significant number of cases of human illness.

A major portion of the load of *Salmonella* Enteritidis in liquid egg prior to pasteurization is introduced at the egg breaking step of egg processing.

Many *Salmonella* serotypes are found in liquid egg products before and after pasteurization (Table C-10). *Salmonella* Enteritidis was the serotype most frequently isolated by the FSIS monitoring program of pasteurized egg products between 1996 and 1997, and *Salmonella* Enteritidis was the third most frequently isolated serotype found by AMS testing of liquid egg product prior to pasteurization in testing conducted in 1989. With the exception of *Salmonella* Give, all the serotypes recovered from pasteurized product were also found in unpasteurized product, in spite of the fact that the testing was done 7 to 8 years apart.

Salmonella Enteritidis is the only serotype, of those listed in Table C-10, commonly isolated from the contents of intact eggs. Therefore, the other serotypes found in egg products before and after pasteurization must originate from a source located after the eggs are broken. Cantor made the same observation in 1948 before *Salmonella* Enteritidis was identified as a contaminant in eggs: "The majority of *Salmonella* types in egg powder do not originate in egg meat" (Cantor, 1948). Cantor's statement was based on the observation that many *Salmonella* serotypes were found in egg powder but *Salmonella* Pullorum was the most common serotype transmitted within eggs at that time in 1948.

Similarly, simulation results suggest that ovarian transmitted SE (SE from the contents of eggs) is less than 1% of the total SE load in liquid eggs prior to pasteurization. Most SE present in liquid egg prior to pasteurization originates from sources other than egg contents. These sources include: contamination from the shell of eggs as bits of shell fall into the liquid product or the egg contents contact the outside surface of the shell in the breaking process, contamination from the breaking machinery, machine operators, and airborne *Salmonella*.

Sensitivity analysis indicates that the number of SE bacteria before pasteurization is positively correlated with the number of SE bacteria remaining in liquid egg after pasteurization. This suggests that reduction of the number of bacteria in liquid egg prior to pasteurization will result in a reduction of bacteria after pasteurization. Plant sanitation is the most promising means of reducing *Salmonella* in the final product. Sanitation techniques include washing and sanitizing of incoming eggs, preventing cross contamination from breaking machinery, preventing contamination from machine operators, preventing contamination from airborne *Salmonella*, and preventing contamination from the surface of the shell during the breaking process.

Egg Products Processing and Distribution Module

The current FSIS minimum time and temperature requirements for pasteurization of egg products are not adequate to ensure that no *Salmonella* will survive pasteurization.

Current FSIS controls of egg product processing include minimum time and temperature requirements for pasteurization. These requirements are based on experimental pasteurization studies on egg products. This SE Risk Assessment model suggests reasons why these controls are not adequate to ensure that no human exposure occurs from *Salmonella* species remains in egg products after pasteurization:

1) The uncertainty in this module's estimate of the log of the reduction of bacteria in liquid egg which has been pasteurized according to FSIS regulations is large (see Table C-11). The 95% confidence interval for whole egg and yolk ranges from about five to more than 17 and the 95% confidence interval for albumen is about one to 16. This large uncertainty is a result of the large variation between the experimental studies upon which the estimates are based. Variation within a study is generally low, but variation between studies is large (see regression charts for whole egg, yolk, and albumen). Minor differences in methods between studies do occur, but no single variable has been identified as responsible for the lack of repeatability of these pasteurization studies conducted at different laboratories. Egg may, by its composition (high fat and globular), provide less repeatable results, or the conditions under which bacteria are grown prior to inoculation may influence experimental results.

Table C-11. Estimates of the reduction in *Salmonella* Enteritidis from pasteurization

Product	FSIS minimum pasteurization requirements	Log of reduction in SE expected	95% confidence interval
whole egg	60°C for 3.5 minutes	8.1	5.2-17.8
yolk	60°C for 6.2 minutes	7.8	4.7-19.6
	61.1°C for 3.5 minutes	8.2	5.4-22.5
albumen (pH=8.3)	55.6°C for 6.2 minutes	3.6	1.1-15.7
	56.7°C for 3.5 minutes	3.7	1.1-16.0

2) The number of *Salmonella* Enteritidis remaining after pasteurization is more closely associated with the number of bacteria before pasteurization than with any other variable in the module. This relationship is true for yolk, whole egg, and albumen. Control of the bacterial load that goes into the pasteurizer is important to insure that the final product is free of SE.

3) The intended use of the final product is an important factor in determining whether human exposure occurs from *Salmonella* species in egg products. The use of egg products can be placed in one of three categories: 1) Egg products may be further processed involving a controlled heat treatment. 2) Egg products may be part of a ready to eat product. 3) Egg products may be sold as products intended for cooking where a final heat treatment may or may not occur (i.e. liquid whole eggs to be cooked as scrambled eggs).

Egg Products Processing and Distribution Module

The risk of human exposure to *Salmonella* Enteritidis from egg products may be reduced by basing the minimum time and temperature requirement for pasteurization on the level of *Salmonella* species in raw product and the intended use of the final product.

Blended whole egg product and blended yolk product may pose a greater risk to consumers than other types of egg products.

This risk assessment does not model *Salmonella* Enteritidis in blended egg products, however the results of the FSIS egg products monitoring program suggest that blended products should be included in future modeling efforts. The FSIS egg products monitoring program found a greater proportion of samples positive for *Salmonella* species in blended egg products (1.0% or 13/1336) than dried (0.5% or 3/661) or liquid non-blended products (0.2% or 9/4034). An analysis of variance indicates that the proportion of *Salmonella* species positive blended samples is significantly higher than the proportion of *Salmonella* species positive liquid unblended products ($p<0.05$). *Salmonella* Enteritidis was the most frequently isolated serotype in blended egg products (5 isolates). All five *Salmonella* Enteritidis isolates were cultured from blended egg products: four from blended yolk with more than 2% added salt or sugar and one from blended whole egg with more than 2.0% added salt or sugar (Table C-9). The FSIS egg products monitoring program is not a random sampling program. The skip lot program used by FSIS targets those plants with a history of positive test results for more frequent testing.

Ingredients such as salt and sugar lower the a_w (water activity) of liquid egg and increase the thermal resistance of *Salmonella* species in the product. Pasteurization studies indicate that the log reduction of *Salmonella* species achieved by pasteurization of egg yolk blended with **10% added sugar** at the minimum time and temperature required in the egg products regulation (63.3° C or 146° F for 3.5 minutes) is about 4.9 logs (Palumbo, 1995). The log reduction of *Salmonella* species in yolk blended with **10% added salt** was 0.3 logs. Pasteurization at the minimum time and temperature requirements of the egg products regulation would not kill all of the 5.3 logs of SE expected to be present in these two blended yolk products prior to pasteurization (expected SE - see page 127).

In conclusion the current FSIS time and temperature regulations do not provide sufficient guidance to the egg products industry for the large range of products it produces. Time and temperature standards based on the amount of bacteria in the raw product, how the raw product will be processed, and the intended use of the final product will provide greater protection to the consumers of egg products.

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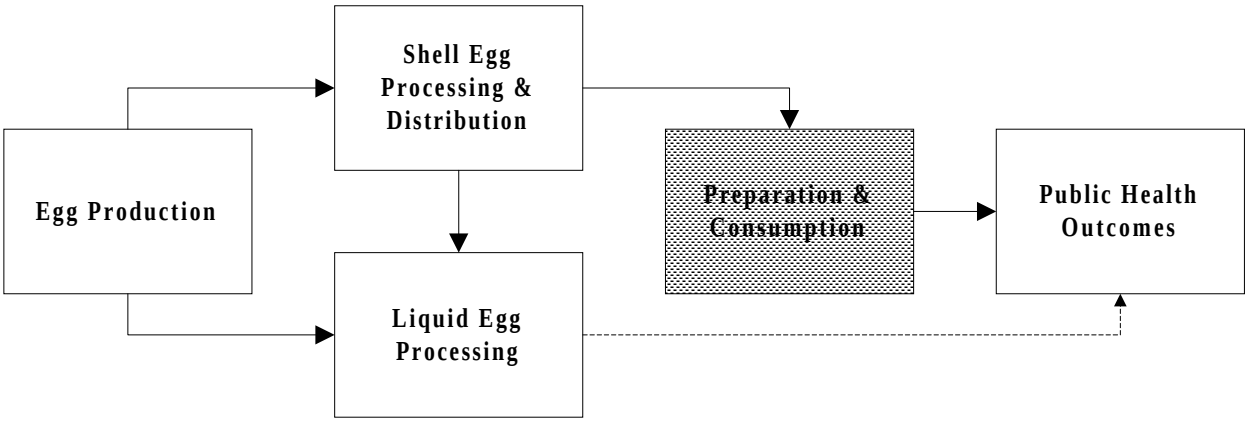
Preparation and Consumption Module



A. Summary of Preparation and Consumption Module

The objective of the Preparation and Consumption module is to determine the number of egg-containing servings contaminated with SE and the extent of the contamination in foods originating from SE contaminated eggs. These distributions are used by the Public Health Outcomes module.

This module describes exposure from the consumption of eggs and egg-containing foods that are contaminated with SE. Eggs for end-user consumption have an associated probability and level of contamination. We make assumptions about home and institutional use, pooling, types of use, and cooking practices and simulate eggs moving through different pathways. With the exception of eggs in pools, contamination of eggs after production is not modeled. Since the prevalence of contaminated eggs is very low, we model only contaminated eggs to avoid needless iterations involving hundreds of thousands of non-contaminated eggs. The final distributions represent sums of all the possible pathways through the model. The final distributions are used with the total number of eggs produced to determine the number of servings contaminated with SE.

The module models sixteen different pathways through preparation and consumption. The sixteen pathways represent all the possible combinations of whether an egg is for home or institutional use, whether the egg is pooled or not pooled, whether the egg is used as an egg or as an ingredient incorporated into another product. Figure D-1 (page 151) shows the processes through which an SE-positive egg passes in the Preparation and Consumption module.

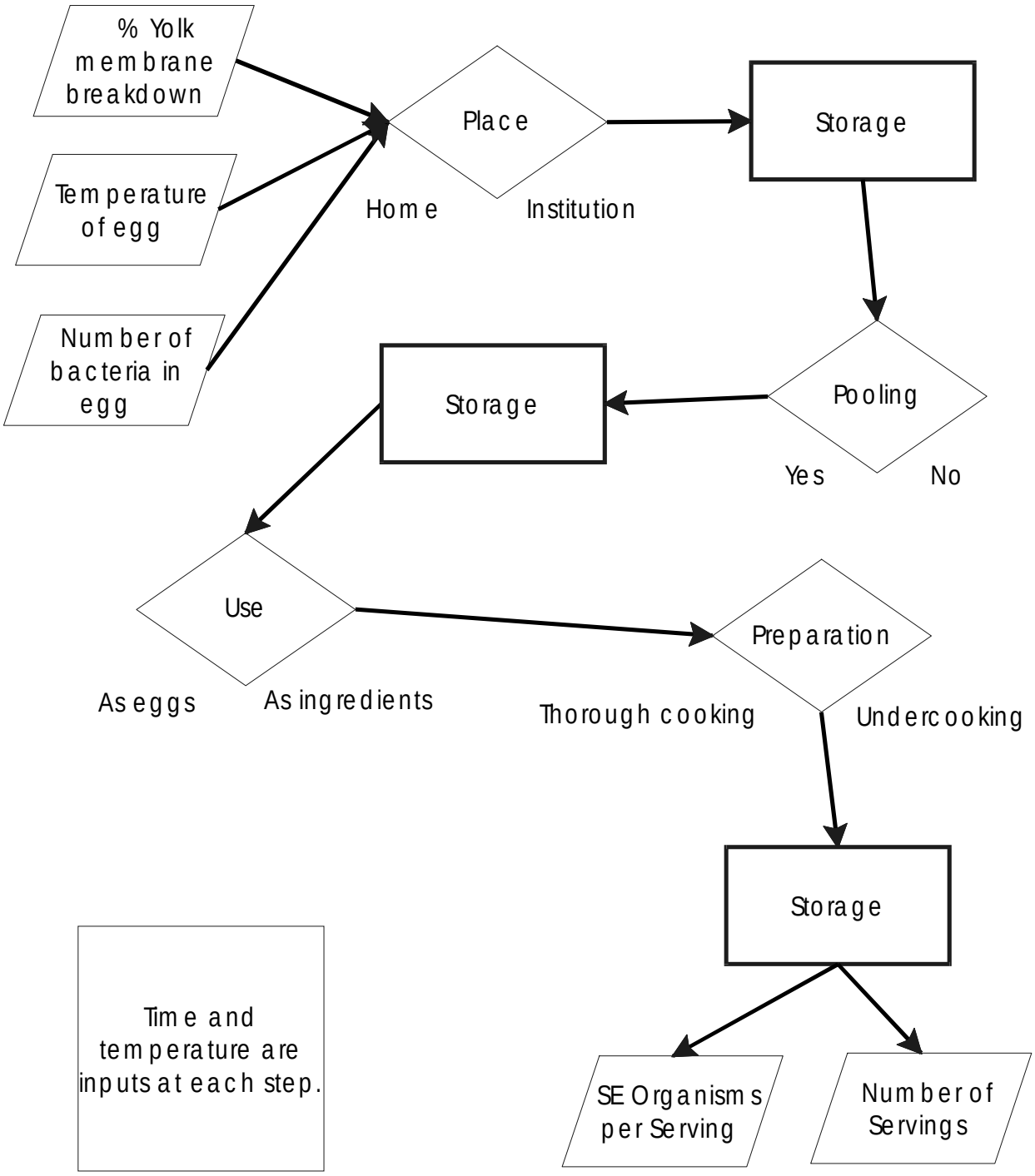
The inputs from the Shell Egg Processing and Distribution module are the percentage of yolk membrane breakdown that has occurred, the internal temperature of the egg, and the number of bacteria in the egg. The egg is either used in the home in which case it is subjected to storage at retail and in the home or it is used in an institutional setting where it is also subjected to storage.

Preparation and Consumption Module

The egg is then either pooled or not pooled before use. If it is pooled before use, it is again subjected to storage. The egg is then either used and eaten as an egg or it is used as an ingredient that is incorporated into a recipe. In either case, the product is then subjected to some type of heat treatment through cooking. After the product is prepared it is subjected to short term storage before consumption. The outputs to the public health module are the number of servings per original SE-positive egg and the number of SE bacteria in each of those servings. At each of these steps the influence of ambient temperature and storage time is included.

Figure D-1

Preparation and Consumption Process Diagram



B. Inputs to Preparation and Consumption Module

1. Number of SE bacteria in contaminated eggs

2. Percent yolk membrane breakdown

C. Preparation and Consumption Module Variables

1. Probability of an egg going to an institutional consumer

   a. Evidence –

   The United Egg Board estimated the following distribution of eggs into the marketplace in 1996

Table D-1. Egg Distribution - 1996

Market distribution	Million cases	Percent
Purchased at retail	94.1	53.0%
Further processing	49.5	27.9%
For food service use	30.9	17.4%
Exported	3.1	1.7%

   b. Mean – 24.7%

   30.9 million cases of eggs are used by institutional consumers (food service) and 125 (94.1 + 30.9) million cases of eggs are produced for the domestic table egg market. Eggs produced for food service are 24.7% (30.9/125) of table eggs produced.

   c. Distribution – None

Precooking Storage Times and Temperatures

2. Retail storage time (days)

   a. Evidence –

      Personal experience

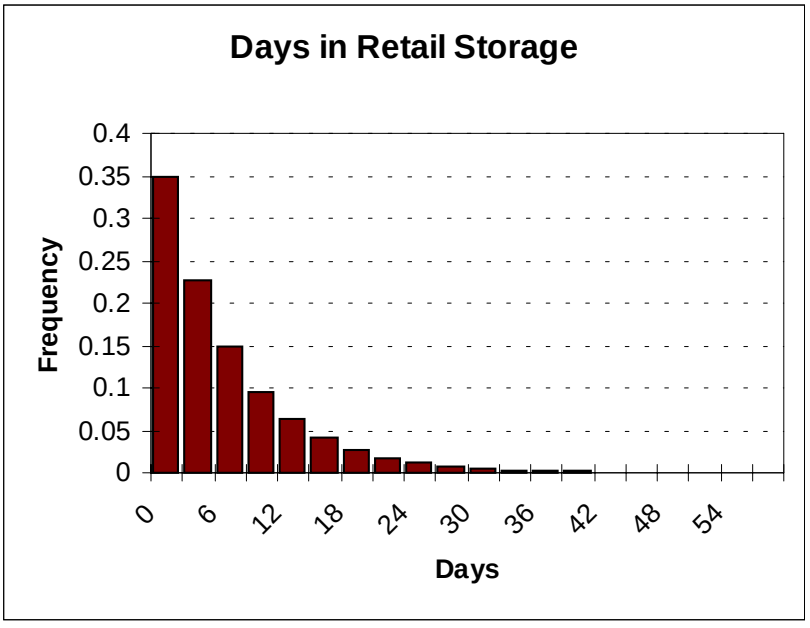
   b. Mean value of distribution – 7 days

      Many egg producers use pull dating on cartons. Pull dating (30 days) is required on cartons with the USDA shield (about 30% of eggs). We assume that half of the eggs will be through retail storage within 14 days.

   c. Distribution – Truncated Exponential(7,0,60)

      This distribution assumes that half of all eggs leave retail storage within 5 days; the other half leave storage within 60 days.

Figure D-2



3. Retail storage temperature (F)

   a. Evidence –

      Personal experience

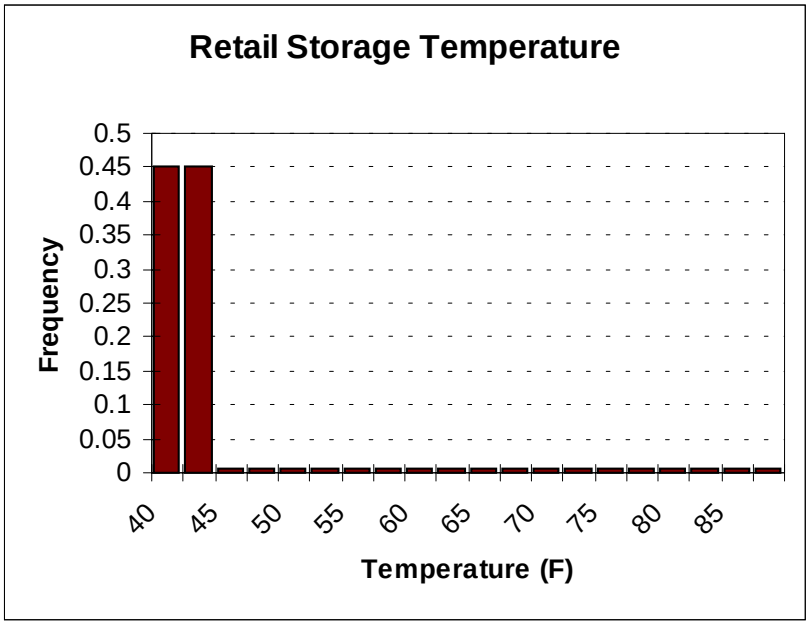
   b. Mean value of distribution – 45° F.

      FDA has defined eggs as "potentially hazardous" since August, 1990. It is reasonable to assume that most retail eggs are stored under refrigeration.

   c. Distribution – Discrete({Uniform(40,45),Uniform(45,90)},{.9,.1}

      This distribution assumes that 90% of eggs are stored under refrigeration at temperatures ranging uniformly from 40-45° F and that 10% of eggs are stored unrefrigerated or poorly refrigerated at temperatures ranging from 45-90° F.

Figure D-3



4. Storage time in home setting (days)

   a. Evidence –

      Personal experience

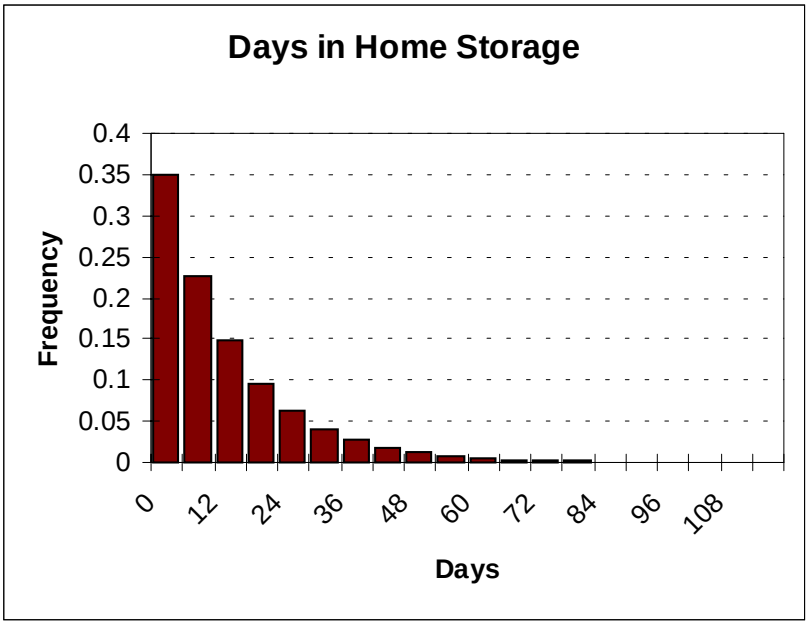
   b. Mean value of distribution – 14 days

      It is assumed that half of all eggs are used within one month in the home.

   c. Distribution – Truncated Exponential(14,0,120)

      This distribution assumes that half of all eggs are used by the consumer within 10 days; the other half are used within 120 days.

Figure D-4



5. Storage temperature in home setting (F)

   a. Evidence –

      Personal experience

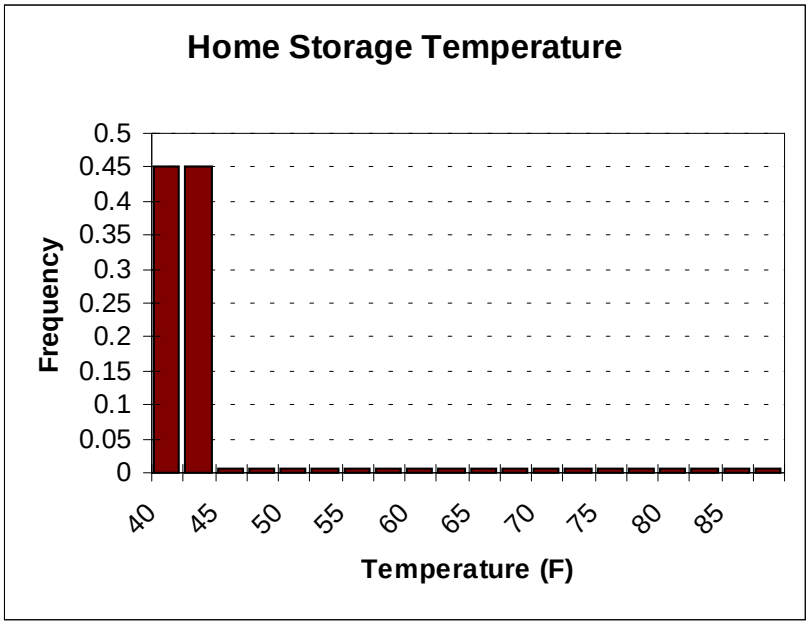
   b. Mean value of distribution – 45° F.

      It is reasonable to assume that most people store eggs under refrigeration at home based on personal experience.

   c. Distribution – Discrete({Uniform(40,45),Uniform(45,90)},{.9,.1}

      This distribution assumes that 90% of eggs are stored under refrigeration at temperatures ranging uniformly from 40-45° F and that 10% of eggs are stored unrefrigerated or poorly refrigerated at temperatures ranging from 45-90° F.

Figure D-5



6. Storage time in institutional setting (days)

a. Evidence –

Personal experience

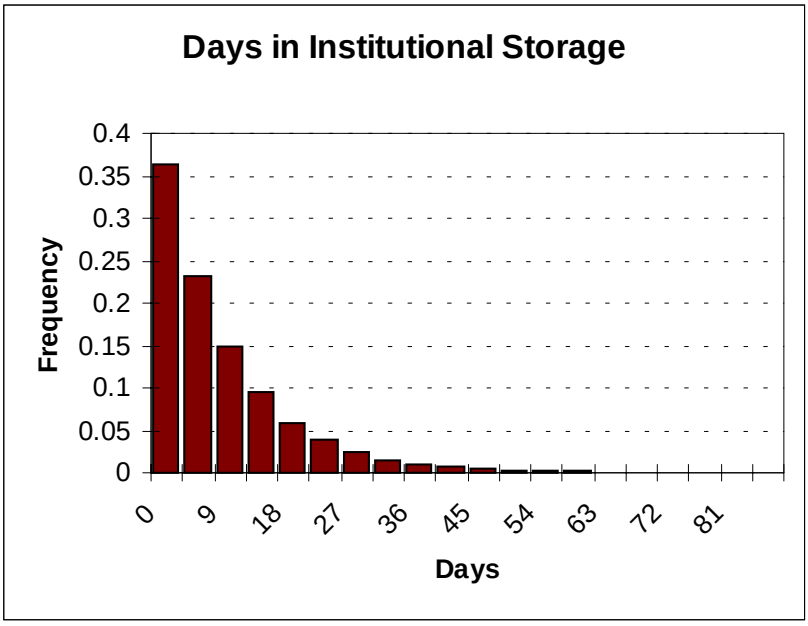
Mean value of distribution – 10 days

Storage of eggs in institutional settings is assumed to be longer than at retail but shorter than in home storage.

b. Distribution – Truncated Exponential (10,0,90)

This distribution assumes that half of all eggs leave storage in an institutional setting within 10 days; the other half leave storage within 90 days.

Figure D-6



7. Storage temperature in institutional setting (F)

   a. Evidence –

      Personal experience

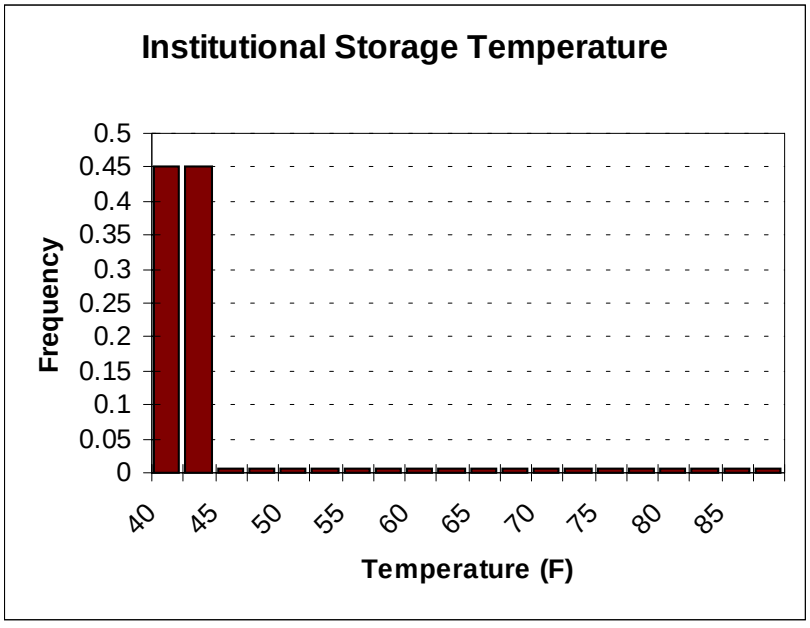
   b. Mean value of distribution – 45° F.

      FDA has defined eggs as potentially hazardous since August, 1990. Thus, it is assumed that most institutional eggs are stored under refrigeration.

   c. Distribution – Discrete({Uniform(40,45),Uniform(45,90)},{.9,.1}

      This distribution assumes that 90% of eggs are stored under refrigeration at temperatures ranging uniformly from 40-45° F and that 10% of eggs are stored unrefrigerated or poorly refrigerated at temperatures ranging from 45-90° F.

Figure D-7



Pooling Variables

8. Probability of pooling in home setting

   a. Evidence –

      Personal experience

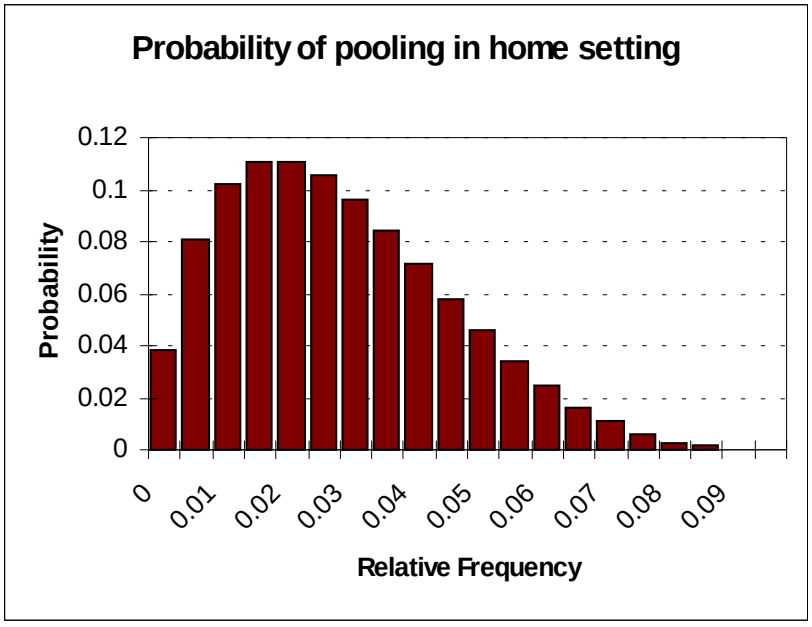
   b. Mean value of distribution – 3%

      It is assumed little pooling of eggs occurs in home settings. Nevertheless, there will be some occasions when eggs are pooled for recipes, later cooking, or separated and stored.

   c. Distribution – Pert(0%,2%,10%)

      The range of probabilities models the uncertainty about the true prevalence of pooling eggs in the home. The probability of pooling eggs at home ranges from 0-10% with half the values falling below 3%.

Figure D-8



9. Number of eggs in pool in home setting

   a. Evidence –

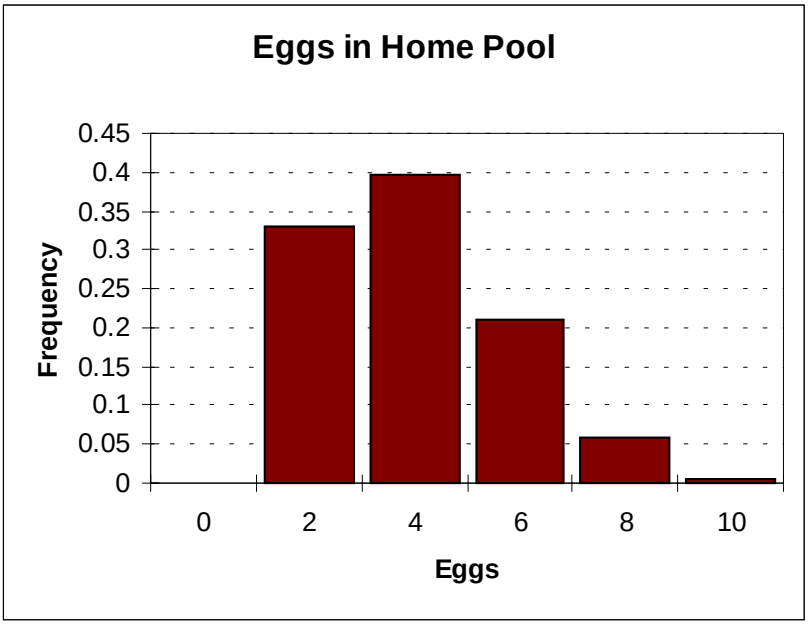
      Personal experience

   b. Mean value of distribution – 5 eggs

   c. Distribution – Round(Pert(2,4,12))

      It is assumed that the number of eggs in a pool in the home varies from 2-12 with half the values at 5 eggs or less.

Figure D-9



10. Storage time after pooling in home setting (hours)

    a. Evidence –

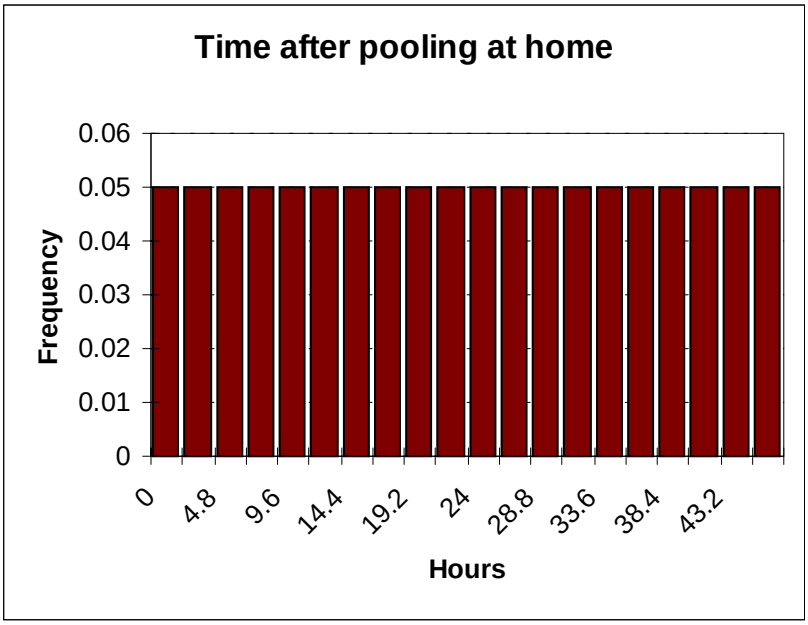
       Personal experience

    b. Mean value of distribution – 24 hours

    c. Distribution – Uniform(0,48)

       This distribution assumes that all eggs that are pooled in a home setting will be used within 48 hours. The time they will be used varies uniformly from 0 to 48 hours.

Figure D-10



11. Storage temperature after pooling in home setting (F)

    a. Evidence –

       Personal experience

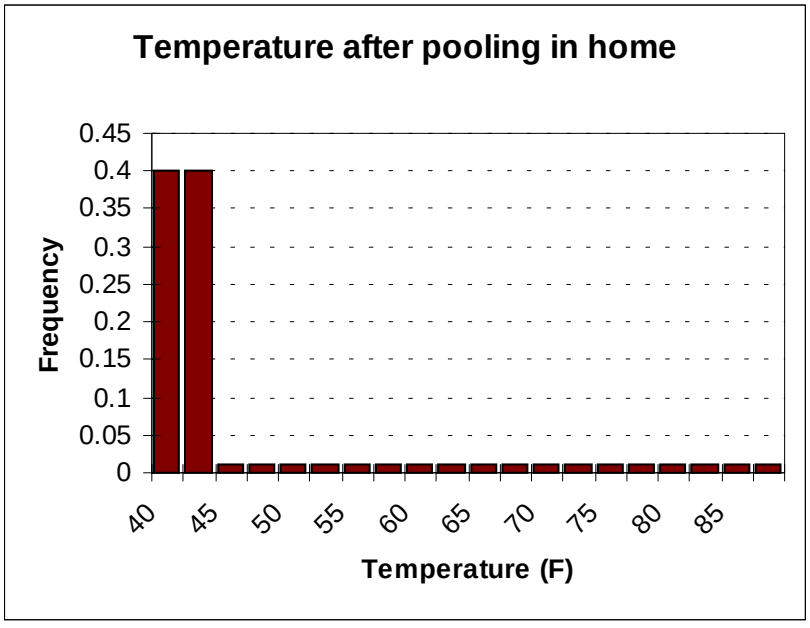
    b. Mean value of distribution – 47.5° F.

       It is assumed that most people, after breaking eggs out for pooling, store them under refrigeration at home, but that the probability of refrigeration adequate to prevent growth is lower.

    c. Distribution – Discrete({Uniform(40,45),Uniform(45,90)},{.8,.2}

       This distribution assumes that 80% of eggs are stored under refrigeration at temperatures ranging uniformly from 40-45° F and that 20% of eggs are stored unrefrigerated or poorly refrigerated at temperatures ranging from 45-90° F.

Figure D-11



12. Probability that a pooled egg in a home setting will be used as an egg

    a. Evidence –

       Personal experience

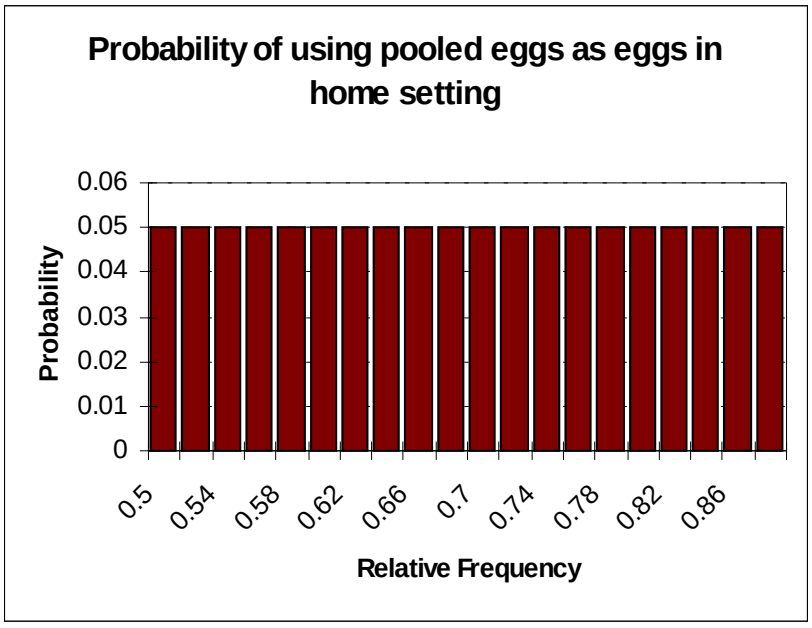
    b. Mean value of distribution – 70%

       It is assumed that over half the pooled eggs used in the home are consumed as eggs.

    c. Distribution – Uniform(50%,90%)

       The wide uniform distribution from 50 to 90% reflects the uncertainty of what the true value of this probability is.

Figure D-12



13. Probability that a pooled egg used as an egg in a home setting will be undercooked

a. Evidence –

The 1996-1997 Food Consumption and Preparation Diary (FCPD) Survey shows that 27% of all egg dishes consumed were undercooked (described as being runny or having either a runny yolk or runny white). On average, each person consumed undercooked eggs 19 times a year. (Lin et al., 1997).

Per capita table egg consumption for 1996 and 1997 was estimated to be about 168 and 164 eggs respectively. (Food and Agricultural Policy Research Institute (FAPRI) Staff Report – 1995)

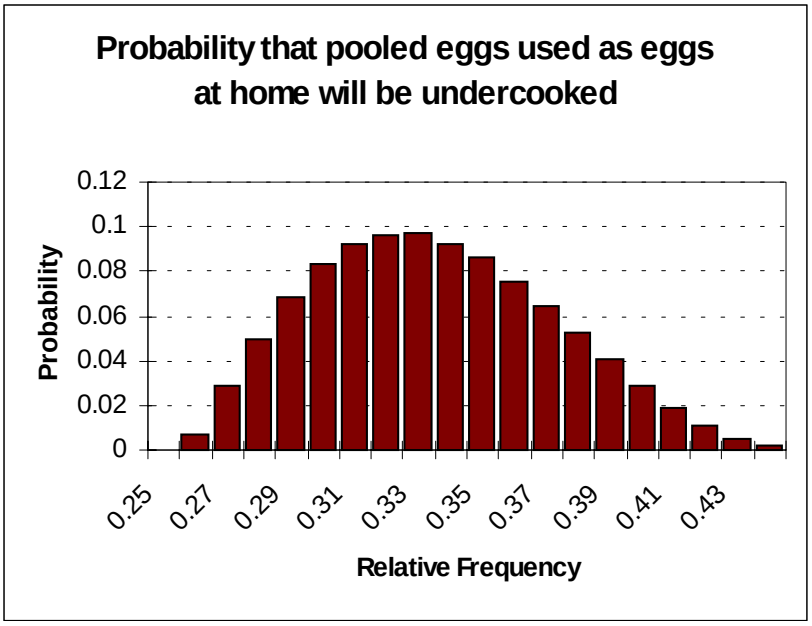
b. Mean value of distribution – 33%

Assume that an average egg dish consists of two eggs. In the section on the percentage of home use non-pooled eggs that are used as eggs, these were 70% of homes use non-pooled eggs. This value had a distribution ranging uniformly from 50 to 90%. 33% is obtained by multiplying 2 eggs per egg dish by 19 egg dishes for 38 undercooked eggs. This is divided by (166 eggs times 70%) 116 eggs for 33%.

c. Distribution – Pert(26%,33%,46%)

The minimum and maximum of the distribution are obtained by assuming that respectively 90% and 50% of the home use non-pooled eggs are used as eggs.

Figure D-13



Preparation and Consumption Module

14. Probability that a pooled egg used as an ingredient in a home setting will not be cooked

a. Evidence –

FDA Food Safety Survey from December 1992 through February 1993 (1,620 respondents) showed that 879 (53%) ate foods containing raw eggs at some time, 700 (44%) did not, and 41 (3%) were not sure. (Klontz et al., 1995). The Menu Census Survey (1992-1995) showed that the average frequency was 0.43 raw egg consumption events per year. (Lin et al., 1997; Market Research Corporation of America, 1995.)

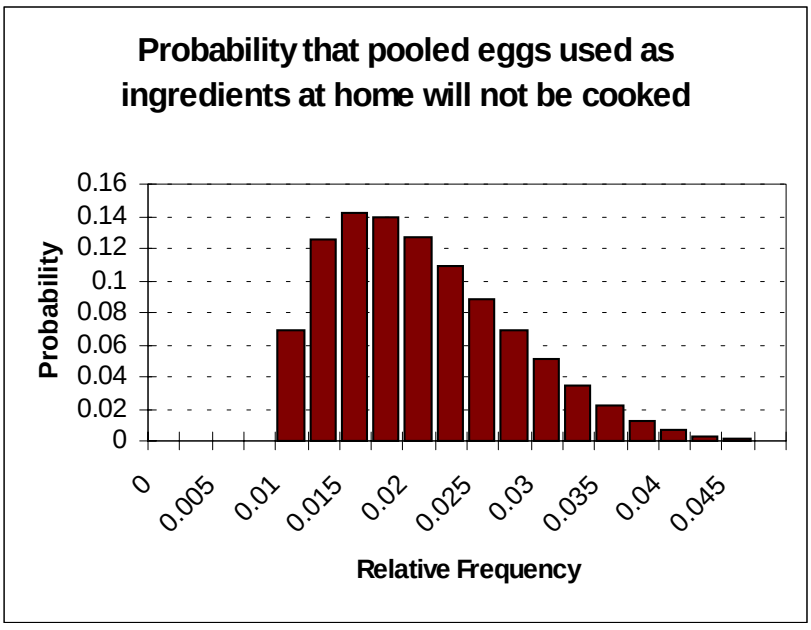
b. Mean value of distribution – 1.7%

In section 22, "Non-pooled eggs that are used as eggs in a home setting", we assumed these were 70% of home use non-pooled eggs. This value had a distribution ranging uniformly from 50 to 90%. Thus 10-50% of home use non-pooled eggs would be used as ingredients. About 50 eggs (166 eggs per capita –116 eggs consumed as eggs) per capita would be used as ingredients. Assume an average of two eggs per use as ingredients. Thus, 0.43 from the survey listed under evidence becomes 0.86 raw egg consumption events. 0.86 eggs / 50 eggs = 1.7%

c. Distribution – Pert(1%,1.7%,5.1%)

The minimum and maximum of the distribution are obtained by assuming that respectively 50% and 10% of the home use non-pooled eggs are used as eggs.

Figure D-14



15. Probability of pooling in an institutional setting

a. Evidence –

Personal experience

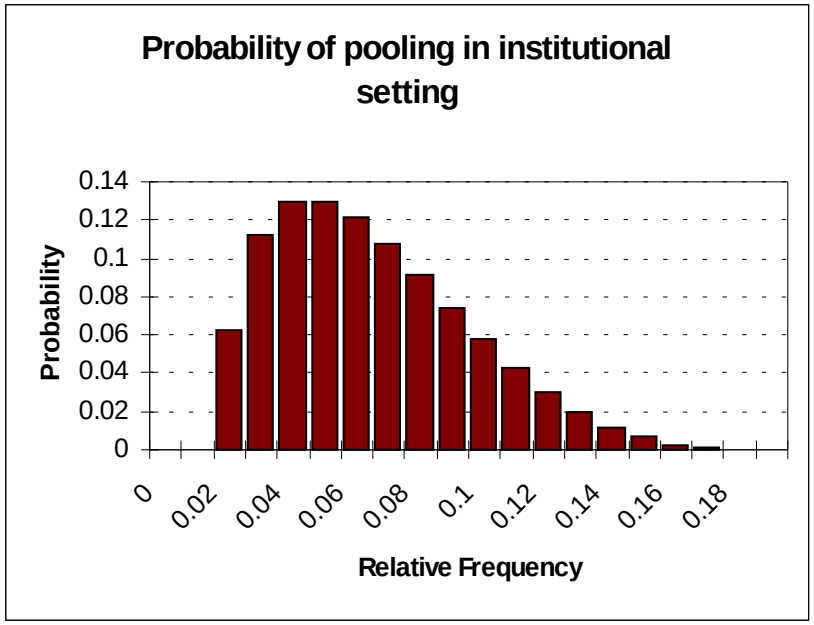
b. Mean value of distribution – 7%

It is assumed that pooling of eggs is more likely in an institutional setting than at home.

c. Distribution – Pert(2%,5%,20%)

It is assumed that the probability of pooling eggs in an institutional setting can range from 2-20% with half the values falling below 7%.

Figure D-15



16. Number of eggs in a pool in an institutional setting

    a. Evidence –

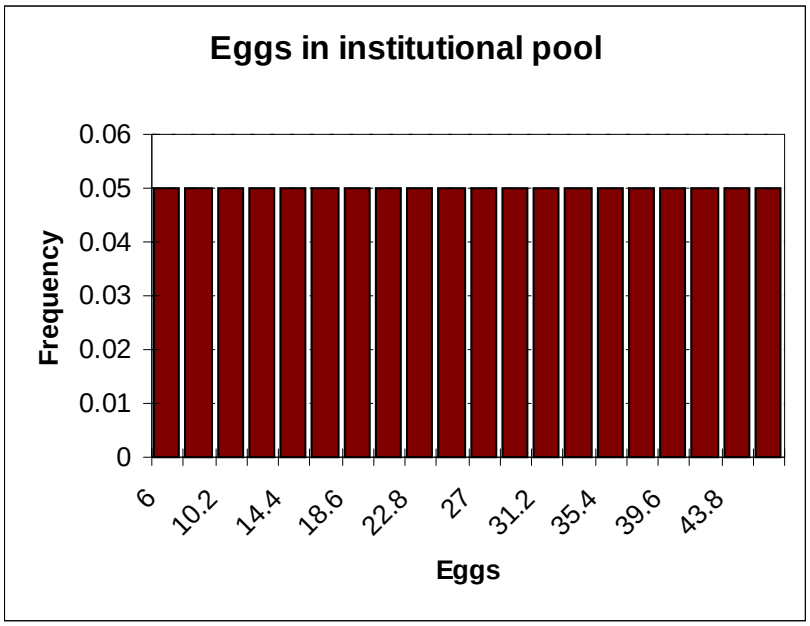
       Personal experience

    b. Mean value of distribution – 27 eggs

    c. Distribution – Uniform(6,48)

       It is assumed that the size of a pool of eggs in an institutional setting is 3 to 4 times larger than the size of a pool of eggs in a home setting.

Figure D-16



17. Storage time after pooling in an institutional setting (hours)

    a. Evidence –

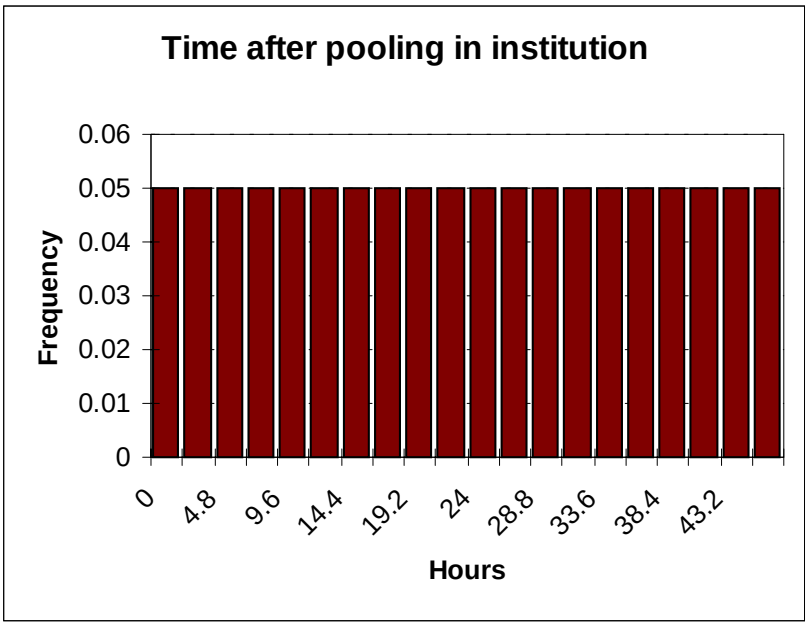
       Personal experience

    b. Mean value of distribution – 24 hours

    c. Distribution – Uniform(0,48)

       This distribution assumes that all eggs that are pooled in an institutional setting will be used within 48 hours. The time they will be used varies uniformly from 0 to 48 hours.

Figure D-17



18. Storage temperature after pooling in an institutional setting (F)

    a. Evidence –

       Personal experience

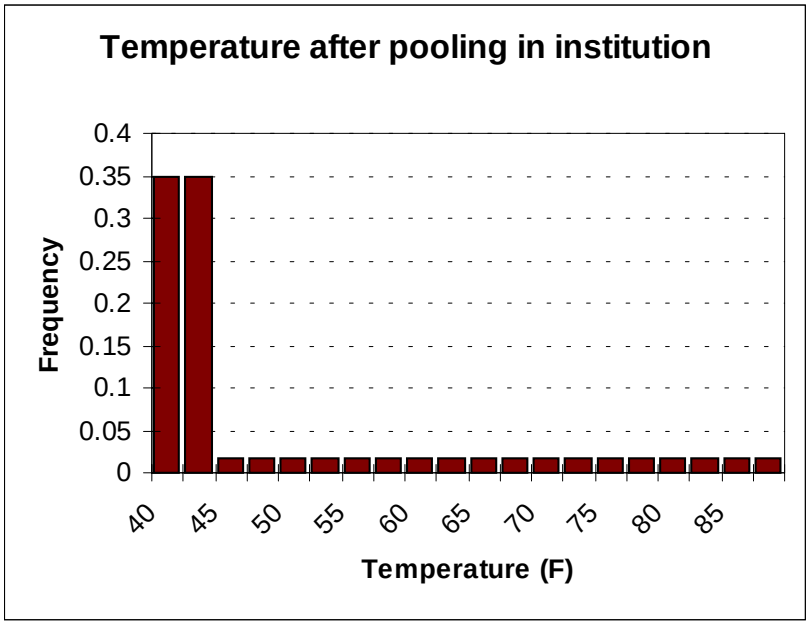
    b. Mean value of distribution – 50° F.

       It is less likely for institutional eggs to be refrigerated after they are broken out and pooled than for home use eggs.

    c. Distribution – Discrete({Uniform(40,45),Uniform(45,90)},{.7,.3})

       This distribution assumes that 70% of eggs are stored under refrigeration at temperatures ranging uniformly from 40-45° F and that 30% of eggs are stored unrefrigerated or poorly refrigerated at temperatures ranging from 45-90° F.

Figure D-18



19. Probability that a pooled egg will be used as an egg in an institutional setting

    a. Evidence –

       Personal experience

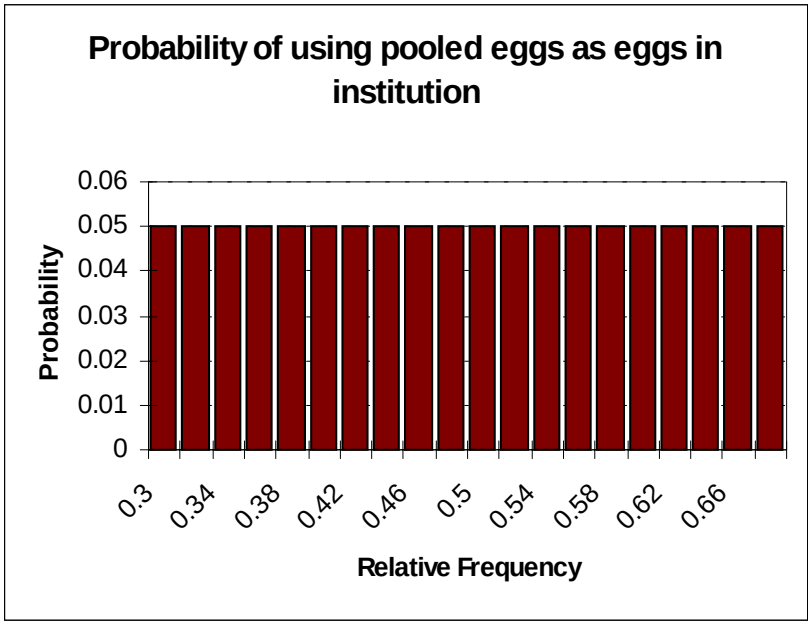
    b. Mean value of distribution – 50%

       It is assumed that about half the pooled eggs used in an institutional setting are consumed as eggs.

    c. Distribution – Uniform(30%,70%)

       The wide uniform distribution from 30 to 70% reflects the uncertainty of the probability of using of pooled eggs as eggs rather than ingredients.

Figure D-19



20. Probability that pooled egg used as an egg will be undercooked in an institutional setting

a. Evidence –

The 1996-1997 Food Consumption and Preparation Diary (FCPD) Survey shows that 27% of all egg dishes consumed were undercooked (described as being runny or having either a runny yolk or runny white). On average, each person consumed undercooked eggs 19 times a year. (Lin et al., 1997). Per capita table egg consumption for 1996 and 1997 was estimated to be about 168 and 164 eggs respectively. (FAPRI Staff Report – 1995)

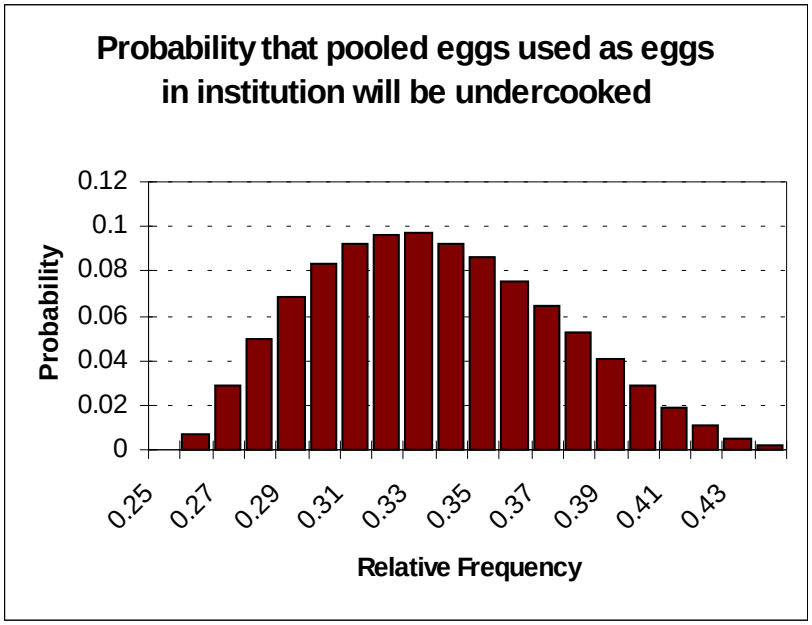
b. Mean value of distribution – 33%

It is assumed that the same percentage of these eggs will be undercooked in an institutional setting as was calculated for a home setting in variable number 13. Given the lack of information on cooking practices we treated all types of institutions as the same.

c. Distribution – Pert(26%,33%,46%)

It is assumed the same distribution for these eggs as was calculated for a home setting in variable number 13.

Figure D-20



21. Probability that pooled egg used as ingredient in an institutional setting will be uncooked

a. Evidence –

FDA Food Safety Survey from December 1992 through February 1993 (1,620 respondents) showed that 879 (53%) ate foods containing raw eggs at some time, 700 (44%) did not, and 41 (3%) were not sure. (Klontz et al., 1995).

The Menu Census Survey (1992-1995) showed that the average frequency of raw egg consumption was 0.43 consumption events per year. (Lin et al., 1997; Market Research Corporation of America, 1995.)

Personal experience

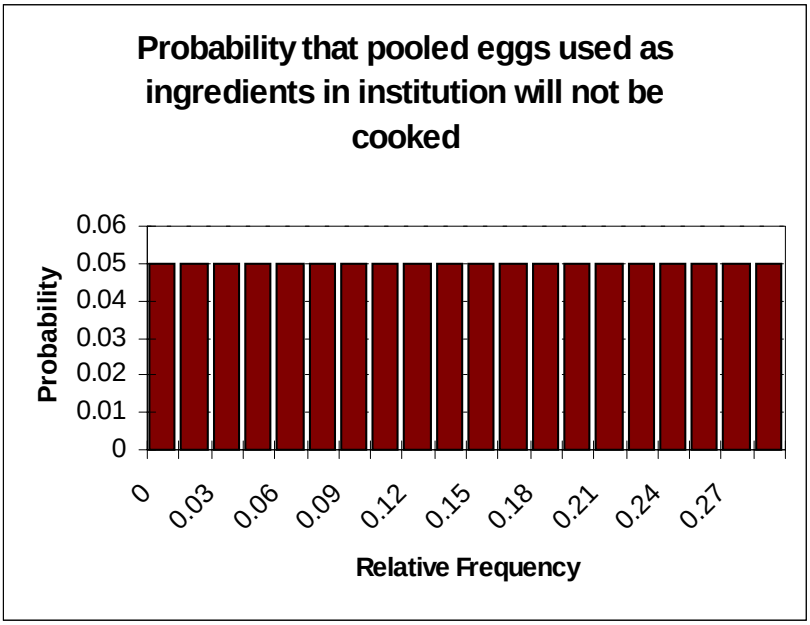
b. Mean value of distribution – 15%

This variable was set higher than other variables of the same type with the same evidence. There is more uncertainty regarding the true number of eggs used as ingredients in institutions that do not get cooked.

c. Distribution – Uniform(0,30)

This variable also has a much wider distribution than other similar variables in this module.

Figure D-21



Non-pooled Egg Variables

22. Probability that non-pooled egg will be used as egg in a home setting

    a. Evidence –

       Personal experience

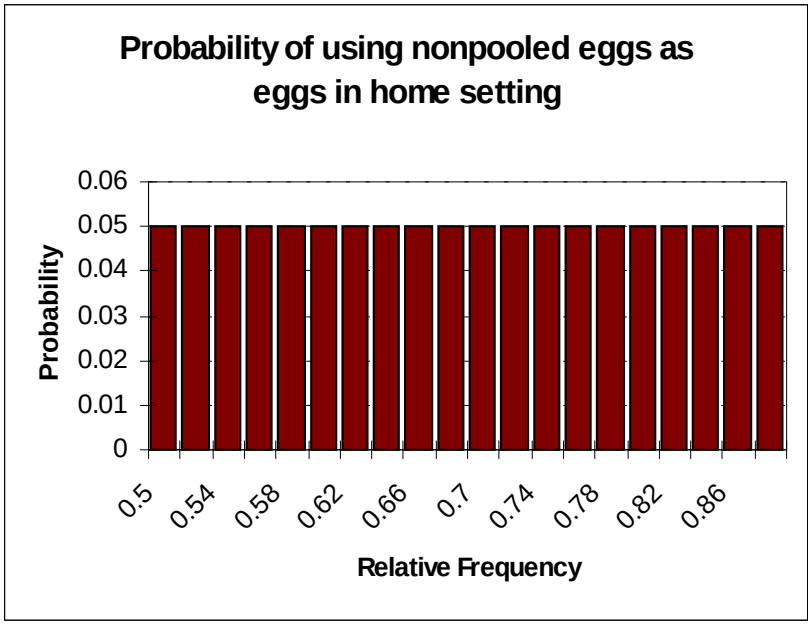
    b. Mean value of distribution – 70%

       It is assumed that most eggs used in the home are consumed as eggs.

    c. Distribution – Uniform(50%,90%)

       The wide uniform distribution from 50 to 90% reflects the uncertainty of probability of using non-pooled eggs as eggs.

Figure D-22



23. Probability that home use non-pooled egg used as egg will be undercooked

a. Evidence –

The 1996-1997 Food Consumption and Preparation Diary (FCPD) Survey shows that 27% of all egg dishes consumed were undercooked (described as being runny or having either a runny yolk or runny white). On average, each person consumed undercooked eggs 19 times a year. (Lin et al., 1997).

Per capita table egg consumption for 1996 and 1997 was estimated to be about 168 and 164 eggs respectively. (FAPRI Staff Report – 1995)

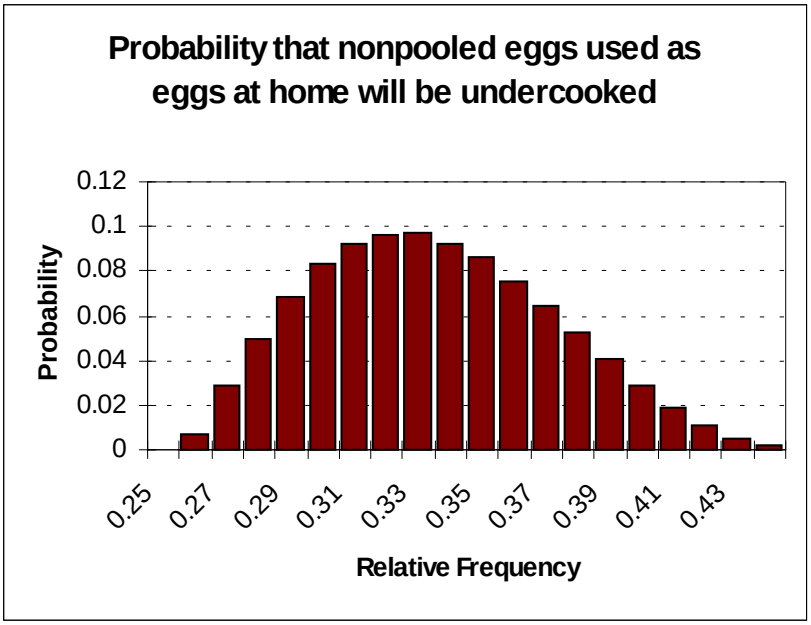
b. Mean value of distribution – 33%

It is assumed that the same percentage of these non-pooled eggs will be undercooked as was calculated for pooled eggs in a home setting in variable number 13.

c. Distribution – Pert(26%,33%,46%)

It is assumed the same distribution for these eggs as was calculated for pooled eggs in a home setting in variable number 13.

Figure D-23



24. Probability that non-pooled egg used as ingredient in a home setting will be uncooked

a. Evidence –

FDA Food Safety Survey from December 1992 through February 1993 (1,620 respondents) showed that 879 (53%) ate foods containing raw eggs at some time, 700 (44%) did not, and 41 (3%) were not sure. (Klontz et al., 1995). Menu Census Survey (1992-1995) showed that the average frequency of raw egg consumption was 0.43 consumption events per year. (Lin et al., 1997; Market Research Corporation of America, 1995.)

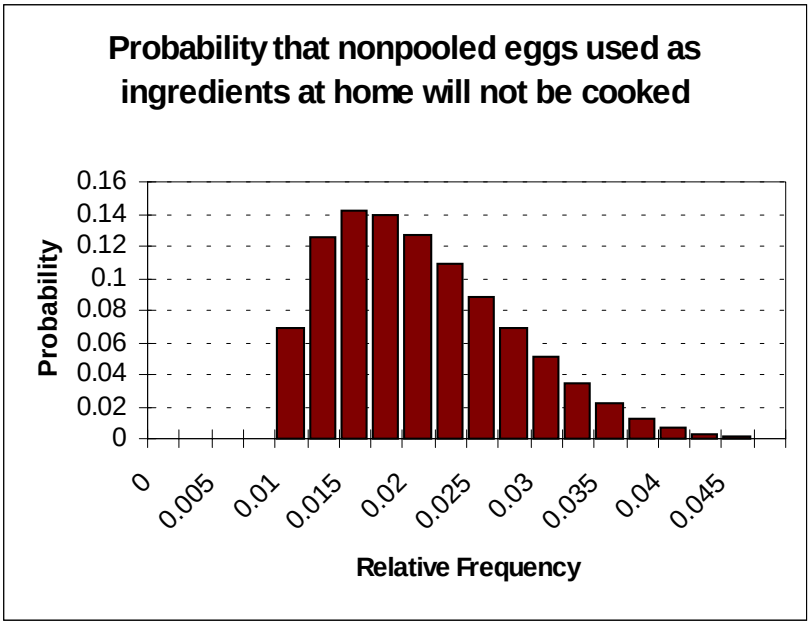
b. Mean value of distribution – 1.7%

It is assumed that 70% of home use non-pooled eggs are used as ingredients. This value had a distribution ranging uniformly from 50 to 90%. Thus 10-50% of home use non-pooled eggs would be used as ingredients. About 50 eggs (166 eggs per capita –116 eggs consumed as eggs) per capita would be used as ingredients. Assume an average of two eggs per use as ingredients. Thus 0.43 consumption events becomes 0.86 raw egg consumption events. 0.86 eggs / 50 eggs = 1.7%

c. Distribution – Pert(1%,1.7%,5.1%)

The minimum and maximum of the distribution are obtained by assuming that respectively 50% and 10% of the home use non-pooled eggs are used as eggs.

Figure D-24



25. Number of servings in a home setting when eggs are used as an ingredient

a. Evidence –

Recipes from a single computerized recipe program (Recipe Wizard) were examined. Of 552 recipes, 129 contained eggs. The number of servings in each of the egg containing recipes were tabulated.

Table D-2. Recipes Containing Eggs

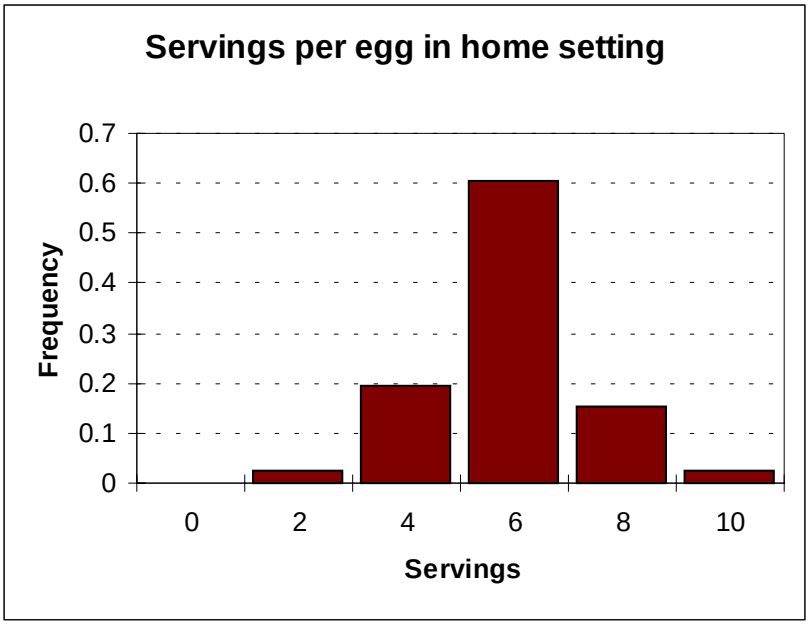
Number of Servings	Number of Recipes	Percent of Recipes
2	3	2.33%
4	25	19.38%
6	78	60.47%
8	19	14.73%
9	1	0.78%
10	3	2.33%
Total	129	100.00%

b. Mean value of distribution – 6 servings

c. Distribution –

Discrete({2,4,6,8,9,10},{0.02,0.19,0.61,0.15,0.01,0.02})

Figure D-25



26. Percent of nonpooled institutional eggs used as eggs

a. Evidence –

Personal experience

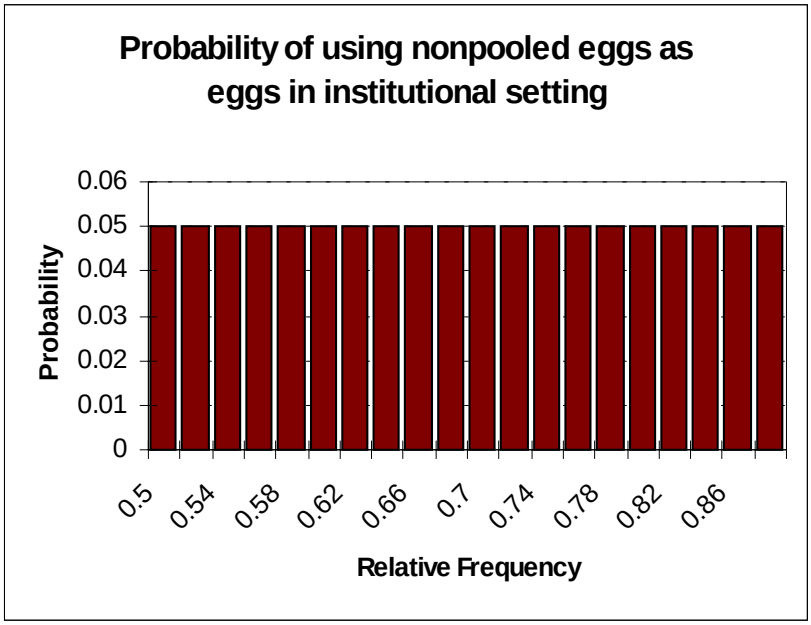
b. Mean value of distribution – 70%

It is assumed that most nonpooled eggs used in an institutional setting are consumed as eggs.

c. Distribution – Uniform(50%,90%)

The wide uniform distribution from 50 to 90% reflects the uncertainty of the probability of using nonpooled eggs as eggs.

Figure D-26



27. Probability that a non-pooled egg used as egg will be undercooked in an institutional setting

a. Evidence –

The 1996-1997 Food Consumption and Preparation Diary (FCPD) Survey shows that 27% of all egg dishes consumed were undercooked (described as being runny or having either a runny yolk or runny white). On average, each person consumed undercooked eggs 19 times a year. (Lin et al., 1997).

Per capita table egg consumption for 1996 and 1997 was estimated to be about 168 and 164 eggs respectively. (FAPRI Staff Report – 1995)

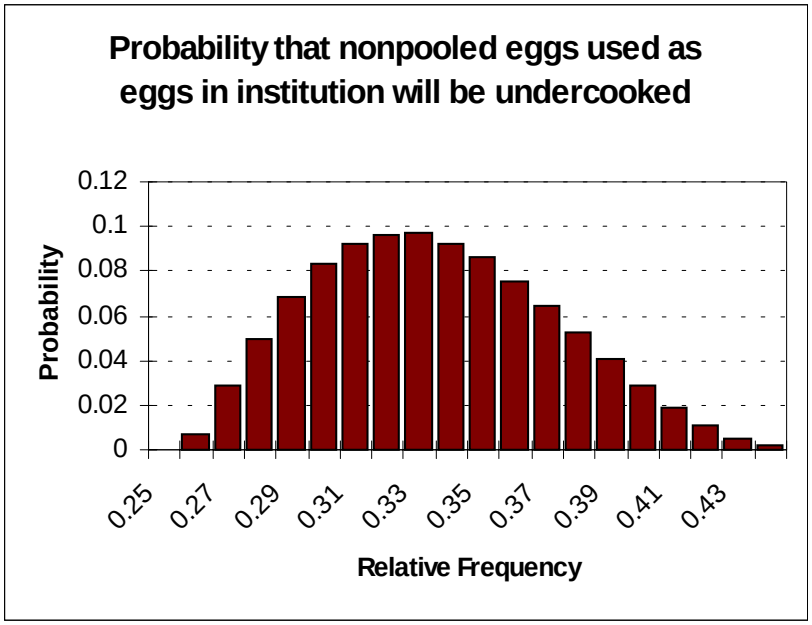
b. Mean value of distribution – 33%

It is assumed that the same percentage of these non-pooled eggs will be undercooked as we calculated for pooled eggs in a home setting in variable number 13.

c. Distribution – Pert(26%,33%,46%)

Assume the same distribution for these eggs as was calculated for pooled eggs in a home setting in variable number 13.

Figure D-27



28. Probability that nonpooled egg used as ingredient will not be cooked in an institutional setting

a. Evidence –

FDA Food Safety Survey from December 1992 through February 1993 (1,620 respondents) showed that 879 (53%) ate foods containing raw eggs at some time, 700 (44%) did not, and 41 (3%) were not sure. (Klontz et al., 1995).

Menu Census Survey (1992-1995) showed that the average frequency of raw egg consumption was 0.43 consumption events per year. (Lin et al., 1997; Market Research Corporation of America, 1995).

Personal experience

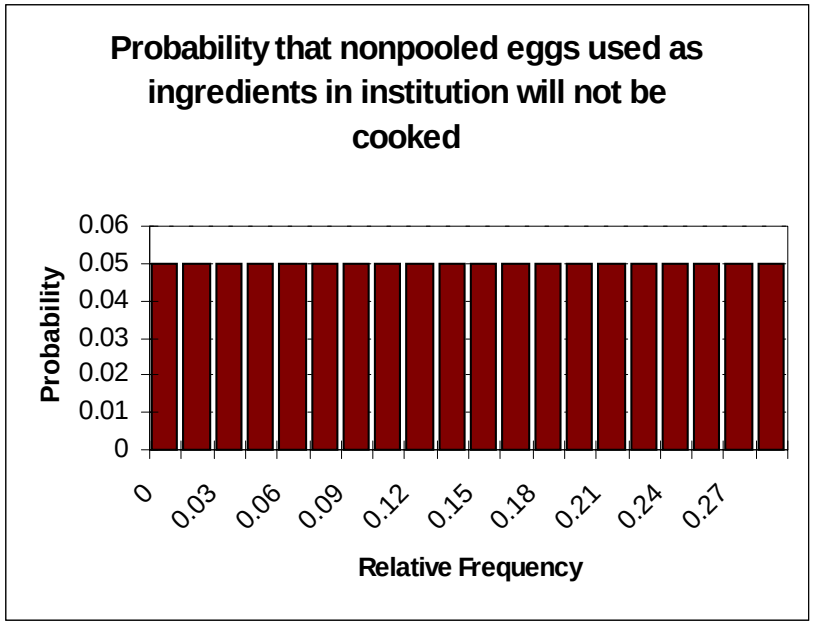
b. Mean value of distribution – 15%

This variable was set higher than other variables of the same type with the same evidence. There is more uncertainty regarding the true number of eggs used as ingredients in institutions that do not get cooked.

c. Distribution – Uniform(0,30)

This variable also has a much wider distribution than other similar variables in this module.

Figure D-28



29. Number of servings when eggs are used as ingredients in an institutional setting

    a. Evidence –

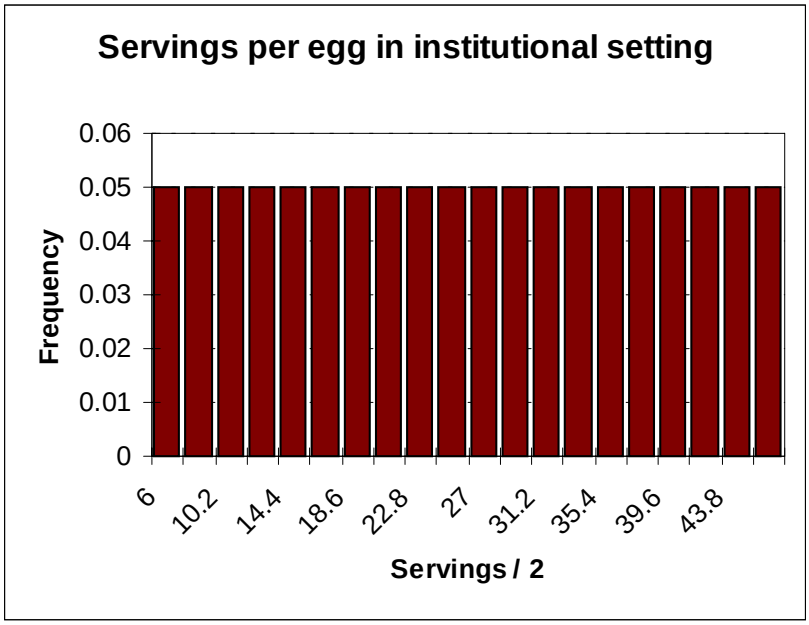
       Personal experience

    b. Mean value of distribution – 54

    c. Distribution – 2*ROUND(Uniform(6,48),0)

       Assume that the number of servings in an institutional setting will range from 12 to 96.

Figure D-29



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Bacterial Death Variables

30. Bacterial death in thoroughly cooked eggs served as eggs

a. Evidence –

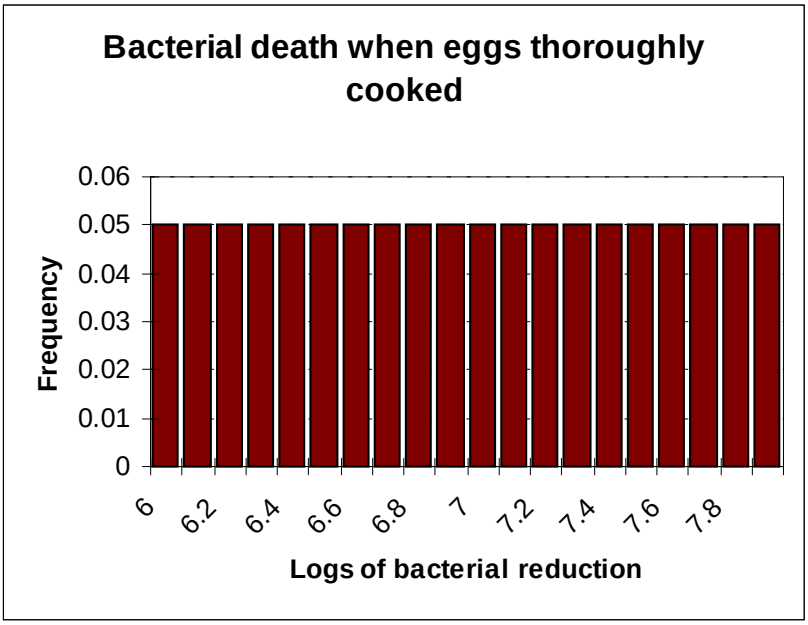
Humphrey (1989) reported that in eggs where the number of cells exceeded 10^8 per gram of yolk, viable cells could be recovered from eggs cooked in any manner

b. Mean value of distribution – 7 logs

Assume that thorough cooking provides about a 7 log decrease in bacterial numbers.

c. Distribution – Uniform(6,8)

Figure D-30



31. Bacterial death in undercooked eggs

a. Evidence –

Table D-3. Thermal Death Rates for *Salmonella Enteritidis*

(Humphrey et al., 1989)

Method of Cooking	Cooking Time (minutes - minimum)	Mean Inoculum (log cfu/gm yolk)	Mean number of survivors (cfu/gm yolk)	Mean yolk temperature post cooking (Centigrade)
Boiling[1]	4	6.81	5.87	54.6
Frying sunny side up[2]	1.6	6.90	5.14	55.2
Frying over easy[2]	2.4	6.88	--	67.7
Scrambled[3]	1.2	6.09	--	82.8
	3.1	5.9	--	73.9

[1] Includes S. Enteritidis PT4 and S. Typhimurium PT110 and PT141 results.
[2] Eggs fried in vegetable oil at approximately 120° C until white appeared solid and opaque. Sunny side up eggs were cooked approximately 1.5 to 2 minutes. Over easy eggs were cooked for up to 1 minute longer.
[3] Includes S. Enteritidis PT4, PT8 and PT13a, and S. Typhimurium PT110 and PT141.

The 1996-1997 Food Consumption and Preparation Diary (FCPD) Survey shows that 27% of all egg dishes consumed were undercooked (described as being runny or having either a runny yolk or runny white). Undercooked preparation of eggs was primarily in the fried egg category (49%) but other styles were sometimes undercooked as well, including scrambled eggs and omelettes (29%), poached eggs (13%), soft boiled eggs (7%) and hard boiled eggs (2%) (Lin et al., 1997).

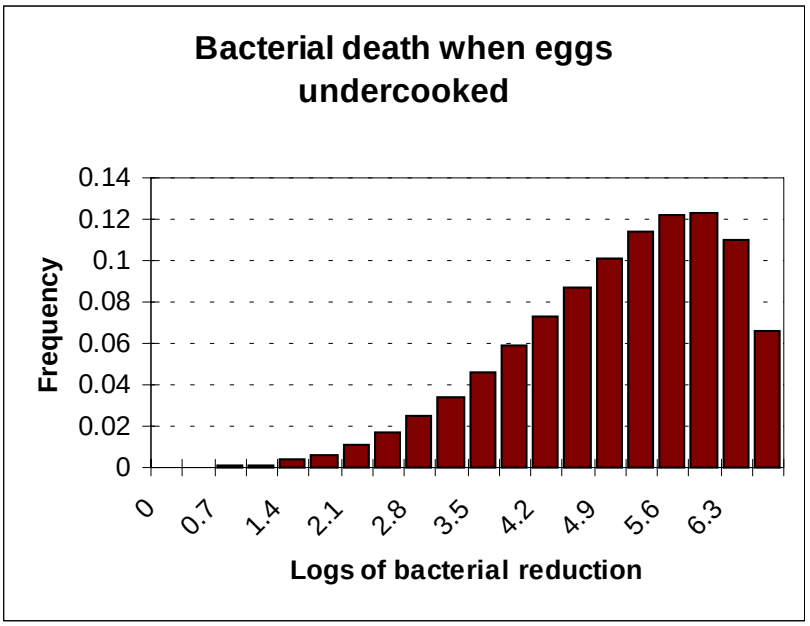
b. Mean value of distribution – 3.8 logs

c. Distribution –

Discrete({Pert(0,1,7),Pert(0,4,7),Pert(0,6,7)},{.22,.49,.29})

The log reductions for boiling, frying, and scrambling are set to vary from 0 to 7. Boiled eggs (poached eggs, soft boiled eggs, hard boiled eggs) account for 22% of the total undercooked eggs. The most likely value for undercooked boiled eggs is set at 1 which is consistent with Humphrey's observations with eggs boiled for four minutes. Fried eggs account for 49% of the total. The most likely value is set at 4 which is the average of the log reductions observed for frying over easy and sunny side up. Scrambled eggs account for 29% of the total.

Figure D-31



32. Bacterial death when eggs are used as ingredients

a. Evidence –

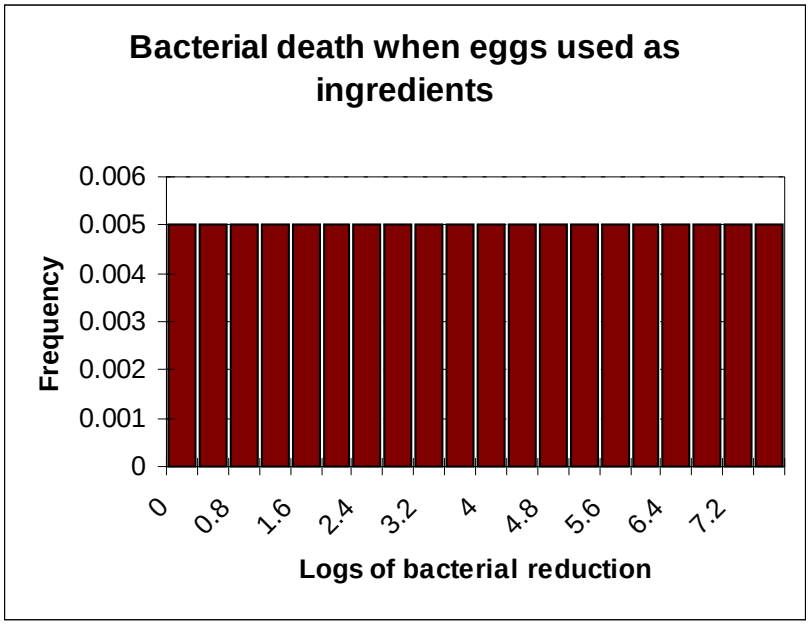
Personal experience

b. Mean value of distribution – 4 logs

c. Distribution – Uniform(0,8)

Assume that when eggs are used as ingredients the final products are subjected to a wide range of cooking temperatures and times. Assumed in this distribution that anywhere from very few to almost all bacteria will be killed as a result of cooking.

Figure D-32



Post Cooking Storage Time and Temperature Variables

33. Post cooking storage temperature for cooked eggs and egg products in the home and in institutions

    a. Evidence –

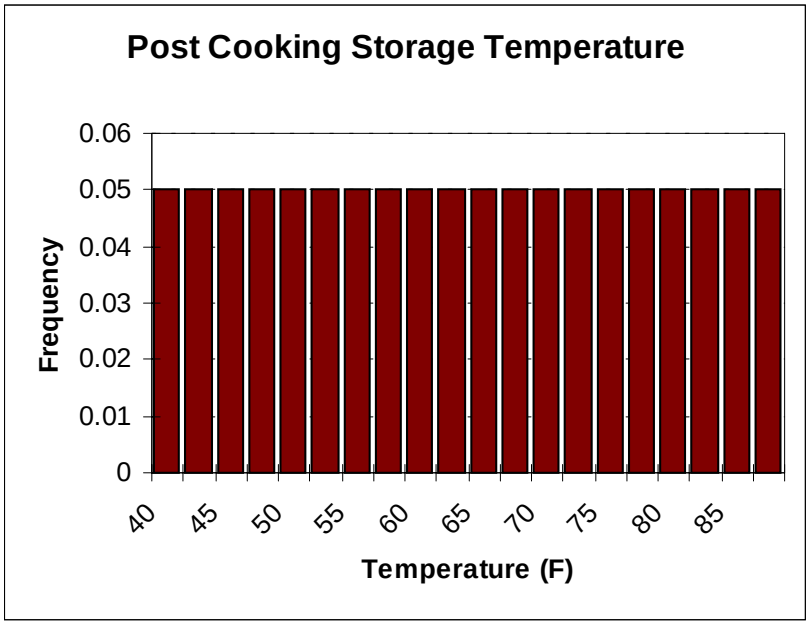
       Personal experience

    b. Mean value of distribution – 65° F.

    c. Distribution – Uniform(40,90)

       Assume that these products may or may not be refrigerated after cooking and stored at temperatures ranging from 40° to 90° F.

Figure D-33



34. Post cooking storage time for cooked eggs in the home

a. Evidence –

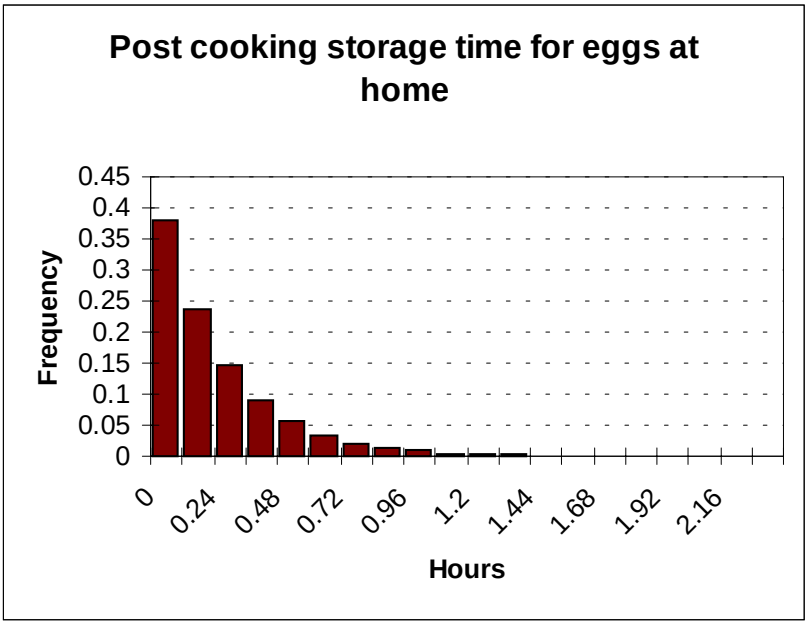
Personal experience

b. Mean value of distribution – 15 minutes

c. Distribution – Exponential(0.25 hours)

Assume that most home cooked eggs will be consumed very shortly after cooking.

Figure D-34



35. Post cooking storage time for home cooked egg containing products

a. Evidence –

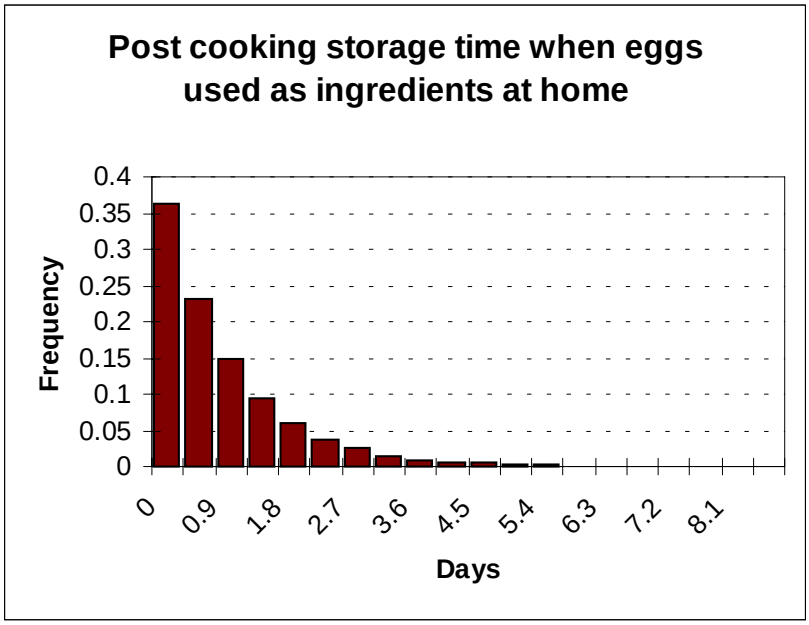
Personal experience

b. Mean value of distribution – 1 day

c. Distribution – Exponential(1 day)

Assume that most home cooked products containing eggs will be consumed very shortly after cooking.

Figure D-35



36. Post cooking storage time for cooked eggs in an institution

a. Evidence –

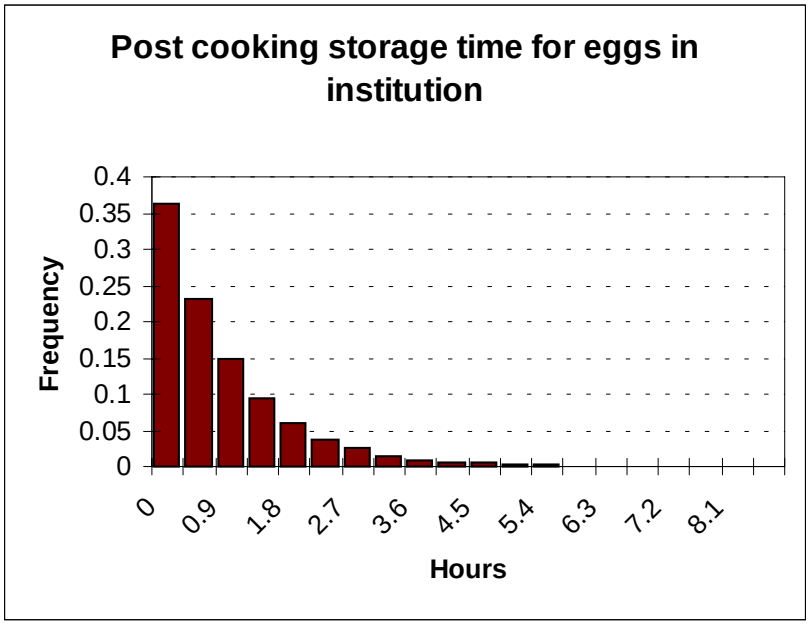
Personal experience

b. Mean value of distribution – 1 hour

c. Distribution – Exponential(1 hour)

Assume that most institutional eggs will be consumed very shortly after cooking (within 45 minutes) but that, on average, they will be stored longer than eggs cooked in the home.

Figure D-36



37. Post cooking storage time for institutional cooked egg containing products

a. Evidence –

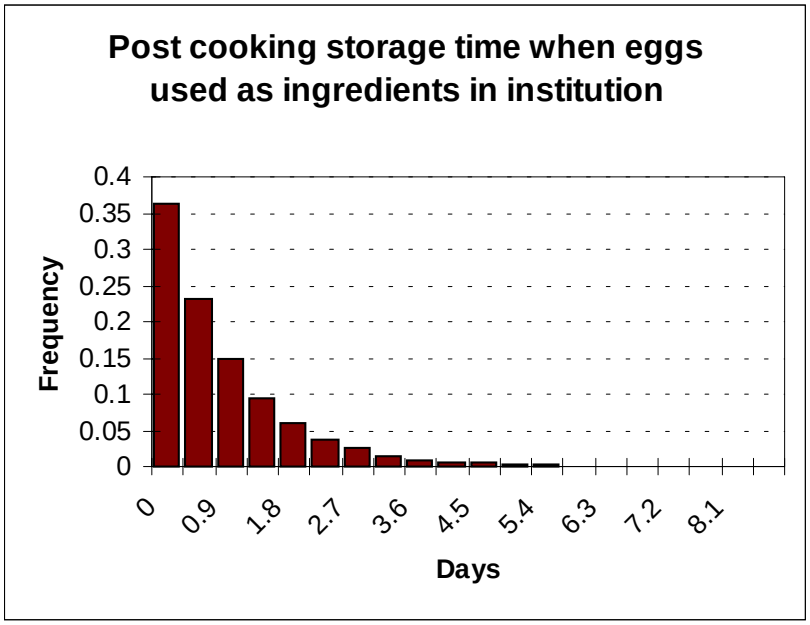
Personal experience

b. Mean value of distribution – 1 day

c. Distribution – Exponential(1 day)

The assumption is made that most products containing eggs and cooked in an institution will be consumed very shortly after cooking.

Figure D-37



D. Results

The Preparation and Consumption Module was simulated using Latin Hypercube sampling in @Risk® for Excel®. Although the module results feed directly into the public health output calculations some conclusions can be drawn from the model output.

Most servings prepared with SE positive eggs have no SE in them at consumption. Of the mean 10.1 million servings prepared with positive eggs, 76% have no SE bacteria in them at consumption.

Most eggs (70%) end up in only one serving. Nevertheless, some eggs are used to make products that serve more than one person. In institutional feeding one egg may end up in a product that feeds one hundred or more people. This both dilutes the number of bacteria per serving and increases the number of people exposed. The mean number of servings was 4.4. This means that each contaminated egg could potentially expose an average of four people.

E. Sensitivity analysis

Due to the structure of this module sensitivity analysis was not performed directly on the module inputs. These outputs feed directly into the public health calculations. Thus the sensitivity of the inputs is proxied by calculating mitigation elasticities with model outputs for variables of interest.

F. References

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Public Health Outcomes Module

A. Summary of the Public Health Outcomes Module

The Public Health Outcomes Module links the exposure to SE in shell eggs and egg products with the adverse health outcomes of morbidity and mortality which may arise from the ingestion of SE bacteria (Fig. E-1). These health outcomes include infection without illness, infection with illness, and the consequences of illness which may include physician visits, medical treatment, hospitalization, post-infection sequelae, and death. The outcome from a single exposure to SE from shell eggs or egg products for the individual varies widely and is a function of the individual's age, health status, immune status, the number of SE bacteria consumed, the fat content of the food vehicle, and other factors such as pregnancy and underlying liver disease or kidney disease. The outcomes of the Public Health Outcomes Module are the primary measure of the public health consequences of exposure to SE from shell eggs and egg products. This module may be used as the primary indicator of the public health benefits of specific risk mitigations introduced into other modules within the SE Risk Assessment Model.

The subsequent sections discuss the following elements of the module:

module structure

distributions used to specify module parameters

module outputs for a specific number of persons exposed to a specific dose

sensitivity analysis to determine the parameters which most influence the module outputs and limitations of the Public Health Outcomes Module.

Public Health Outcomes Module

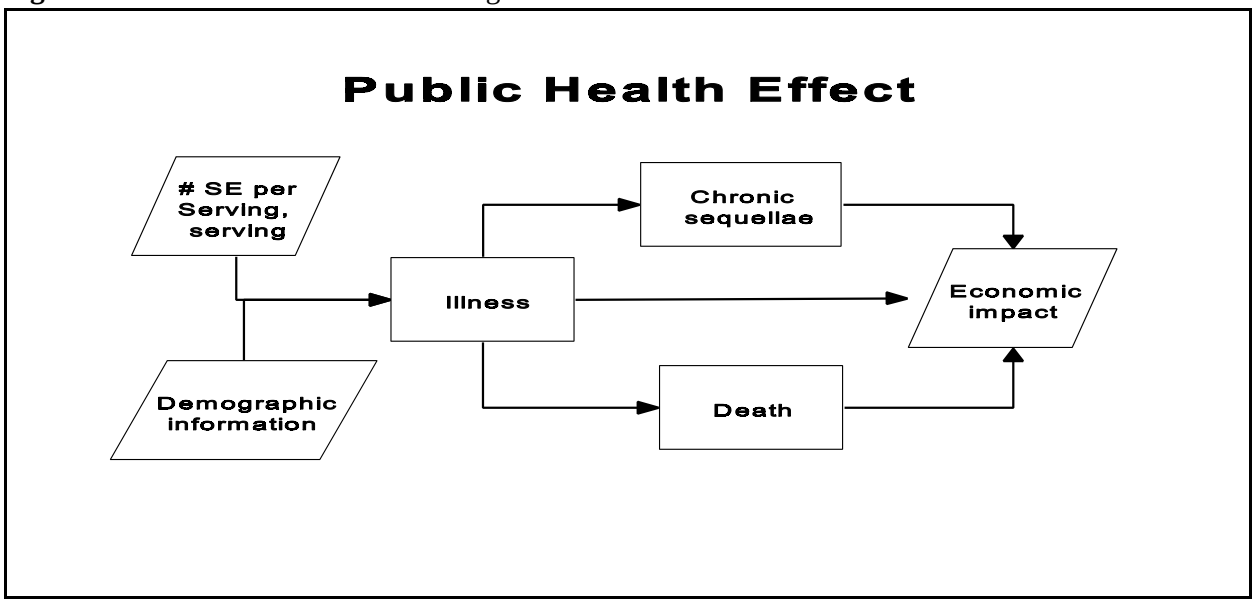
1. **Overall Structure of the Public Health Outcomes Module and the Relationship of the Public Health Outcomes Module to SE Risk Assessment Model**

   In the context of the entire SE risk assessment model, the Public Health Outcomes Module receives inputs from the Preparation and Consumption Module. Thus the Public Health Outcomes Module indirectly incorporates inputs from all other preceding modules (see figure above and Fig. E-1). The public health impacts of exposure to SE through shell eggs and egg products are computed in terms of numbers of illnesses and specific case outcomes on an annual basis. The relative worth of specific risk mitigation efforts to reduce exposure to SE in shell eggs and egg products is measured in terms of the outputs of the Public Health Outcomes Module. Although morbidity and mortality have measurable economic impacts, the economic costs of illness and the economic costs and benefits of mitigation activities are not included in this module.

2. **Basic Module Flow**

   This section contains a brief, non-mathematical description of the Public Health Outcomes Module, and the specific inputs to the module, and the specific outputs produced by the module. A more detailed and mathematical presentation of the module, and the distributions of the input and output variables, and the specific details of the modeling algorithms are found in the sections which follow.

Figure E-1 Flow of Data Into and Through the Public Health Outcomes Module



Public Health Outcomes Module

A more detailed diagram of the structure of the Public Health Outcomes Module is shown in Fig. E-2. Fig. E-2 illustrates the basic form of the Public Health Outcomes Module and its outputs. The flow of data in the module and the information generated by the Public Health Outcomes Module are as follows:

a. A given number of people are each exposed to a specific dose of SE bacteria.

b. The population of people exposed to SE is partitioned into two sub-populations. One sub-population is assumed to be in good health and is referred to as a 'normal sub-population' in order to reflect the level of risk for disease from SE in shell eggs and egg products which is usually seen in the general population. The second sub-population is referred to as the 'susceptible sub-population'. The susceptible sub-population is composed of persons who are at increased risk of illness from SE in shell eggs and egg products. This susceptible sub-population includes the elderly, newborn infants, persons with immunodeficiency from treatment for cancer, pregnant women, persons with chronic illness (e.g. diabetes or rheumatoid arthritis), and persons with HIV infections and AIDS. For the purposes of this module, the assumption is made that both sub-populations have the same food consumption patterns. However, it is recognized that some sub-populations (not defined here) may consume foods which utilize raw or undercooked eggs.

c. For each sub-population, the probability of an individual person within a sub-population becoming ill from exposure to a specified dose of SE from shell eggs and egg products is calculated using a stochastic dose-response function that incorporates the uncertainty in parameters of the dose-response function.

d. From the number of persons exposed and the computed probability of becoming ill from exposure to a specified dose of SE from shell eggs and egg products, the distribution of the number of persons becoming ill in each sub-population (normal and susceptible) is computed. It should be noted that not every person exposed to the dose of SE becomes ill. The ill persons in each sub-population are then partitioned into four mutually exclusive groups based on clinical outcomes after exposure to the SE and the development of illness. The mutually exclusive clinical outcomes are:

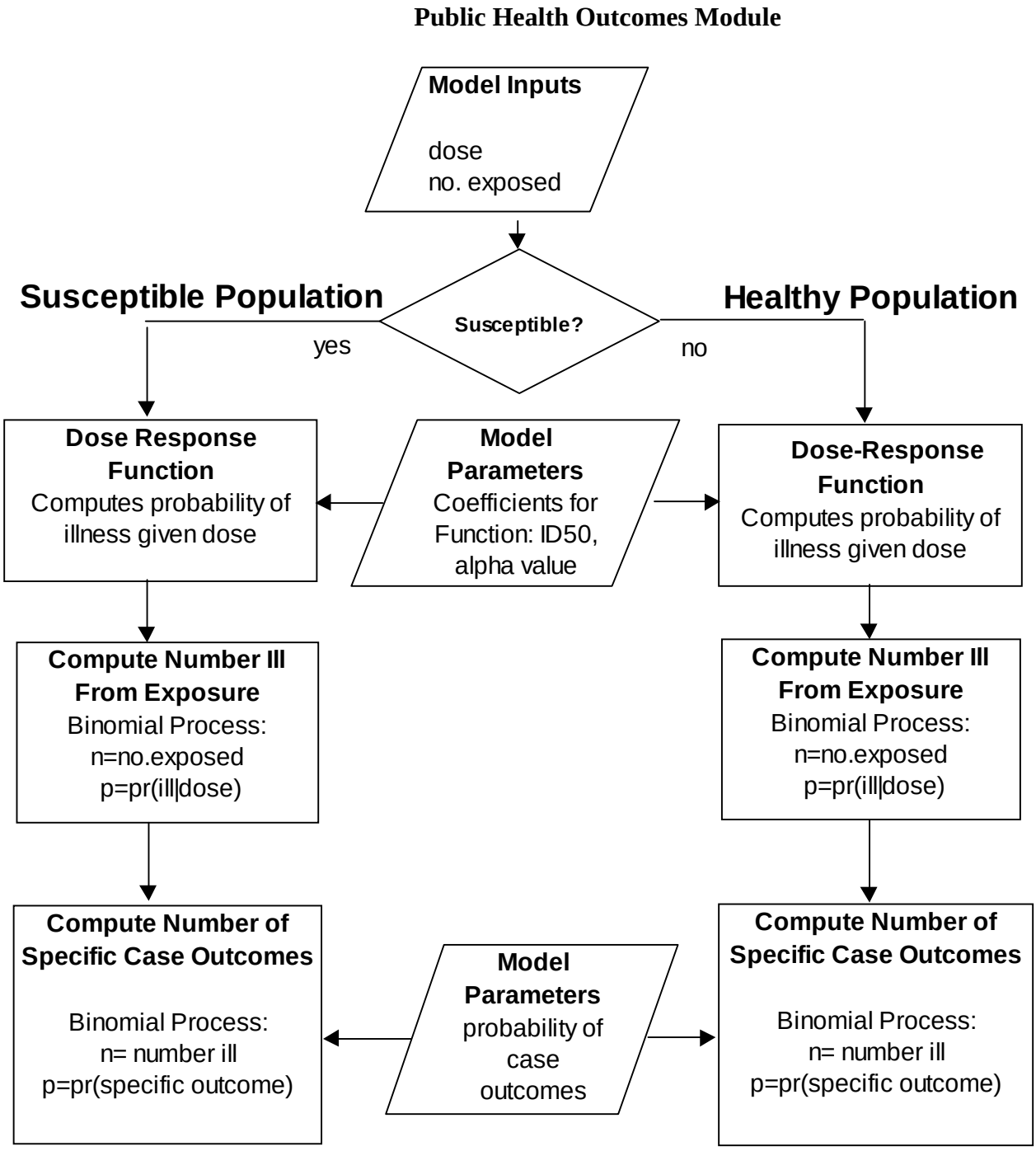
   (1) Recovery from illness with no medical treatment

   (2) Treatment by a physician with recovery from illness

   (3) Hospitalization and subsequent recovery from illness

   (4) Death from infection with SE from shell eggs and egg products

   (5) Development of long-term sequelae such as reactive arthritis after the SE infection.



B. Inputs, Parameters, and Variables for the Public Health Outcomes Module

1. Definitions: Each of the parameters used in the Public Health Outcomes Module has a distribution of possible outcomes. The Public Health Outcomes Module contains four distinct types of data: inputs, explicit parameters, implicit parameters, and state variables. Each of these four distinct types of data are defined below.

a. Inputs: Input values to the Public Health Outcomes Module are variables created in the Preparation and Consumption Module. These inputs are exogenous to the Public Health Outcomes Module and are not subject to modification within the Public Health Outcomes Module.

b. Explicit parameters: Explicit parameters are explicitly described as scalars or random variables within the Public Health Outcomes Module. Changes in the inputs to the Public Health Outcomes Module or to the structure of the Public Health Outcomes Module do not change the value of an explicit parameter. An example of an explicit parameter is the probability of visiting a physician given a person is ill.

c. Implicit parameters: Implicit parameters are derived solely from the explicit parameters and are not influenced by the inputs to the Public Health Outcomes Module or the structure of the Public Health Outcomes Module. Implicit parameters function in the same way as explicit parameters and are derived by an algebraic combination of explicit parameters instead of being explicitly specified as scalars or distributions. In the Public Health Outcomes Module, the implicit parameters are used to specify rate variables which describe the probability or rate of persons in one state of health moving into another state of health. An example of an implicit parameter is the probability of not visiting a physician given that a person is ill.

d. Output Variables and State Variables: The term ‘state variable’ refers to variables which describe the various states of health in which an ill person can be found, including temporary states such as “ill”. The output variables, which the Public Health Outcomes Module tracks, are state variables which describe permanent states of health, e.g., recover without medical treatment. Output variables and state variables are derived by an algebraic combination of inputs to the module, explicit parameters, and implicit parameters.

The specific module inputs, explicit parameters, implicit parameters, and output variables are described in the following section.

2. Input Variables From The Preparation & Consumption Module

a. Dose: The Preparation and Consumption Module (which takes inputs from other preceding modules in the SE Risk Assessment Model) provides the input variable of dose in the form of the number of viable and infectious SE bacteria that are present after food preparation activities. The entire dose of SE bacteria is assumed to be ingested by every member of the exposed population.

b. Number of persons exposed: The Preparation and Consumption Module provides the number of persons who are each exposed to the specified dose.

c. A total of 60 pairs of ‘dose-number exposed’ are given as input to the Public

Health Outcomes Module from the Preparation and Consumption Module in order to fully represent the full range of doses to which the population is exposed. For example, the Preparation and Consumption Module may say that the range of the dose to which the population is exposed is between 10 SE bacteria and 1000 SE bacteria. Not everyone will receive 10 SE bacteria and not everyone will receive 1000 SE bacteria. There will be a certain number of persons in the exposed population who will receive a specific dose. It is this pairing of 'dose' and 'number exposed' which is given as input to the Public Health Outcomes Module, and there are 60 of these 'dose-number exposed' pairs which are given to the Public Health Outcomes Module in order to determine the number ill persons and the types of illnesses based on the input from the Preparation and Consumption Module.

3. Explicit Parameters

Although the Public Health Outcomes Module includes many implicit parameters and other variables, there are only ten explicit parameters. These ten explicit parameters and the inputs from the Preparation and Consumption Module drive the Public Health Outcomes Module. The evidence and specifications of the ten explicit parameters are covered in the section titled "D. Parameters in the Public Health Outcomes Module: Evidence and Specification". Table E-1 contains a summary of the explicit parameters and the implicit parameters and the derivation of the implicit parameters. The ten explicit parameters are described below.

a. The first explicit parameter is the probability of a person being in a sub-population which is more susceptible to illness from exposure to SE from shell eggs and egg products.

b. The probability of becoming ill after ingesting a specific dose of SE bacteria is also an explicit parameter which is calculated for each sub-population so that two explicit parameters are produced. These two explicit parameters are calculated from a dose-response function which is further described in the section titled: "E. Probability of Infection: Microbial Dose-Response Modeling".

c. Six conditional probabilities describing three clinical outcomes of illness for each of the two sub-populations (specified separately for the normal sub-population and for the susceptible sub-populations, thus totaling six parameters). These conditional probabilities are

(1) The probability of seeing a physician given the person is ill, denoted by the expression: Pr(physician visit | ill);

(2) The probability a person is hospitalized given they are being treated by a physician, denoted by the expression:
Pr(hospitalized | treated by physician).

(3) The probability a hospitalized person dies, denoted by the expression: Pr(death | hospitalized).

d. The last explicit parameter is the probability of developing a sequela of an infection with SE after recovering from the initial illness due to SE from shell eggs and egg products. In this module, the probability of developing reactive arthritis is the only post-illness sequela which is modeled.

4. Implicit Parameters

Several parameters of the Public Health Outcomes Module are not specified directly, (i.e. explicitly) but are derived from the explicit parameters. These implicit parameters are (see also Table E-1):

a. Probability that a person exposed to SE from shell eggs and egg products is in the normal sub-population with respect to susceptibility to pathogens.

b. Probability of final clinical outcomes of illness which are conditioned on a person being ill after ingesting a specific dose of SE bacteria. This probability is derived separately for susceptible sub-populations and for normal sub-populations.

c. Probabilities of recovery from the various clinical outcomes of gastroenteritis due to SE are not entered as parameters; they are derived from three implicit parameters, which are the three conditional probabilities listed:

Pr(physician visit | ill)

Pr(hospitalized | treated by physician)

Pr(death | hospitalized).

Table E-1. Explicit and Implicit Parameters in Public Health Outcomes Module [1,2]

Explicit Parameter	Implicit Parameter	Derivation of Implicit Parameter
Pr(susceptible)	Pr(normal)	1 - Pr(susceptible)
Pr(physician visit|ill)	Pr(recover without medical treatment)	1 - Pr(physician visit|ill)
Pr(hospitalized|physician visit)	Pr(recover without being hospitalized|physician visit) [3]	1 - Pr(hospitalized|physician visit)
Pr(death|hospitalized)	Pr(recover|hospitalized)	1 - Pr(death|hospitalized)
Pr(reactive arthritis|ill)		
ID_n :Public Health Outcomes parameter for normal sub-population	ID_s :dose parameter for susceptible sub-population	$ID_n \div 10$
	Pr(see physician and recover without hospitalization)	Pr(physician visit|ill) × {1-Pr(hospitalize |physician visit)}
	Pr(see physician, are hospitalized, recover)	Pr(physician visit|ill) × Pr(hospitalized|physician visit) × {1 - Pr(death|hospitalized)}
	Pr(death)	Pr(visit physician|ill × Pr(hospitalized|physician visit) × Pr(death|hospitalized)

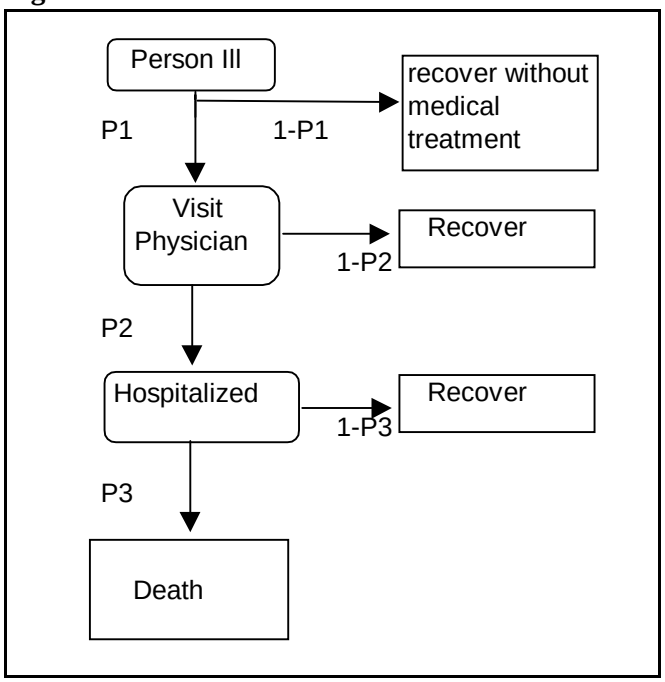
[1] All parameters are specified separately for susceptible and normal sub-populations except for pr(reactive arthritis).

[2] Derivation of implicit probabilities of clinical outcomes is contained in Module Parameters section of text. All conditional and unconditional probabilities of clinical outcomes are for ill persons.

[3] Persons who are treated by a physician and recover without being hospitalized.

Fig. E-3 shows the relationship between the explicit parameters associated with illness, visiting a physician, and the implicit parameters associated with recovery without treatment, recovery after physician visit, recovery after being hospitalized.

Figure E-3. Outcomes of Illness



With the conditional probabilities:[1]

P1 = Pr(physician visit | ill)

P2 = Pr(hospitalized | physician visit)

P3 = Pr(death|hospitalized) and their compliments

1-P1 = Pr(recover without medical treatment)

1-P2 = Pr(recover without being hospitalized | treated by physician)

1-P3 = Pr(recover | hospitalized).

The implicit parameters are derived from and are consistent with the probability axioms:

(1) for a Bernoulli random variable without outcomes A and Å, where Å equals "not A", Pr(Å) = 1 - Pr(A)

(2) for events A and B, probability of both A and B occurring = $Pr(A \cap B) = Pr(A)Pr(B|A)$

(3) for independent events A, B, and C, probability of A, B, and C occurring = $Pr(A \cap B \cap C) = Pr(A)Pr(B)Pr(c)$.

The probabilities of the final outcomes are computed as follows:

(1) Pr(recover without medical treatment) = 1-P1

[1] Notation: Pr(A) is read as "the probability of A occurring"; Pr(A|B) is read as "the probability of A occurring given B occurs or has occurred".

(2) Pr(physician visit and recover) =
Pr(physician visit|ill) * Pr(recover without being hospitalized|physician visit) =
P1 * (1-P2)

(3) Pr(hospitalized and recover) =
Pr(physician visit|ill)*Pr(hospitalized|physician visit)*Pr(recover|hospitalized) =
P1 * P2 * (1-P3)

(4) Pr(death) =
Pr(physician visit|ill) * Pr(hospitalized|physician visit) * Pr(death|hospitalized) =
P1 * P2 * P3

The specific case outcomes are mutually exclusive. For example, those persons who were hospitalized are assumed to have seen a physician prior to being hospitalized and are included in the group who saw a physician and were hospitalized; they are not included in the group who saw a physician and were not hospitalized. The values of the implicit parameters and the explicit parameters are estimated separately for the susceptible sub-population and for the normal sub-population.

5. Module Outputs

In the Public Health Outcomes Module the following outputs are estimated for both the susceptible sub-population and the normal sub-population and are separately presented as totals for the susceptible sub-population and for the normal sub-population as well as for the entire U.S. population. These outputs are for all cases and outcomes for the time period of one year.

a. Number exposed

b. Number ill

c. Number with specific clinical outcomes:

(1) Recover with no treatment

(2) Are treated by a physician and recover without being hospitalized;

(3) Are hospitalized and recover;

(4) Are hospitalized and die;

(5) Develop reactive arthritis after recovering from SE infection.

d. Indicators of case-fatality rates:

(1) Proportion of those ill who die (number deaths/number ill)

(2) Deaths per 100,000 persons ill.

The outputs of the Public Health Outcomes Module include the uncertainty contained in all related variables in both the Public Health Outcomes Module as well as all previous modules. The outcomes are expressed as probability distributions rather than constants. In addition to specific summary statistics for each outcome variable (mean, minimum, maximum, and 90% confidence limits), a frequency distribution for each output is presented in graphic form in the section titled "D. Parameters in the Public Health Outcomes Module: Evidence and Specification".

6. Modeling Conventions

The probability distributions of specific outcomes are used to compute the numbers of persons with each outcome based on the number of people who become ill. Thus the initial case-outcome probability statement, Pr(physician visit| ill), is consistent with the corresponding state variable, the number of people ill from exposure to the specified dose of SE, in that only those who become ill from a specific dose of SE are considered in the group for whom there is a probability distribution of being seen by a physician.

The numbers of persons with each of the four mutually exclusive outcomes shown above are modeled as binomial distributions using the normal approximation (normal or Gaussian distribution) for the binomial distribution where the mean and standard deviation parameters of the normal distribution are estimated from the binomial parameters n and p:

mean = np

standard deviation = $(npq)^{½}$ where $q = 1-p$.

In each computation n = number of persons in the appropriate state and p = pr(specific outcome from that state) as derived above. Note that both n and p are distributions which are either specified as implicit parameters or are derived as implicit parameters or are derived as parameters of functions or other state variables. Thus the resulting distributions, which are normal distributions with mean = np and std. dev. = $(npq)^{½}$ **,** will not necessarily appear to be normally distributed despite the fact that the resulting distributions are specified as normal distributions in the module. As will be seen in the section titled "F. Outputs of the Public Health Outcomes Module", most state or output variables are log-normally distributed, and this is expected because the distributions of the outputs are derived as <u>products</u> of other distributions.

C. Parameters in the Public Health Outcomes Module: Variables

This section examines in detail the parameters specific to the Public Health Outcomes Module. The paired input distributions of 'dose - number exposed' which are produced by the Preparation and Consumption Module are described in the section of this report titled "Preparation and Consumption Module". The role of the parameters described here can be visualized in Fig. E-2 - Flow Chart of the Public Health Outcomes Module and in Fig E-3. - Outcomes of Illness.

Explicit Parameters

1. **Proportion Susceptible - the proportion of the population which is more susceptible to illness.**

   a. Evidence

   The susceptibility to infection and disease from exposure to any pathogen depends on a complex interaction between the host and the pathogen. Certain sub-populations have been identified which are more susceptible to *Salmonella* as well as other infectious than the general population. A partial list of persons with increased susceptibility to infectious agents includes pregnant women, infants, the elderly, immunocompromised persons (including persons with diabetes, those infected with HIV, inter alia), persons with chronic diseases, nursing home residents, cancer patients, and organ transplant recipients. This group now constitutes nearly 10% of the U.S. population (CAST, 1994.) Recent analysis, which includes more categories of susceptible persons, suggests that the sub-population in the USA which has an increased susceptibility to infections accounts for 20% of the total population (Gerba et al., 1996).

   The elderly are particularly susceptible to infectious agents such as SE for a number of reasons. The disproportionate impact of severe complications and death from salmonellosis in the elderly is illustrated by the epidemiologic evidence:

   (1) 62% of deaths from diarrheal diseases are accounted for by persons over the age of 74 (Lew et al., 1991);

   (2) The case-fatality rate in *Salmonella* outbreaks in nursing homes is 40 times the case-fatality rate for the general population (Levine et al., 1991).

   (3) Acid production in the stomach is recognized as a protective mechanism against ingested pathogens such as SE. However, rates of acid production decline with advancing age, and this places the elderly at further risk.

   There is increasing awareness that the use of antibiotics within 30 days prior to

exposure to *Salmonella* increases susceptibility to *Salmonella* as an enteric pathogen. Oral administration of streptomycin to mice reduced the infectious dose of SE from 10^6 to 10^1 (Bonhoff et al., 1964).

In addition, those persons taking antacids and H2 blockers appear to be at increased risk of salmonellosis because of reduced stomach acidity. Acid production in the stomach is recognized as a protective mechanism against ingested pathogens such as SE.

The observations and evidence above demonstrate that the dose-response relationship found in the data from the feeding trials of different species of *Salmonella* do not accurately represent the likelihood of susceptible individuals developing disease after exposure to *Salmonella* Enteritidis. The available evidence suggests that these susceptible individuals are 10 to 100 times more susceptible to infection, illness, and death from SE than is the general population.

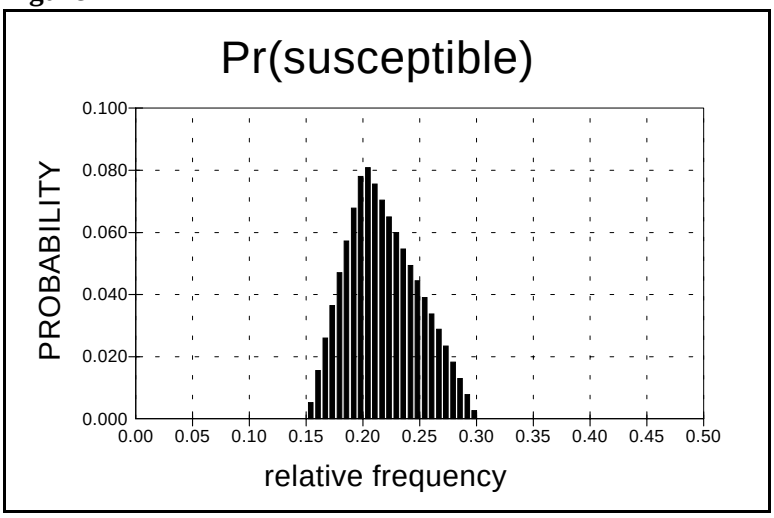
b. Expected Value: 0.22

It is expected that on average, 22% of the population is more susceptible to illness from SE than the normal sub-population.

c. Distribution:[2] Triangular(0.15, 0.20, 0.30)

Mean	0.217
Minimum	0.150
Mode	0.200
Maximum	0.300
$X_{0.05}$	0.184
$X_{0.95}$	0.273

Figure E-4



[2] The distribution for each parameter is described in the syntax of @Risk (the simulation software used to execute this module) in the following general form: DistributionName(parameter 1, parameter 2, etc). For example the triangular distribution has three parameters or arguments, minimum, most likely, and maximum and is specified as "triangular(minimum, most likely, maximum). Statistics include the mean or average value, the mode or most likely value, and the lower and upper 90% confidence limits, the $X_{0.05}$ and $X_{0.95}$ values.

2. Probability Of Physician Visit given Illness, Normal Sub-Population

a. Evidence:

The primary evidence for this parameter comes from the FoodNet active surveillance program carried out by the FDA, USDA, and CDC (CDC, 1997). In the population survey, about 1 in 20 persons who had diarrheal disease reported that they visited a physician for treatment. We used this estimated, 1/20, as the most likely value and estimated minimum and maximum rates by adjusting the numerator by increments of five.

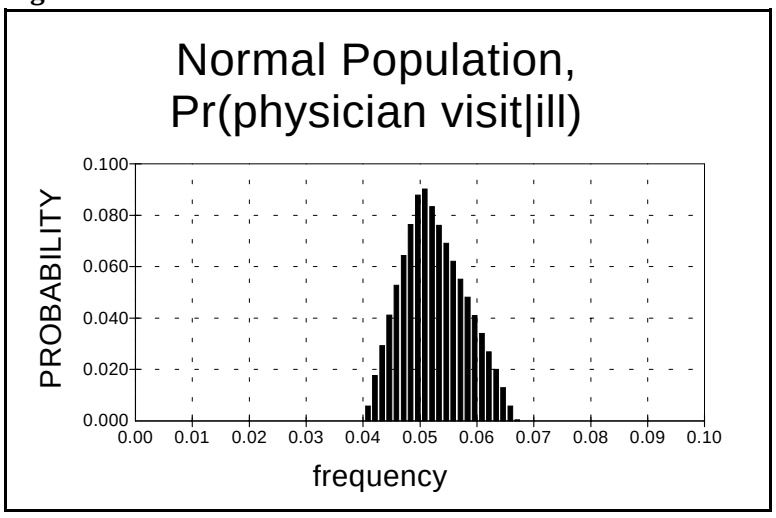
b. Expected Value: 0.0522

It is expected that on average, 522 persons per 10,000 persons in the normal sub-population who become ill from SE will visit a physician.

c. Distribution: Triangular(1/25, 1/20, 1/15)

Mean	0.0522
Minimum	0.0400
Mode	0.0500
Maximum	0.0625
$X_{0.05}$	0.0436
$X_{0.95}$	0.0619

Figure E-5



3. Probability Of Physician Visit Given Illness, Susceptible Sub-Population

a. Evidence:

Clinical and professional experience suggest that susceptible persons are at risk for increased severity and frequency of illness from SE than the normal sub-population, and, therefore, these susceptible persons have a higher probability of seeking medical treatment because of these more severe symptoms and more frequent occurrence of symptoms. In addition, many institutionalized patients and elderly persons in nursing homes will be treated by attending physicians in the institution or nursing home. This may result in an under-reporting of the number of persons seeking care.

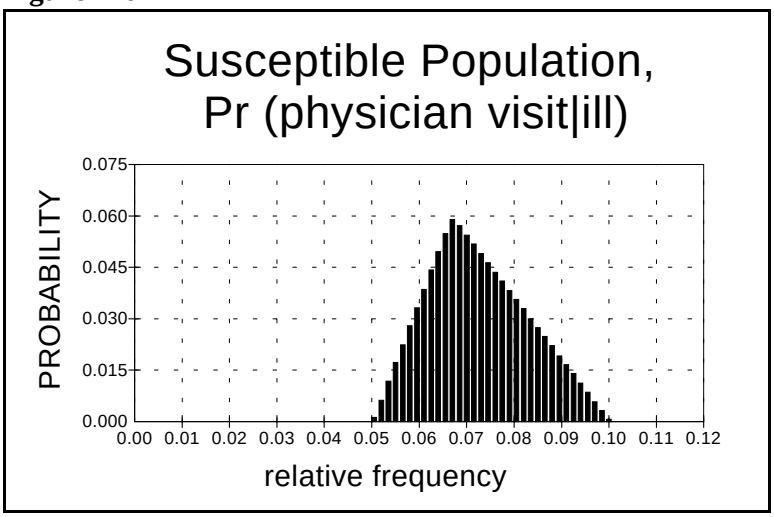
b. Expected Value: 0.0722

It is expected that on average, 722 persons per 10,000 persons in the susceptible sub-population who become ill from SE will visit a physician.

c. Distribution: Triangular(1/20. 1/15, 1/10)

Mean	0.0522
Minimum	0.0500
Mode	0.0667
Maximum	0.1000
$X_{0.05}$	0.0564
$X_{0.95}$	0.0909

Figure E-6



4. Probability Of Being Hospitalized Given Physician Visit, Normal Sub-Population.

a. Evidence: Clinical and professional experience.

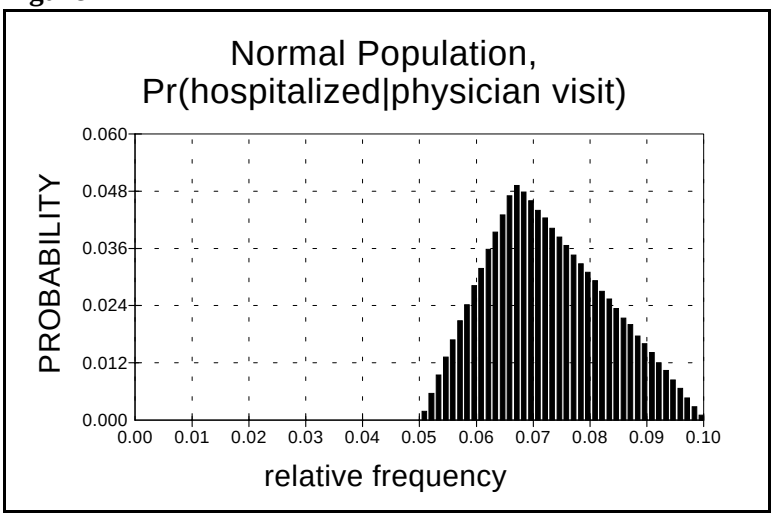
b. Expected Value: 0.0722

It is expected that on average, 722 persons per 10,000 persons in the normal sub-population who become ill from SE and who visit a physician, will be hospitalized.

c. Distribution: Triangular(1/20, 1/15, 1/10)

Mean	0.0722
Minimum	0.0500
Mode	0.0667
Maximum	0.1000
$X_{0.05}$	0.0564
$X_{0.95}$	0.0909

Figure E-7



5. Probability Of Being Hospitalized Given Physician Visit, Susceptible Sub-Population

a. Evidence: Clinical and professional experience. Additional evidence from literature of more severe symptoms in susceptible persons and increased likelihood of hospitalization to treat these conditions.

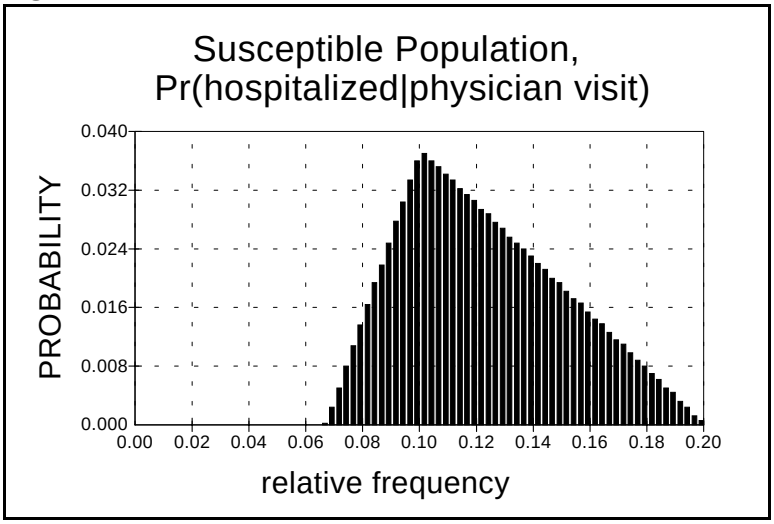
b. Expected Value: 0.1220

It is expected that on average, 1220 persons per 10,000 persons in the susceptible sub-population who become ill from SE and who visit a physician, will be hospitalized.

c. Distribution: Triangular(1/15, 1/10, 1/4)

Mean	0.1220
Minimum	0.0667
Mode	0.1000
Maximum	0.2500
$X_{0.05}$	0.0816
$X_{0.95}$	0.1740

Figure E-8



6. Probability Of Death Given that the Patient is Hospitalized, Normal Sub-Population.

a. Evidence: Clinical and professional experience.

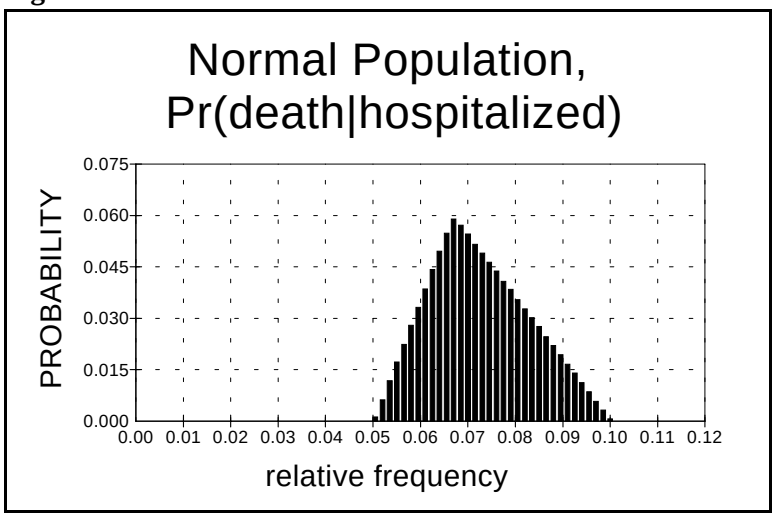
b. Expected value: 0.0722

It is expected that on average, 722 persons per 10,000 persons in the normal sub-population who become ill from SE and who visit a physician and who are hospitalized, will die.

c. Distribution: Triangular(1/20, 1/15, 1/10)

Mean	0.0722
Minimum	0.0500
Mode	0.0667
Maximum	0.1000
$X_{0.05}$	0.0565
$X_{0.95}$	0.0909

Figure E-9



Public Health Outcomes Module

7. Probability Of Death Given Patient Hospitalized, Susceptible Sub-Population.

a. Evidence:

Clinical and professional experience. Published evidence includes reports of case fatality rates in nursing home outbreaks of SE gastroenteritis are 40 times higher than the case fatality rates reported for outbreaks of SE gastroenteritis in general population. In addition, high case fatality rates are reported for severely immunocompromised persons such as those with advanced AIDS and persons undergoing organ transplants**.**

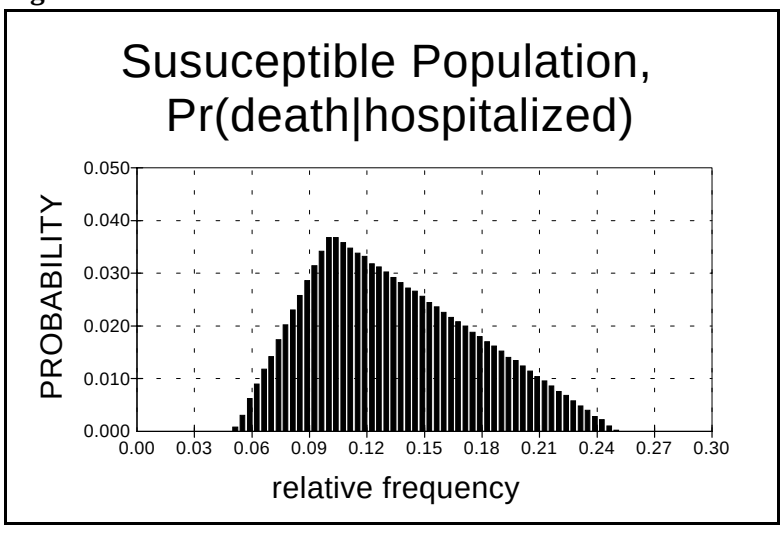
b. Expected value: 0.133

It is expected that on average, 1330 persons per 10,000 persons in the susceptible sub-population who become ill from SE and who visit a physician and who are hospitalized, will die from the SE infection.

c. Distribution: Triangular(1/20, 1/15, 1/4)

Mean	0.1333
Minimum	0.0500
Mode	0.0667
Maximum	0.2500
$X_{0.05}$	0.0723
$X_{0.95}$	0.2112

Figure E-10



8. Probability Of Developing Reactive Arthritis As A Post-Illness Sequela, Normal And Susceptible Sub-Populations.

a. Evidence: Published reports estimate that 2-3% of persons infected with SE and a few other enteric pathogens develop reactive arthritis as a sequela to the infection (CAST, 1994).

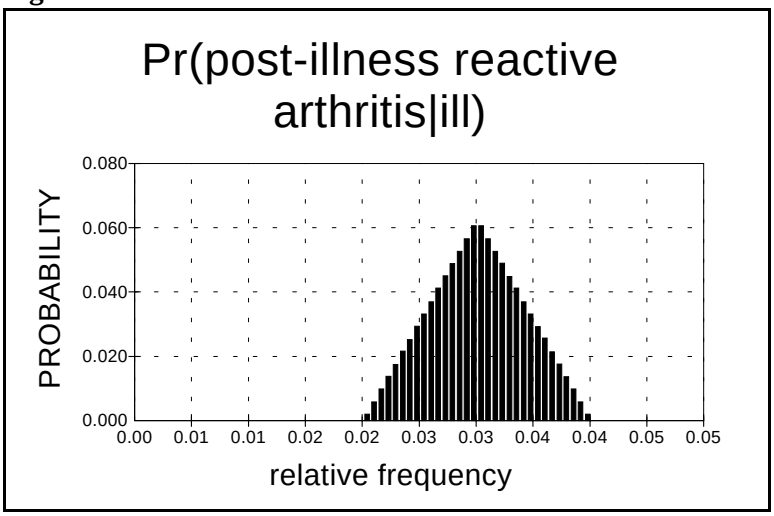
b. Expected value: 0.0300

It is expected that on the average, 300 persons per 10,000 persons in the total population who become ill from SE, will experience joint pain sometime after the recovery from the diarrhea of SE-induce gastroenteritis. This arthritis is called 'reactive arthritis'.

c. Distribution Triangular(0.02,0.03,0.04)

Mean	0.0300
Minimum	0.0200
Mode	0.0300
Maximum	0.0400
$X_{0.05}$	0.0232
$X_{0.95}$	0.0368

Figure E-11



Implicit Parameters

The implicit parameters are derived directly from the explicit parameters. For this reason the implicit parameters do not have distributions specified in the same way as the explicit parameters. The derivation of these implicit parameters is presented in the section titled "B. Inputs, Parameters, and Variables for the Public Health Outcomes Module"on page 198. The statistics describing the following distributions (mean or expected value, minimum, maximum, mode, 5^{th} and 95^{th} percentiles on the cumulative distribution) are generated by a simulation process and are not entered as arguments in functions which produce a distribution. The evidence for the implicit parameters comes from the explicit parameters from which they are derived.

9. Probability Of Recovery Without Medical Treatment, Normal Sub-Population.

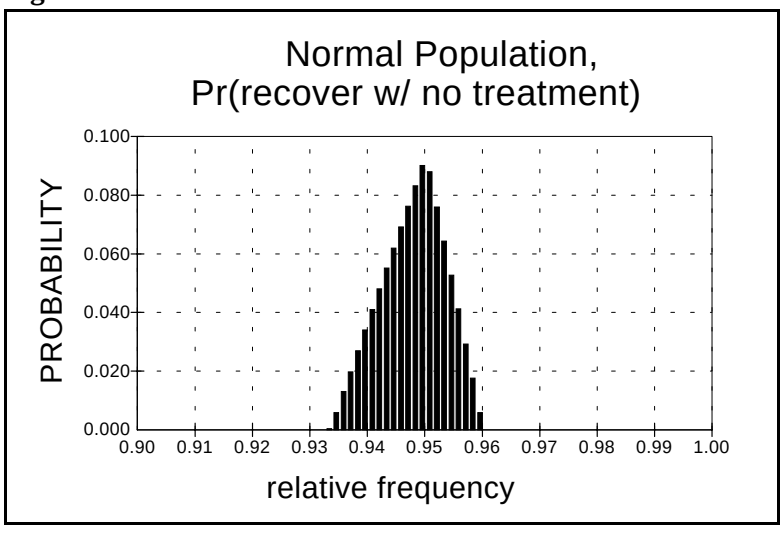
a. Expected value:

It is expected that on average, 9480 persons of 10,000 persons in the normal sub-population who are infected with SE and become ill will recover without seeing a physician.

b. Distribution Statistics:

Mean	0.948
Minimum	0.934
Mode	0.950
Maximum	0.960
$X_{0.05}$	0.938
$X_{0.95}$	0.956

Figure E-12



Public Health Outcomes Module

10. Probability Of Recovery Without Medical Treatment, Susceptible Sub-Population.

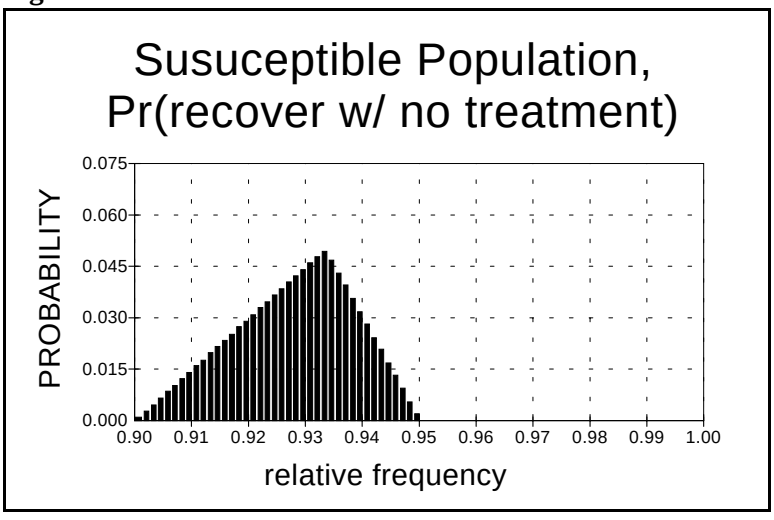
a. Expected value:

It is expected that on average, 9280 persons of 10,000 persons in the susceptible sub-population who are infected with SE and become ill will recover without seeing a physician.

b. Distribution Statistics:

Mean	0.928
Minimum	0.900
Mode	0.933
Maximum	0.950
$X_{0.05}$	0.933
$X_{0.95}$	0.944

Figure E-13



11. Probability Of Physician Visit And Recovery Without Hospitalization, Normal Sub-Population.

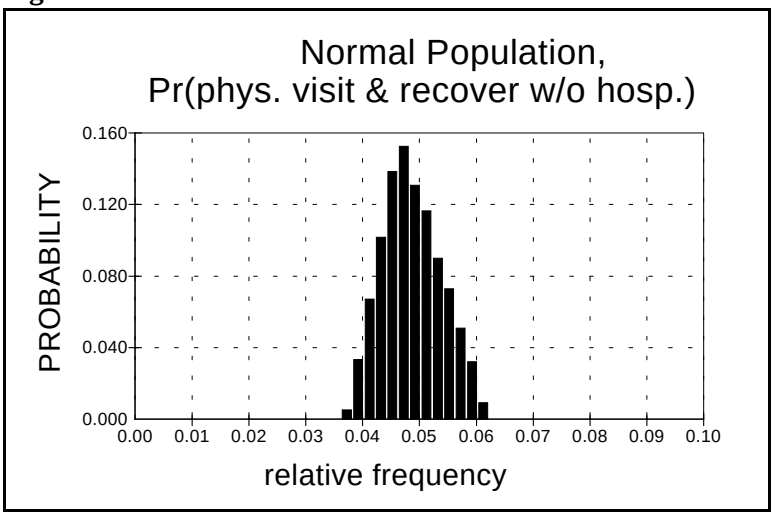
a. Expected value:

It is expected that on average, 485 persons of 10,000 persons in the normal sub-population who are infected with SE and become ill, will see a physician and will recover without being hospitalized.

b. Distribution Statistics:

Mean	0.0485
Minimum	0.0364
Mode	0.0480
Maximum	0.0629
$X_{0.05}$	0.0405
$X_{0.95}$	0.0576

Figure E-14



12. **Probability Of Physician Visit And Recovery Without Hospitalization, Susceptible Sub-Population**.

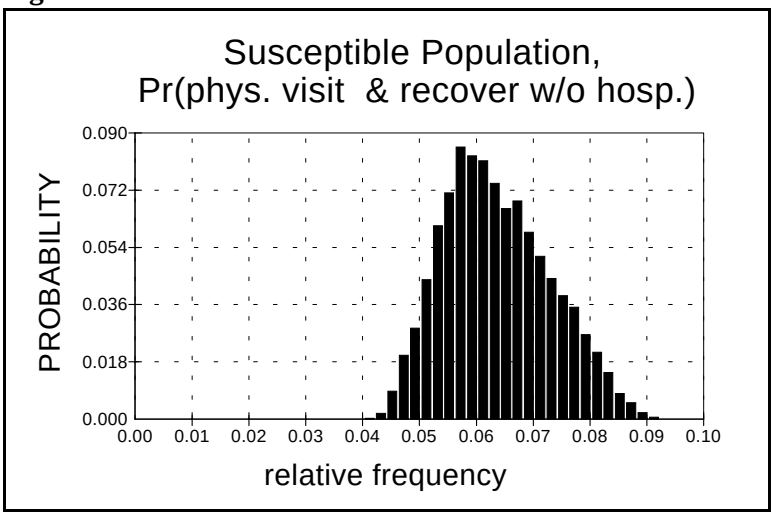
a. Expected value:

It is expected that on average, 634 persons of 10,000 persons in the susceptible sub-population who are infected with SE and become ill, will see a physician and will recover without being hospitalized.

b. Distribution Statistics:

Mean	0.0634
Minimum	0.0437
Mode	0.0699
Maximum	0.0911
$X_{0.05}$	0.0492
$X_{0.95}$	0.0802

Figure E-15



Public Health Outcomes Module

13. Probability Of Physician Visit and Recovery After Hospitalization, Normal Sub-Population.

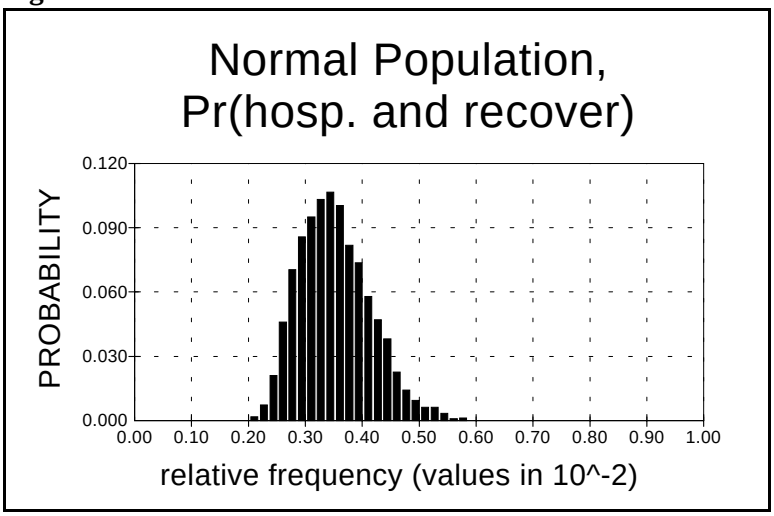
a. Expected value:

It is expected that on average, 35 persons of 10,000 persons in the normal sub-population who are infected with SE and become ill, will see a physician and be hospitalized, and will recover.

b. Distribution Statistics:

Mean	0.00350
Minimum	0.00204
Mode	0.00349
Maximum	0.00596
$X_{0.05}$	0.00256
$X_{0.95}$	0.00462

Figure E-16



Public Health Outcomes Module

14. Probability Of Physician Visit and Recovery After Hospitalization, Susceptible Sub-Population.

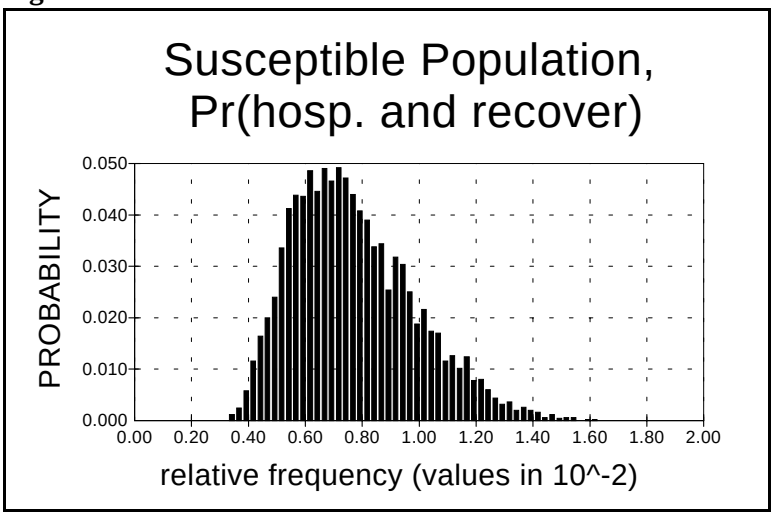
a. Expected value:

It is expected that on average, 77 persons of 10,000 persons in the susceptible sub-population who are infected with SE and become ill, will see a physician and be hospitalized, and will recover.

b. Distribution Statistics:

Mean	0.00765
Minimum	0.00324
Mode	0.00643
Maximum	0.01660
$X_{0.05}$	0.00468
$X_{0.95}$	0.01170

Figure E-17



Public Health Outcomes Module

15. Probability Of Death, Normal Sub-Population.

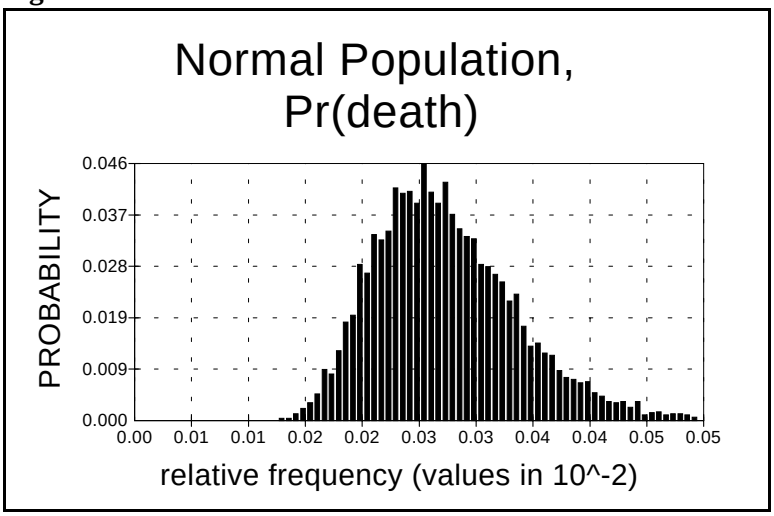
a. Expected value:

It is expected that on average, 3 persons of 10,000 persons in the normal sub-population who are infected with SE and become ill, will see a physician and be hospitalized, and will die.

b. Distribution Statistics:

Mean	0.000272
Minimum	0.000127
Mode	0.000254
Maximum	0.000553
$X_{0.05}$	0.000184
$X_{0.95}$	0.000385

Figure E-18



Public Health Outcomes Module

16. Probability Of Death, Susceptible Sub-Population.

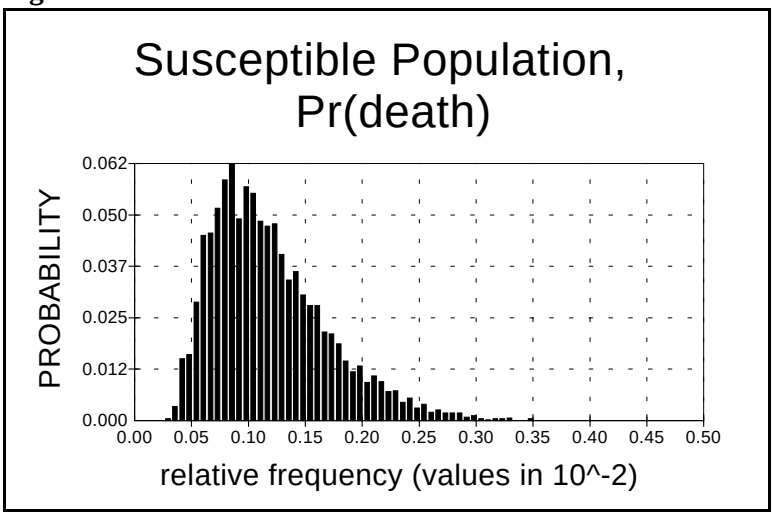
a. Expected value:

It is expected that on average, 11 persons of 10,000 persons in the susceptible sub-population who are infected with SE and become ill, will see a physician and be hospitalized, and will die.

b. Distribution Statistics:

Mean	0.001180
Minimum	0.000248
Mode	0.000783
Maximum	0.003870
$X_{0.05}$	0.000533
$X_{0.95}$	0.002160

Figure E-19



D. Probability of Infection: Microbial Dose-Response Modeling

The probability of infection with illness after ingestion of a specific dose of SE bacteria is not established in the literature. There is no feeding trial with SE bacteria in the literature which establishes a dose-response (i.e. illness) relationship for SE bacteria. There is a large volume of associated scientific literature and theoretical considerations upon which a putative dose-response (i.e. illness) relationship for SE bacteria may be built. Because of the importance of the dose-response (i.e. illness) relationship for SE bacteria to the SERA model, this scientific literature is reviewed in this section which is separate from the other sections of the Public Health Outcomes Module which discuss parameters and inputs.

1. Evidence

Because of the ethical issues involved in testing human responses to toxins and pathogens, few trials using human subjects have been conducted in the United States for decades. Thus, dose-response analysis and inference remains one of the most perplexing and pervasive issues in environmental health and risk analysis for a wide variety of microbial agents.

The analysis of dose-response relationships is based on two distinct types of data: (1) feeding trials using human subjects, and (2) epidemiologic data from "natural experiments". Feeding trials are controlled experiments in which healthy volunteers are fed carefully quantitated doses of pathogens, and the response of the healthy volunteers to the exposure is monitored. "Natural experiments" are outbreaks of bacterial food poisoning in which people are accidentally exposed to bacterial pathogens and become ill in sufficiently large numbers that public health authorities conduct an outbreak investigation. A bacterial cause may be identified, and a specific food containing the pathogen may be identified. Dozens of such outbreaks occur annually in the United States, but implicated food is rarely analyzed to determine the number of organisms per gram of food material.

a. Feeding Trials

Feedings trials have been carried out for a variety of bacterial genera, including *Salmonella*, *Shigella*, *Campylobacter*, *E. coli*, and *Listeria*. Nine *Salmonella* feeding trials were conducted between 1930 and 1973. Six of the nine trials used healthy, male prison volunteers. The most extensive *Salmonella* trials were performed by McCullough and Eisele in 1951 and used *Salmonella* serotypes other than *Salmonella* Enteritidis. The overall conclusion of these feeding trials was that infective doses in the range of 10^5 organisms were needed to achieve a substantial probability of infection or illness (McCullough and Eisele, 1951a, 1951b). However, this conclusion has been repudiated by other work and epidemiologic evidence (D'Aoust, 1989). The shortcomings of the *Salmonella* feeding trials have been summarized by Blaser and Newman (1982): (1) the exclusive use of healthy, young, male prisoners; (2) repeat testing of same subjects with the resulting intestinal immunity as a confounding variable; (3)

small sample sizes; (4) failure to determine minimum infective dose; (5) too few subjects at low doses. Specific limitations of the feeding trials are:

- 18 of the 22 tests-doses had less than 6 subjects.
- *Salmonella* serotypes used in feeding trials include Typhimurium, Anatum, Meleagridis, Newport, Derby, Bareilly, Pullorum, Sofia, Bovis, and Typhi. For all non- typhi *Salmonella* tested, the smallest dose administered was greater than 10^4 *Salmonella* bacteria. Eleven of the 15 tests used a minimum dose exceeding 10^5 *Salmonella* bacteria.
- In all the 11 non-*typhi Salmonella* trials, the lowest dose to cause infection was the lowest dose tested.
- In 6 of 15 trials the lowest dose to cause disease was the lowest dose tested (Blaser and Newman, 1982).
- Experimental evidence suggest that retesting or re-challenging subjects with the same pathogen lowers the probability of illness and/or disease for a given dose (Black et al., 1988).
- Repeated exposure to pathogens reduces likelihood of infection and severity of symptoms to individuals in developing countries (Taylor, 1992).

b. Epidemiologic Evidence from Outbreaks

The food vehicle implicated in most foodborne disease outbreaks is often consumed or discarded before clinical symptoms develop in the exposed individuals. As a result, specific food vehicles and causative agents are confirmed in less than half of all outbreaks, and the pathogen is not commonly cultured from the implicated food vehicle. In the few cases where the implicated food vehicle is available and culture of the implicated food vehicle is done, the bacterial pathogen is even less frequently enumerated. *Salmonella* was enumerated in the implicated food vehicle in some outbreaks before 1982 as summarized by Blaser and Newman (1982). From these outbreak studies and other published outbreak studies since 1982, it has become clear that *Salmonella* is infective and capable of producing disease at doses below the minimum dose used in the feeding trials of 1951. Specific outbreak studies which demonstrated that low doses are capable of causing illness include:

- A large *Salmonella* Enteritidis outbreak in Europe from contaminated candy produced clinical symptoms from the ingestion of less than 50 organisms. It is suspected that the fat content of the chocolate had the effect of protecting the *Salmonella* Enteritidis from gastric acidity, and this made a lower dose exposure effective (Greenwood and Hooper, 1983).

- A single *Salmonella* bacterium was capable of causing disease (D'Aoust, 1985).

- An outbreak of salmonellosis from eating contaminated cheese was reported. Quantitative culture of the cheese showed that consumption of 100-500 SE was the infective dose sufficient to cause symptoms. The fat content of the cheese may have the effect of reducing the infective dose of SE (Fontaine et al., 1980).

- Salmonellosis has been reported from the consumption of 60-230 SE bacteria in hamburger. Again, hamburger is a food containing fat. (Woodburn and Strong, 1960).

- An outbreak of foodborne illness due to SE and involving 150 persons was reported by public health officials in Minnesota. The implicated food vehicle was ice cream. Based on an estimate of the attack rate of 6.6% and the volume of ice cream distributed, it was estimated by number calculation that as many as 29,000 persons in Minnesota may have had diarrhea associated with the SE-contaminated ice cream. In this study the researchers cultured 266 unopened containers of the implicated ice cream. Eight of the containers were positive for SE. Phage typing was done for five of the eight samples and all were phage type 8. Concentration in four of the eight samples was determined and the highest enumeration of SE was 6 SE bacteria per 65 gram sample. This quantity was found in two of eight containers which were positive for SE (Hennessy et al., 1996). A recent study by Vought (Vought, 1998) re-analyzing the data from the enumeration of SE in the implicated ice cream suggests an upper limit of 26 organisms per 65 gram serving.

- An outbreak of salmonellosis due to SE was investigated, and the implicated food was hollandaise sauce. An informal quantitation of one sample of the sauce revealed 10^3 SE bacteria per gram. However, the culture was not performed to extinction, and the specimen had been refrigerated for 72 hours after being taken home in a "doggie bag". If two tablespoons of sauce were used, then the exposure would be about 10^4 SE per person. In this outbreak all of the 39 exposed individuals became ill and 20 were hospitalized (Levy et al., 1996; bacterial count data provided by Dr. M. Moody of the DC Commission on Public Health, personal communication).

* In 12 outbreaks of salmonellosis the *Salmonella* was enumerated in the implicated food vehicle. In 10 of the 12 outbreaks less than 1.5×10^5 *Salmonella* were ingested; in 7 of 10 studies less than 500 *Salmonella* were ingested. This dose is four orders of magnitude less than the minimum dose in most *Salmonella* feeding trials (Blaser and Newman, 1982).

The data from these citations are presented in Table E-3 (see page 235) and shown graphically in Fig. E-23 (see page 233). The few outbreaks of foodborne illness due to SE which report data on the concentration of SE present in the implicated food suggest that the infectious dose which resulting in illness is several orders of magnitude lower than (1) the doses reported in the *Salmonella* feeding trials and (2) the doses which are predicted by dose-response models constructed from the *Salmonella* feeding trials.

- The beta-poisson model was fitted to the pooled data from all of the *Salmonella* feeding trials; the resulting model estimates a probability of infection of 0.20 from ingesting 10^4 *Salmonella* bacteria. Because an infectious dose does not necessarily lead to illness, the probability of infection is greater than the probability of illness. It should be noted that *Salmonella* serotypes other than Enteritidis were used in the *Salmonella* feeding trials (Fazil, 1996).

2. Quantifying Dose-Response Relationships

Mathematical estimation of dose-response relationships is analyzed in a probabilistic framework where illness or other consequence is related to dose as an increasing function. This analysis produces a function that can be used in a predictive model. Issues of concern in quantifying the dose-response relationship include selecting an appropriate functional form, modeling specific outcomes (illness or infection as a function of dose), and extrapolating from the data to lower doses. This analysis is further complicated by the absence of a feeding trail done specifically with SE. For this reason an appropriate *Salmonella* species or other bacteria for which feeding trials have been done must be considered as a surrogate for SE.

Functional Form: A number of mathematical functions or models have been investigated and used for developing predictive models for dose-response relationships for pathogens including parasites, viruses, and bacteria (Crockett et al. 1996; Rose et al., 1991; Haas, 1983; Coleman and Marks, 1997; Morales, 1997). These functional forms include the beta-poisson, exponential, log-normal, log-probit, logit, and Gompertz models. Each has its own particular attributes and drawbacks. Thus the selection of an appropriate functional form should include criteria other than statistical measures. Additional criteria are goodness-of-fit measurements, biological plausibility, and consistency with available evidence, especially when working in a sparse data environment (NSF Workshop on "Specifying Probability Distributions With Limited Data", Proceedings forthcoming in Risk Analysis).

A comprehensive analysis of the known *Salmonella* exposure studies was conducted by fitting a variety of functional forms including the beta-poisson model and exponential model by maximum-likelihood estimation using a spreadsheet (Fazil, 1996). In most cases the beta-poisson had substantially better goodness-of-fit characteristics. The probability of illness by the estimated dose-response functions differs substantially from the attack rates observed in outbreaks of diarrhea due to SE-induced gastroenteritis.

However, the confidence intervals for these estimators can be large. In many cases the 95% confidence area for the dose-response curve included nearly the entire range of the data instead of a smaller range around the estimator of interest. A large 95% confidence interval suggests that the data is extremely variable, sparse, or the functional form does not accurately describe the data.

In general the beta-poisson functional form appears to be a better model for diseases due to viruses and bacteria, while the exponential functional form is a better model for diseases due to parasites. The original form of the beta-poisson, as used by Fazil and Hass (1997), has been modified by several authors (Morales et al, 1996; Teunis et al. 1996) to make parameter estimation more efficient. In this modified form the probability of illness is computed as:

$$Pr(\text{infection}) = 1 - (1 + \text{dose}/\beta)^{-\alpha}.$$

- The beta-poisson function fits the data from the *Shigella* feeding trials better than the exponential function (Crockett et al.,1996).

- The beta-poisson function fits all *Salmonella* feeding trial data, considered separately or pooled, better than the exponential function. (Fazil et al., in press).

- The beta-poisson function has the best goodness-of-fit characteristics, followed by the exponential function, then log-normal and logit functions when fitting a dose-response curve to the data from *Salmonella* feeding trials (Morales et al., 1996)

- The exponential functional form is a better functional form for modeling dose-response data for waterborne parasites such as *Giardia (*Rose et al., 1991).

In general, when fitted to the same data, the exponential function produces a much steeper dose-response curve than the beta-poisson function when fitted to the same data. The beta-poisson seems to overcome some of the limitations of the feeding trial design which rely on a restricted set of subjects who are young, healthy, incarcerated men. It has been observed that flatter dose-response curves are typical of tests conducted on a more heterogeneous population (Morgan, 1992).

3. **Suitable Surrogate Organism for *Salmonella* Enteritidis**

There are no known *Salmonella* Enteritidis feeding trials involving human test subjects upon which a dose-response function may be based. The alternative to this absence of data for SE is to select an appropriate surrogate bacteria for which dose-response data is available. The data for all *Salmonella* species used in feeding trials was analyzed by Fazil (1996). None appear to be appropriate because (1) in some trials the exposure dose was given with water and in other trials the exposure dose was given with food, (2) the

Salmonella species used in the feeding trials appear to be less virulent than SE, based on the epidemiologic data. Morales et al (1996) fitted the data from the *Salmonella* species and *Shigella* species feeding trials to several dose-response functional forms and concluded that the *Salmonella* feeding trial data and low-dose extrapolation of the fitted dose-response functions did not adequately model the attack rates found in the epidemiologic investigations of SE outbreaks involving low-dose exposures (<1,000 organisms) to humans. From their analysis of the *Shigella* species feeding trial data, Morales et al. (1996) proposed *Shigella dysenteriae* as a surrogate for SE in modeling the probability of illness.

The beta-poisson functional form was estimated for the *Shigella dysenteriae* [131] feeding trials by Morales et al. (1996). The resulting dose-response curve was found to also fit the epidemiologic data from the 1994 outbreak of SE associated with ice cream in the low dose range. The 1994 outbreak of SE associated with ice cream was found to have a calculated attack rate of 6.6%, and the infectious dose was assumed to be 6 SE bacteria per 65 gram serving of ice cream (Hennessy, 1995).

4. Adapting the Shigella dysenteriae dose-response function to the Public Health module.

a. Dose-Response Function for the Normal and Susceptible Sub-populations

As discussed in the prior section, there is a sub-population consisting of persons who for a variety of reasons are more susceptible to infection. The clinical and laboratory evidence suggests that these persons are from 10 to 100 times more susceptible to infection than normal, healthy people. The beta-poisson fitted to the *Shigella dysenteriae* [131] data (Morales, 1996) was plotted in two formulations: one formulation with the ID_{50} parameter (related to the infectious dose for 50% of the population) as estimated and another formulation with the ID_{50} parameter reduced by a factor of 10 to indicate a possible dose-response function for susceptible people. These curves were then superimposed on the epidemiologic data (Table E-2, see page 198) to illustrate the compatibility of the *Shigella dysenteriae* dose-response curve and the epidemiologic data (Fig. E-24, see page 234).

b. Introducing Uncertainty To The Dose-Response Function.

The beta-poisson dose-response function is typically expressed with scalar coefficients to produce a deterministic function that computes the probability of illness given an exposure to a specified dose. To make this relationship stochastic, the ID_{50} parameter of the function was expressed as a probability distribution instead of as a constant. Because the beta-poisson functional form is a two-parameter model, the confidence limits can not be estimated by a simple adjustment of the statistical mean by some numerical adjustment of the variance. Confidence limits to these functions are typically estimated by a bootstrap simulation, and the confidence bounds are determined by identifying the

appropriate outliers. To develop an appropriate distribution, the approximate 95% confidence bounds for the *Shigella dysenteriae* were determined from the beta-poisson dose-response function estimated by Teunis et al. (1996). Because the confidence limits appeared to approximately normally distributed in the range of doses of 1,000 to 10,000 bacteria, those bounds were used as the criterion for the stochastic dose-response function using a normal distribution for the ID_{50} parameter. The variance in the distribution (using the estimated ID_{50} parameter as the mean) was iteratively increased until a 95% confidence interval around the probability of illness at a dose of 10^4 organisms was achieved and matched that determined by Teunis et al. (1996).

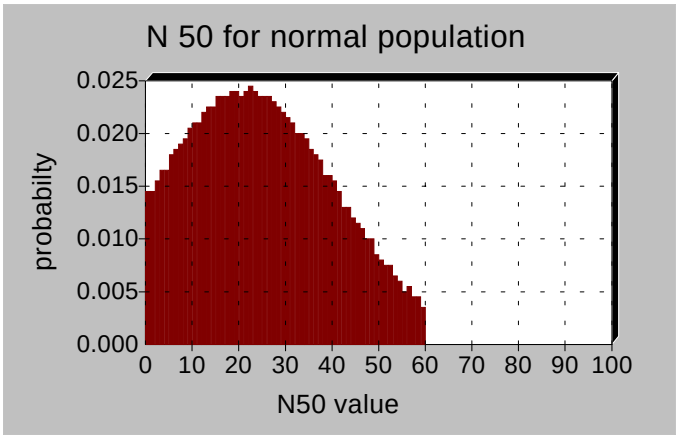
The distribution was then specified as a normal distribution truncated at zero as a minimum to avoid generating negative values which creates an error in the dose-response calculation. This distribution was used for the normal sub-population. For the susceptible sub-population, that sub-population was assumed to at least 10 times as sensitive as the normal sub-population so the distribution parameters were divided by ten.

(1) ID_{50} parameter for the normal sub-population.

Distribution: Truncated normal

Mean = 21.57
Variance = 20,
Minimum = 0
Maximum = 60

Figure E-20

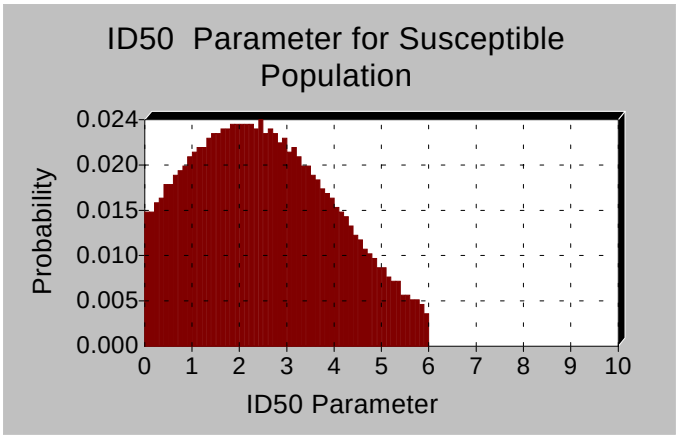


(2) ID_{50} parameter for the susceptible sub-population

Distribution: Truncated normal

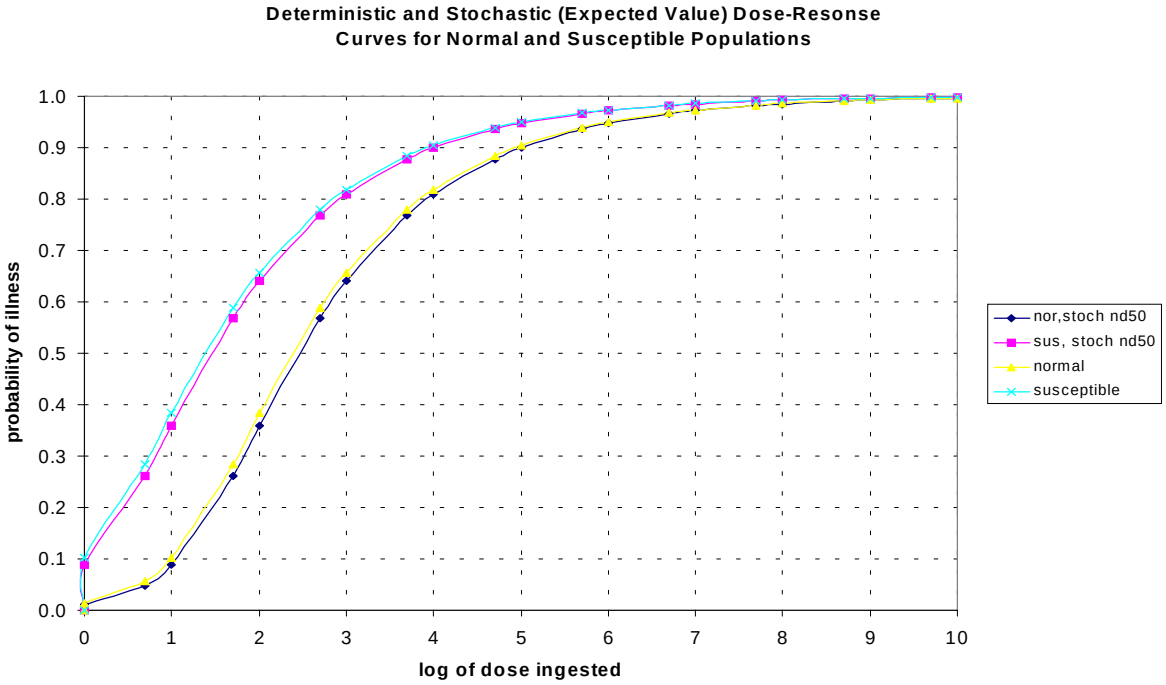
Mean = 2.1157
Std. Dev. = 2.0
Minimum = 0
maximum = 6

Figure E-21



The means of the resulting distributions are slightly different from the specified mean because the distribution is truncated at zero and at the upper bound of 60 for the normal sub-population and 6 for the susceptible sub-population. This imparts a slight downward bias in the probability of illness compared to the deterministic calculation. The two sets of dose-response curves for the expected value of the probabilistic model and the deterministic calculations are displayed in Fig. E-22. The upward bias is evident, but it is less than 2%.

Figure E-22 Comparison of deterministic and expected value of beta-poisson dose response curves



[1] parameter values for deterministic dose response curves estimates by Morales et al (1996).
Susceptible dose-response curve is based on:

ID_{50} of the susceptible sub-population = (ID_{50} normal sub-population)/10.

Figure E-23 Dose and Attack rate in outbreaks of different *Salmonella* species. See table E-3

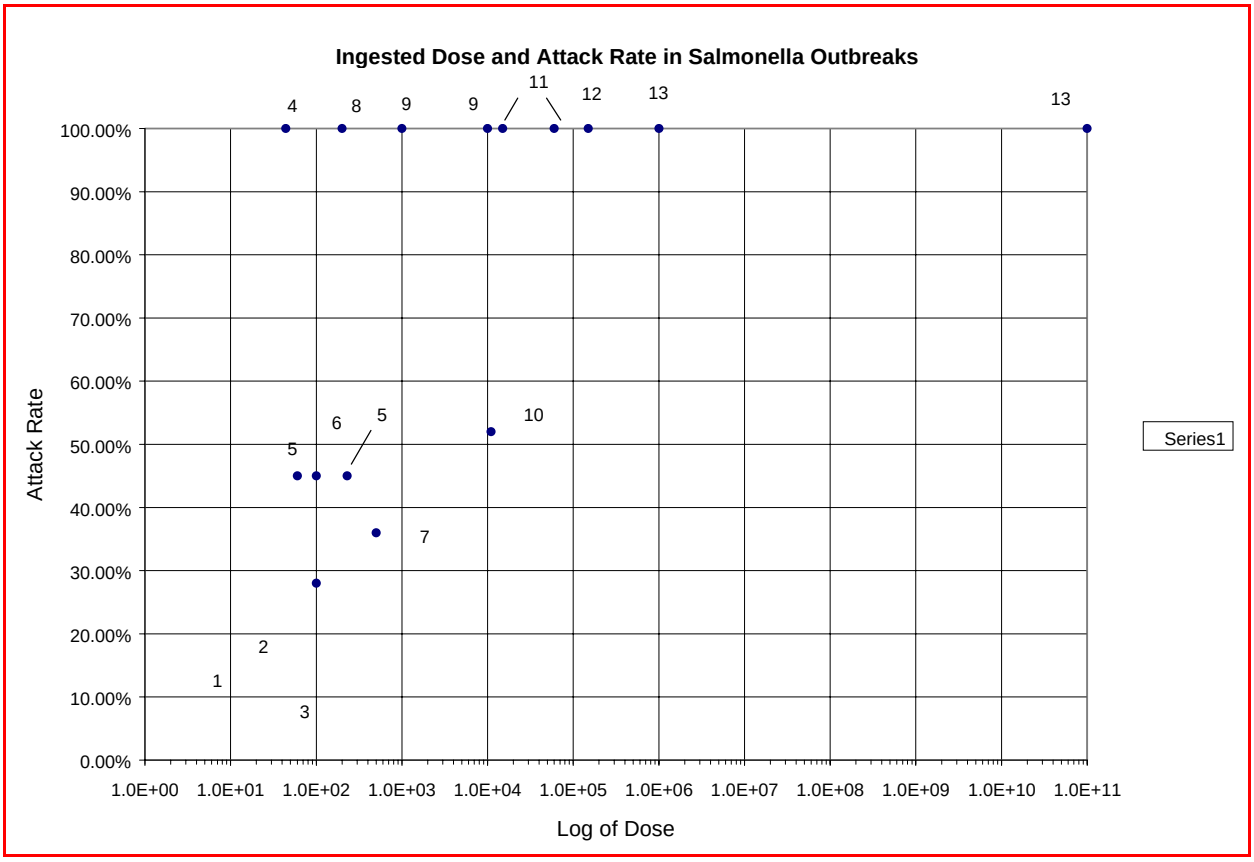


Figure E-24 *Salmonella* outbreak data (ingested dose and attack rate) and beta-poisson dose response curves for *Shigella dysenteriae* estimated for normal and susceptible sub-populations.

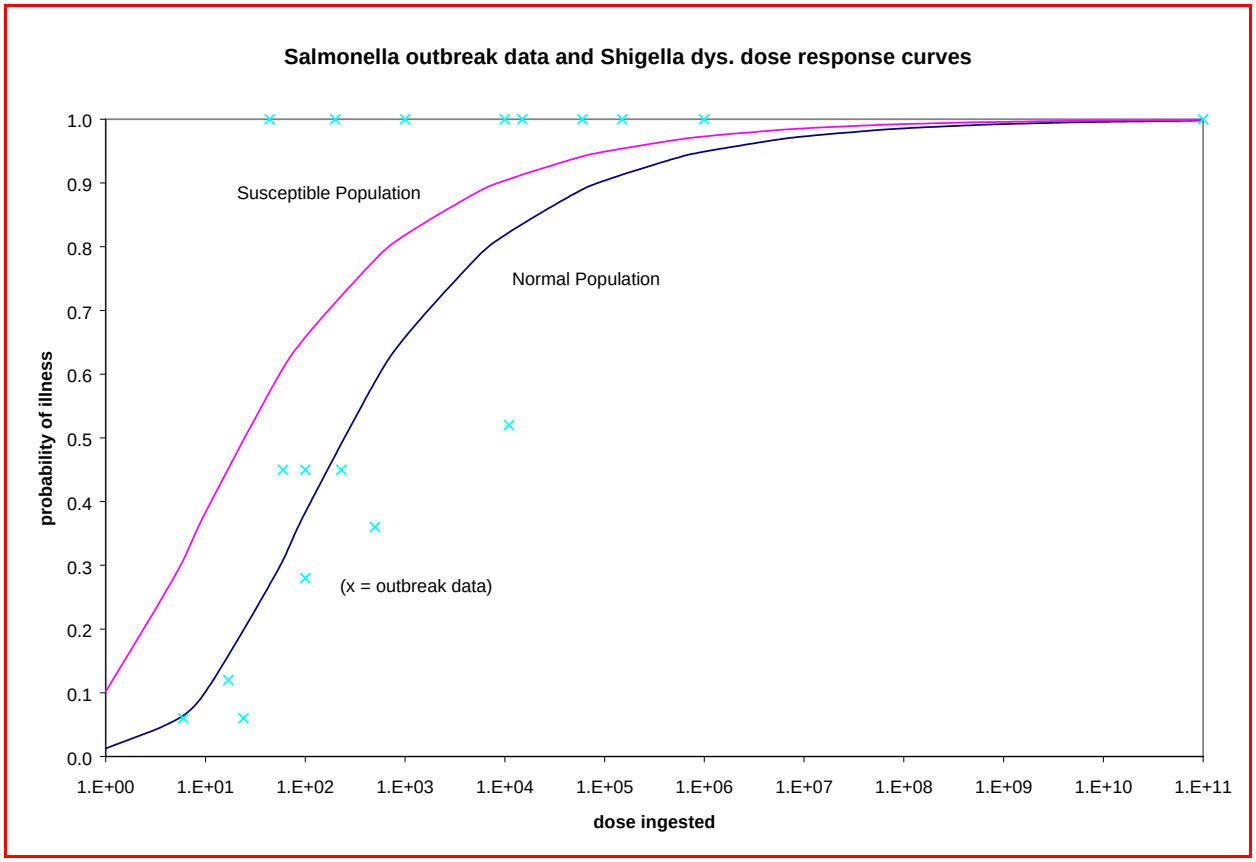


Table E-3. Estimated dose and attack rates in outbreaks of human salmonellosis.

	Serovar	Dose	Log(10) of Dose	Attack Rate	Number Ill	Label number for Fig.E-23 [1]
Boring, J.R. et al.	typhimurium	1.7 x 10	1.23	12%	16,000	2
Lipson, A.	schwarzengrund	44	1.64	100%	1	4
Fontaine, R.E., Arnon, S. et al.	newport	60	1.78	45%	48	5
D'Aoust, J.Y., Aris, B.J., et al.	eastbourne	100	2.00	45%	95	6
Fontaine, R.E., Cohen M.L., et al.	heidelberg	100	2.00	28%	339	7
George, R.H.	heidelberg	200	2.30	100%	1	8
Fontaine, R.E., Arnon, S. et al.	newport	230	2.36	45%	46	5
Fontaine, R.E., Cohen M.L., et al.	heidelberg	500	2.70	36%	339	7
Armstrong, R.W.	typhimurium	11,000	4.04	52%	1,790	10
Lang, D.J., et al.	cubana	15,000	4.18	100%	28	11
Lang, D.J., et al.	cubana	60,000	4.78	100%	28	11
Reitler, R.	zanzibar	150,000	5.18	100%	6	12
Angelotti, R., et al	infantis	1,000,000	6.00	100%	5	13
Reitler, R.	zanzibar	1×10^{11}	11.00	100%	8	12
Hennessy	Enteritidis	6	0.77	6%	>1,000	1
Vought	Enteritidis	24	1.38	6%	>1,000	3
Levy	Enteritidis	1,000	3.00	100%	39	9
Levy	Enteritidis	10,000	4.00	100%	39	9

1. The data for doses and attack rates are shown graphically in Fig. E-23. When two doses are reported for the same study, this indicates that the study reported the exposure dose as a range. Note that the papers by Fontaine, R.E., Arnon, S. et al. and D'Aoust, J.Y., Aris, B.J., et al. did not provide an unambiguous attack rate, and the value of 0.45 was used arbitrarily.

E. Output of the Public Health Outcomes Module

This section describes the typical outputs from the Public Health Outcomes Module as a demonstration of a simulation of a total population 100,000 persons, each ingesting 1,000 SE bacteria. These outputs can be used for validation of the Public Health Outcomes Module, checking the Public Health Outcomes Module for internal consistency, or comparing the results of the Public Health Outcomes Module with other evidence. However, the value of this demonstration simulation for module validation is limited because the number of exposed persons in each sub-population (normal and susceptible) will be different with each simulation. A single simulation run such as this demonstration examines the effects of exposing a total of 100,000 persons to a specific exposure. Readers should note this when examining the number of specific clinical outcomes. In this context a more useful measure for comparing outputs are the rates per 10,000 person exposed or per 10,000 persons who become ill.

Module output is presented graphically in Figs. E-25, E-26, and E-27 (see page 240), and the public health outcomes (number exposed, ill, recover with no treatment, physician visit, hospitalized, death, and reactive arthritis) are illustrated for the normal, susceptible, and total populations, respectively. Summary statistics (mean, minimum, maximum, and the 5^{th} and 95^{th} percentiles of the cumulative distribution) for each group and outcome are presented in Table E-4 (see page 239).

An examination of the graphic output shows all the outputs appear normally distributed on the logarithmic scale; thus all outputs are lognormally distributed. The second feature is the fact that although there is a high probability of illness (averaging 0.65, 0.81, and 0.63 for the normal, susceptible, and total population (Table E-4, see page 239), the vast majority of those ill recover without any medical treatment. The number who are ill is reduced by a 1.5 log reduction to show the number of persons who are ill and being treated by a physician and recovering without being hospitalized. A one log reduction of that group reveals the number of persons who are hospitalized, and a further one log reduction of the hospitalized group shows the number of deaths. In most cases, the uncertainty in the numbers increases as severity of clinical outcome increases. The erratic shape of the curves representing deaths in the normal and total populations and the small blips or tails of the distributions in the normal and susceptible sub-populations (between 3 and 5 logs) are artifacts of the simulation and do not imply any real anomalies.

An interesting feature of the demonstration simulation is the number of cases of reactive arthritis, which is rarely considered in analyzing the impacts of foodborne disease. There are between one-half of a log to one log more cases of persons with reactive arthritis than the number of persons who are hospitalized. This aspect of SE infections in humans may have a more significant clinical and economic impact than previously suspected; many persons suffering from reactive arthritis may not make the connection between a prior episode of gastroenteritis and the delayed onset of reactive arthritis.

The differences in case fatality rates --measure by number deaths/number people ill and deaths per 100,000 ill persons-- suggest (1) the parameter values that influence these numbers should be carefully evaluated and more evidence assembled to improve them, and (2) finding mitigation efforts in this sub-population may have a large impact on reducing mortality from SE infection.

The large uncertainty in the estimates (the 90% confidence limits to the deaths/100,000 susceptible persons are 42.3 persons and 230.2 persons) further indicate the need to refine the parameter values that influence this particular outcome. In general, the estimates for the total population are consistent with case fatality rates previously recorded (CAST, 1994).

The reader should note these results are not the public health outcome of the SE risk assessment; Table E-4 (see page 239) shows the results of a single exposure-dose and do not reflect the other exposures that occur. A full description of the complete public health outcomes is contained in the section containing baseline results.

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Public Health Outcomes Module

Table E-4 Summary statistics for public health outcomes for normal, susceptible, and total populations from the baseline simulation of 100,000 total population exposed to 1,000 SE organisms.

	Statistic				
Population Category and Outcome	Mean	Minimum	Maximum	5 th % *	95 th % *
Normal Sub-Population					
Pr(illness)	0.65	0.55	0.98	0.57	0.79
Ill	78,333	70,106	84,882	72,733	83,601
Exposed	54,548	39,732	77,616	43,655	62,698
Recover, no treatment	48,856	37,445	73,804	41,349	59,180
Physician visit, recover	2,497	1,571	4,221	1,922	3,123
Physician visit, hospitalized, recover	180	69	391	121	254
Death	14	0	42	6	23
Reactive Arthritis	1,546	861	2,782	1,123	2,047
No. Deaths / No. Ill	2.7E-04	0.0E+00	6.9E-04	1.3E-04	4.4E-04
Deaths per 100,000 ill	27.0	0.0	69.0	12.3	44.2
Susceptible Sub-Population					
Pr(illness)	0.82	0.76	0.98	0.77	0.89
Ill	21,677	15,118	29,894	16,934	27,256
Exposed	17,223	11,762	26,494	13,706	22,540
Recover, no treatment	16,443	10,769	24,329	12,700	20,927
Physician visit, recover	1,113	563	2,073	771	1,566
Physician visit, hospitalized, recover	136	35	368	74	218
Death	21	0	78	7	40
Reactive Arthritis	531	240	1,061	369	732
No. Deaths / No. Ill	1.2E-03	0.0E-00	3.4E-03	4.2E-04	2.3E-03
Deaths per 100,000 ill	118	0.0	383	42.4	230.2
Total Population					
Ill	69,270	58,931	93,990	61,890	79,926
Recover, no treatment	65,300	55,132	88,264	58,327	78,426
Physician visit, recover	3,620	2,553	5,844	2,988	4,361
Physician visit, hospitalized, recover	316	171	605	230	417
Death	35	4	89	18	56
Reactive Arthritis	2,071	1,309	3,256	1,644	2,573
No. Deaths / No. Ill	5.1E-04	6.0E-05	1.3E-05	2.7E-04	8.1E-04
Deaths per 100,000 ill	50.5	6.0	134.0	26.8	81.3

* 5 th % and 95 th % are the fractiles of the cumulative distribution

Figure E-25

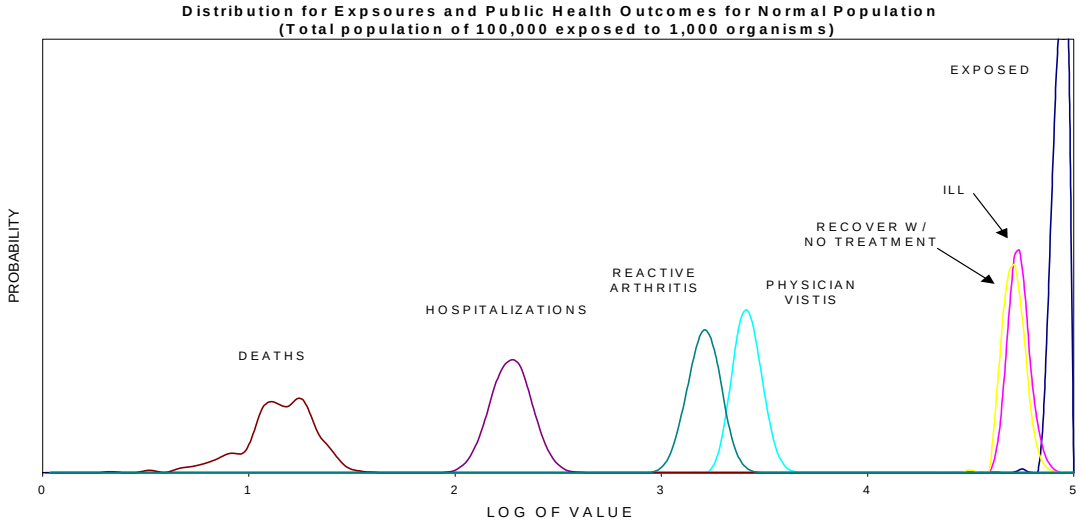


Figure E-26

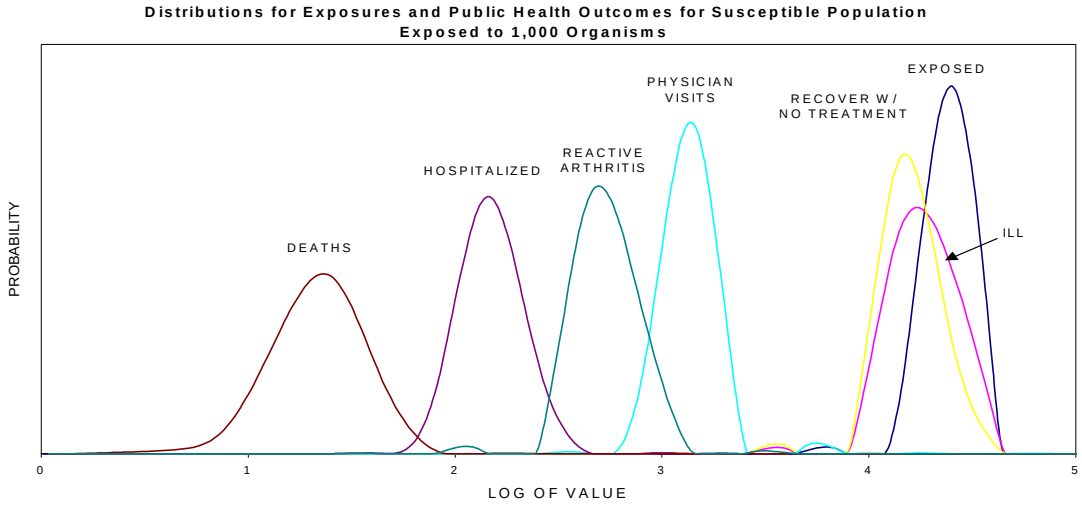
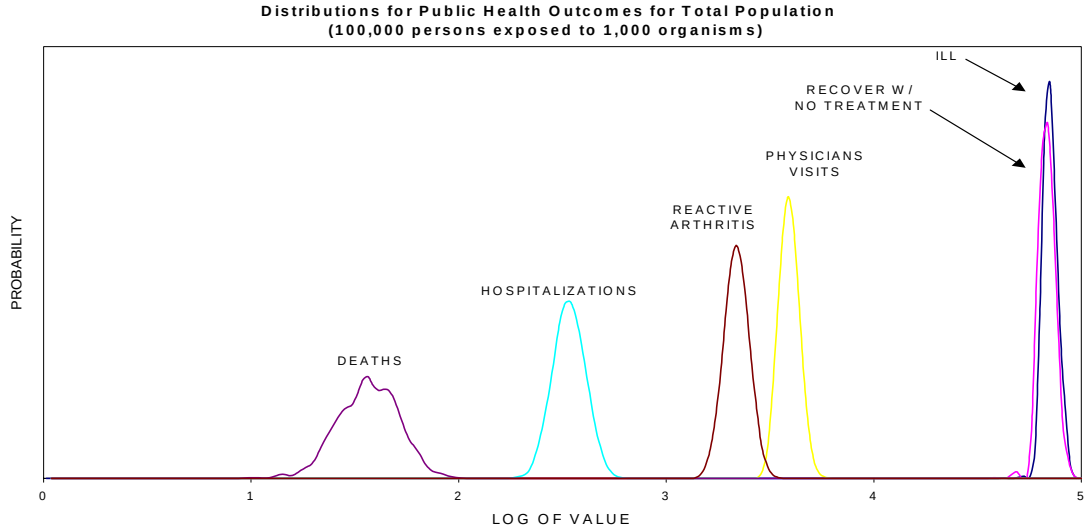


Figure E-27


Distributions for Public Health Outcomes for Total Population
(100,000 persons exposed to 1,000 organisms)
ILL
RECOVER W/
NO TREATMENT
PHYSICIANS
VISITS
REACTIVE
ARTHRITIS
HOSPITALIZATIONS
DEATHS
PROBABILITY
0
1
2
3
4
5
LOG OF VALUE

F. Sensitivity Analysis

1. Purpose

Sensitivity analysis is performed to identify how changes in the parameters of the Public Health Outcomes Module change the values of state or outcome variables. @Risk, the simulation software used in this analysis generates two kinds of sensitivity statistics: (1) regression analysis r^2 values and (2) correlation coefficients. The r^2 values computed for parameters in the Public Health Outcomes Module were all near zero. This indicates a non-linear relationship between the parameters and state variables, and thus the r^2 values are not reported. The rank correlation coefficient is a measure of the degree of association between a parameter and a state or rate variable. Correlation coefficients have values between -1 and +1, inclusive. Negative coefficients indicate the variables are negatively correlated--i.e. a high value for one parameter is associated with a low value in a state or rate variable. The converse is true for positive correlation coefficients, with high value for one variable being correlated to a high value for the other. A rank correlation coefficient approaching zero means little association has been found between a parameter and a variable. A coefficient's absolute value is the measure of the degree of association; the sign indicates a negative or positive correlation.

2. Results

The sensitive analysis results for the demonstration simulation of 100,000 total population with each person exposed to a dose of 1,000 SE bacteria are displayed in Tables E-5 through Table E-10. Tables E-5 to E-7 (see page 244) show the input parameters in the order the input parameters occur in the module. This series of Tables E-5 through E-7 (see page 244) will be most useful for readers seeking to examine the significance of a specific parameter and how it changes between output variables and between normal, susceptible, and total population groups. In Tables E-8 to E-10 (see page 248) the input parameters are listed in descending rank order of correlation. This series of tables will be most useful to the reader seeking to identify the most significant parameters for a specific output variable in the normal, susceptible, or total population groups.

The results shown are specific to the exposure and dose and should not be extrapolated to other doses or exposures. The sensitivity analysis provided for the complete output--the entire range of exposures and doses--will incorporate all the variation and differences in response to different doses. The sensitivity results from the demonstration simulation (100,000 total population each exposed to 1,000 SE bacteria) have value as the correlation coefficients can be examined and analyzed without the complicating factors of other exposures and doses.

A prominent feature of the results for this demonstration simulation is that the significance of a particular parameter varies widely depending on the output. For example, the probability of being in the susceptible sub-population has correlation coefficients ranging from -0.36 to -0.11 for outputs from the normal sub-population (Table E-5, see page 244); yet in the susceptible sub-population, the coefficients are all positive, ranging from +0.28 to +0.95 (Table E-6). For the total population the results are mixed; the coefficients for pr(susceptible) range from -0.09 to +0.77 (Table E-7). In general, for the normal sub-population, all the parameters have significant

effects--with the exception of the outcome for reactive arthritis, only three output-parameter pairs had a correlation with absolute value less than 0.10 and 12 of the 17 output-parameter pairs had coefficients with absolute value greater than 0.25.

The situation is similar for the susceptible sub-population except the pr(susceptible) parameter has more influence, as would be expected. Those parameters with coefficients with absolute value greater than 0.5 include Pr(susceptible), Pr(physician visit), Pr(hosp.|physician visit), and Pr(death|hospitalized). Thus the parameters relating to susceptibility and the probability of clinical outcomes have a larger influence on outcome variables than does the parameter relating to probability of illness, the ID_{50} parameter.

When the outcomes for the susceptible sub-population and the normal sub-population are combined into the total, some of the effects which were quite noticeable in the susceptible sub-population or in the normal sub-population statistics are dampened in the total population outcomes while others emerge as more powerful. For example, the ID_{50} parameters for both the normal sub-population and susceptible sub-population range from -0.11 to -0.97, but in general are quite high, indicating that this parameter is one of the most important in terms of its effect on the outcome values (Table E-7).

When the input parameters are listed by their rank order (in descending order of absolute value of the correlation coefficient), the relative significance of specific parameters for either a specific output or between outputs is more clear. As one would expect, the most significant parameter for each output is the one most closely related to it, e.g., in the normal sub-population, for the number of persons seeing physician and recovering (without being hospitalized), the most significant parameter is pr(hosp|physician visit) (Table E-8, see page 248). In general, as a parameter is further distanced from an output in terms of the illness to clinical outcomes continuum, its correlation coefficient (absolute value) declines. The ID_{50} parameters for the normal sub-population and susceptible sub-population have high rank order for total ill, number recovering without treatment, and number seeing physician and recovering. The ID_{50} parameters begin to decline to where they are last in rank order for the number of deaths (Table E-10). An inspection of the tables will reveal there are no unimportant variables, e.g., those with consistently low rank correlation; they are all significant to one or more output variables.

Table E-5. Sensitivity Analysis for Normal Sub-Population Outputs

Output Variable	Input Parameter	Correlation Coefficient
Number recover with no treatment	Pr(susceptible)	-0.367372
	NP: ID50 parameter	-0.918353
	NP: Pr(physician visit)	-6.16E-02
number physician visit and recover	Pr(susceptible)	-0.250138
	NP: ID50 parameter	-0.628577
	NP: Pr(physician visit)	+0.680765
	NP: Pr(hosp.|phys vis)	-8.15E-02
number hospitalized and recover	Pr(susceptible)	-0.162457
	NP: ID50 parameter	-0.424199
	NP: Pr(physician visit)	+0.458259
	NP: Pr(hosp.|phys. visit)	+0.637448
	NP: Pr(death|hosp.)	-6.14E-02
number deaths	Pr(susceptible)	-0.106447
	NP: ID50 parameter	-0.250416
	NP: Pr(physician visit)	+0.269777
	NP: Pr(hosp.|phys. visit)	+0.369393
	NP: Pr(death|hosp.)	+0.364551
cases of reactive arthritis	Pr(susceptible)	-0.228819
	NP: ID50 parameter	-0.549129
	NP: Pr(physician visit)	-1.38E-02
	NP: Pr(hosp.|phys. visit	-1.25E-02
	NP: Pr(death|hosp.)	+1.04E-03
	NP: Pr(reactive arthritis)	+0.773724

Table E-6. Sensitivity Analysis for Susceptible Sub-Population Outputs

Output Variable	Input Parameter	Correlation Coefficient
total ill	Pr(susceptible)	
	SP: ID50 parameter	
number recover with no treatment	Pr(susceptible)	+0.952977
	SP: ID50 parameter	-0.282389
	SP: Pr(physician visit)	-4.23E-02
number physician visits and recover	Pr(susceptible)	+0.770726
	SP: ID50 parameter	-0.232542
	SP: Pr(physician visit)	+0.525231
	SP: Pr(hosp.|phys vis)	-0.173962
number hospitalized and recover	Pr(susceptible)	+0.460219
	SP: ID50 parameter	-0.137337
	SP: Pr(physician visit)	-0.303962
	SP: Pr(hosp.|phys. visit)	+0.740909
	SP: Pr(death|hosp.)	-0.147705
number deaths	Pr(susceptible)	+0.287700
	SP: ID50 parameter	-9.72E-02
	SP: Pr(physician visit)	+0.186787
	SP: Pr(hosp.|phys. visit)	+0.455073
	SP: Pr(death|hosp.)	+0.659489
number cases of reactive arthritis	Pr(susceptible)	+0.681972
	SP: ID50 parameter	-0.193067
	SP: Pr(physician visit)	+5.52E-03
	SP: Pr(hosp.|phys. visit)	-1.31E-04
	SP: Pr(death|hosp.)	-1.89E-04
	SP: Pr(reactive arthritis)	-0.647577

Table E-7. Sensitivity Analysis for Total Population Outputs

Output Variable	Input Parameter	Correlation Coefficient
total ill	Pr(susceptible)	+0.104012
	SP: ID50 parameter	-0.159807
	NP: ID50 parameter	-0.976487
number recover with no treatment	Pr(susceptible)	+0.089920
	SP: ID50 parameter	-0.154922
	SP: Pr(physician visit)	+3.00E-03
	NP: ID50 parameter	-0.976811
	NP: Pr(physician visit)	-6.40E-02
number physician visits and recover	Pr(susceptible)	+0.770726
	SP: ID50 parameter	-0.232542
	SP: Pr(physician visit)	0.525231
	SP: Pr(hosp.|phys vis)	-8.173962
	NP: ID50 parameter	-0.590174
	NP: Pr(physician visit)	+0.638876
	NP: Pr(hosp|phys vis)	-6.45E-02
number hospitalized and recover	Pr(susceptible)	+0.237280
	SP: ID50 parameter	-0.111802
	SP: Pr(physician visit)	+0.232600
	SP: Pr(hosp.|phys. visit)	+0.564520
	SP: Pr(death|hosp.)	-0.117790
	NP: ID50 parameter	-0.297148
	NP: Pr(physician visit)	+0.315010
	NP: Pr(hosp.|phys. visit)	+0.440054
	NP: Pr(death|hosp.)	-3.80E-02

(Table continued on next page)

Table E-7. Sensitivity Analysis for Total Population Outputs, continued

Output Variable	Input Parameter	Correlation Coefficient
number deaths	SP: ID50 parameter	-9.52E-02
	Pr(susceptible)	+0.208832
	SP: Pr(physician visit)	+0.169202
	SP: Pr(hosp.|phys. visit)	+0.408376
	SP: Pr(death|hosp.)	+0.594600
	NP: Pr (physician visit)	+0.129622
	NP: Pr(hosp.|phys. visit)	+0.172914
	NP: Pr(death|hosp.)	+0.165032
	NP: ID50 parameter	-0.113232
number cases of reactive arthritis	Pr(susceptible)	+3.94E-02
	SP: ID50 parameter	-9.35E-02
	SP: Pr(physician visit)	+5.65E-03
	SP: Pr(hosp.|phys. visit)	-8.94E-03
	SP: Pr(death|hosp.)	-7.69E-03
	SP: Pr(reactive arthritis)	+0.249099
	NP: ID50 parameter	-0.543518
	NP: Pr(physician visit)	-9.05E-03
	NP: Pr(hosp.|phys. visit)	-3.52E-03
	NP: Pr(death|hosp.)	-2.88E-03
	NP: Pr(reactive arthritis)	+0.772666

Table E-8. Sensitivity Analysis for Normal Sub-Population: Input Parameters by Rank Order Correlation

Output Variable	Input Parameter	Correlation Coefficient
Number recover with no treatment	NP: ID50 parameter	-0.918353
	Pr(susceptible)	-0.367372
	NP: Pr(physician visit)	-6.16E-02
number physician visit and recover	NP: Pr(physician visit)	+0.680765
	NP: ID50 parameter	-0.628577
	Pr(susceptible)	-0.250138
	NP: Pr(hosp.|phys vis)	-8.15E-02
number hospitalized and recover	NP: Pr(hosp.|phys. visit)	+0.637448
	NP: Pr(physician visit)	+0.458259
	NP: ID50 parameter	-0.424199
	Pr(susceptible)	-0.162457
	NP: Pr(death|hosp.)	-6.14E-02
number deaths	NP: Pr(hosp.|phys. visit)	+0.369393
	NP: Pr(death|hosp.)	+0.364551
	NP: Pr(physician visit)	+0.269777
	NP: ID50 parameter	-0.250416
	Pr(susceptible)	-0.106447
cases of reactive arthritis	NP: Pr(reactive arthritis)	+0.773724
	NP: ID50 parameter	-0.549129
	Pr(susceptible)	-0.228819
	NP: Pr(physician visit)	-1.38E-02
	NP: Pr(hosp.|phys. visit)	-1.25E-02
	NP: Pr(death|hosp.)	+1.04E-03

Table E-9. Sensitivity Analysis for Susceptible Sub-Population Outputs: Input Parameters by Rank Order Correlation.

Output Variable	Input Parameter	Correlation Coefficient
number recover	Pr(susceptible)	+0.952977
with no treatment	SP: ID50 parameter	-0.282389
	SP: Pr(physician visit)	-4.23E-02
number physician	Pr(susceptible)	+0.770726
visits and recover	SP: Pr(physician visit)	+0.525231
	SP: ID50 parameter	-0.232542
	SP: Pr(hosp.|phys visit)	-0.173962
number hospitalized	SP: Pr(hosp.|phys. visit)	+0.740909
and recover	Pr(susceptible)	+0.460219
	SP: Pr(physician visit)	-0.303962
	SP: Pr(death|hosp.)	-0.147705
	SP: ID50 parameter	-0.137337
number deaths	SP: Pr(death|hosp.)	+0.659489
	SP: Pr(hosp.|phys. visit)	+0.455073
	Pr(susceptible)	+0.287700
	SP: Pr(physician visit)	+0.186787
	SP: ID50 parameter	-9.72E-02
number cases of	Pr(susceptible)	+0.681972
reactive arthritis	SP: Pr(reactive arthritis)	+0.647577
	SP: ID50 parameter	-0.193067
	SP: Pr(physician visit)	+5.52E-03
	SP: Pr(death|hosp.)	-1.89E-04
	SP: Pr(hosp.|phys. visit)	-1.31E-04

Table E-10. Sensitivity Analysis for Total Population Outputs: Input Parameters by Rank Order Correlation

Output Variable	Input Parameter	Correlation Coefficient
total ill	NP: ID50 parameter	-0.976487
	Pr(susceptible)	+0.104012
	SP: ID50 parameter	-0.159807
number recover with no treatment	NP: ID50 parameter	-0.976811
	SP: ID50 parameter	-0.154922
	Pr(susceptible)	+0.089920
	NP: Pr(physician visit)	-6.40E-02
	SP: Pr(physician visit)	+3.00E-03
number physician visits and recover	Pr(susceptible)	+0.770726
	NP: Pr(physician visit)	+0.638876
	NP: ID50 parameter	-0.590174
	SP: Pr(physician visit)	+ 0.525231
	SP: ID50 parameter	-0.232542
	SP: Pr(hosp.|phys. visit)	-8.173962
	NP: Pr(hosp.|phys. visit)	-6.45E-02
number hospitalized and recover	SP: Pr(hosp.|phys. visit)	+0.564520
	NP: Pr(hosp.|phys. visit)	+0.440054
	NP: Pr(physician visit)	+0.315010
	NP: ID50 parameter	-0.297148
	Pr(susceptible)	+0.237280
	SP: Pr(physician visit)	+0.232600
	SP: Pr(death|hosp.)	-0.117790
	SP: ID50 parameter	-0.111802
	NP: Pr(death|hosp.)	-3.80E-02

(Table continued on next page)

Table E-10. Sensitivity Analysis for Total Population Outputs: Input Parameters by Rank Order Correlation, continued

Output Variable	Input Parameter	Correlation Coefficient
number deaths	SP: Pr(death|hosp.)	+0.594600
	SP: Pr(hosp.|phys. visit)	+0.408376
	Pr(susceptible)	+0.208832
	NP: Pr(hosp.|phys. visit)	+0.172914
	NP: Pr(death|hosp.)	+0.165032
	SP: Pr(physician visit)	+0.169202
	NP: Pr (physician visit)	+0.129622
	NP: ID50 parameter	-0.113232
	SP: ID50 parameter	-9.52E-02
number cases of reactive arthritis	NP: Pr(reactive arthritis)	+0.772666
	NP: ID50 parameter	-0.543518
	SP: Pr(reactive arthritis)	+0.249099
	SP: ID50 parameter	-9.35E-02
	Pr(susceptible)	+3.94E-02
	Pr(susceptible)	+3.94E-02
	SP: Pr(hosp.|phys. visit)	-8.94E-03
	SP: Pr(death|hosp.)	-7.69E-03
	SP: Pr(physician visit)	+5.65E-03
	NP: Pr(hosp.|phys. visit)	-3.52E-03
	NP: Pr(death|hosp.)	-2.88E-03

G. Limitations

1. Model Parameters.

a. Proportion susceptible.

Although several sources identify and quantify the types and numbers of persons who are deemed to be more susceptible to foodborne pathogens (Gerba, 1994; CAST, 1994), these data have several limitations. Among the susceptible sub-population there is a large range of susceptibility to pathogens, and there are significant differences in the probability of specific clinical outcomes among the susceptible sub-population. For example, the probability of death after the onset of illness (i.e. Pr(death|ill)) for nursing home residents involved in *Salmonella* outbreaks is 70 times higher than the overall case-fatality rate in outbreaks of salmonellosis in the general population (Mishu et al. 1994). The probability of specific clinical outcomes for the most robust of the susceptible group may be nearly that of the most susceptible person in the normal sub-population. The probability of specific clinical outcomes could be modeled more accurately by further stratifying the susceptible sub-population. In addition, we have no information about the disease avoidance behaviors, which may be unique to the susceptible sub-population, and we have no information about the prevalence of such behaviors among the susceptible sub-population.

b. Dose-Response Parameters (probability of illness)

The calculation of the probability of illness after exposure to a specific dose has several limitations.

(1) The most significant limitation is the absence in the literature of a feeding trial in which SE is the bacteria being studied with the intention of describing a dose- response relationship.

(2) Limitations of data from feeding trials of enteric pathogens.

The section titled “C. Parameters in the Public Health Outcomes Module: Variables” (see page 206) details the limitations of the data from the feeding trial studies on enteric pathogens. Among the shortcomings of these studies are the small sample sizes at each dose-exposure level, the repeated use of the same subjects in the same feeding trial, the absence of exposure of test subjects to low doses of the enteric pathogen, and the use of minimum doses which were relatively large in most trials. Furthermore, large differences were observed between strains of specific serovars. These large differences make it difficult to extrapolate from the results of strains used in the feeding trial studies to exposure of humans to different strains not used in the feeding trial studies. These large differences produce a dose-response curve which

has very wide 95% confidence interval curves around the dose-response curve which has been fitted to the data form the appropriate feeding trials. The consequence of these large differences is to limit our confidence in the expected values which are generated from the dose-response curves of the feeding trial studies.

(3) Functional form for expressing dose-response relationships.

Combined with the data limitations of the feeding trials, it is not obvious which of the mathematical functional forms best characterizes the dose-response relationship between the bacterial enteric pathogens of the feeding trial studies and the population of test subjects in those feeding trials. The appropriate choice of mathematical functional form continues to plague dose-response analysis in bacterial risk assessment. Although the beta-poisson functional form has the best "goodness-of-fit" characteristics, when it is used to model most bacterial pathogens (Crockett, 1995; Fazil, 1997; Hass, 1996; Morales, 1996), several analysts have noted shortcomings in the use of the beta-poisson (Morales, 1996; Vose, 1998) on theoretical grounds as well as in parameter estimation for use in practical applications. Visual inspection of the confidence limits for a typical beta-poisson dose-response function reveals that a wide variety of functional forms will produce dose-response curves which are contained within the confidence limits of the beta-poisson dose-response function. The appropriate functional form for modeling a dose-response relationship for low-dose exposure has not been established. The functional form for modeling a dose-response relationship for low-dose exposure may be different from the functional form for modeling a dose-response relationship for moderate- or high-dose exposure to bacterial pathogens. Finally, there are arguments in the literature for the use of functional forms other than the beta-poisson functional form; it is argued that these other functional forms may better model the probability of illness after exposure (Morales, 1996).

(4) Incorporating uncertainty in calculating probability of illness.

Because the beta-poisson functional form is a two-parameter model, confidence intervals for the beta-poisson functional form are computed by a bootstrap method and are not computed analytically. This requirement to use a bootstrap method of calculation for the confidence interval complicates the explicit specification of uncertainty in dose-response calculations. Thus the uncertainty in dose-response calculations can not be specified by incorporating some numerical multiple of the variance of a particular estimator. Furthermore, the confidence interval around the probability of illness after an exposure to a specific number of organisms is not constant over the range of doses to

which people are exposed in daily life. The practical result of using the beta-poisson functional form is that risk-analysts must resort to the types of approximations we have used in modeling the dose-response relationship with the beta-poisson functional form. Additional research in quantitative methods is needed to remedy this aspect of bacterial risk modeling.

(5) Variation in response to pathogens in different food vehicles and different meal sizes.

It is well established that foods with a high-fat content protect bacteria from the bactericidal effects of gastric acidity. It is also recognized that, when the same number of bacteria are consumed but the total amount of food varies, the amount of food consumed is negatively correlated to probability of illness - i.e. for the same number of bacteria, the more food eaten, then the less likely the risk of diarrhea . Food vehicle and meal size are, therefore, two important variables in predicting the response to exposure to a given number of bacteria. These two factors further complicate the construction of an appropriate dose-response curve.

c. Probability of clinical outcomes when ill.

Several of the parameters which describe the probabilities for clinical outcomes of disease were not described explicitly because of the lack of data. These parameters were derived from other conditional probabilities which were explicitly described based on clinical professional experience.

(1) Probability of seeing a physician, if ill.

The basic source of evidence for this parameter is the FoodNet project results (CDC, 1998). We assumed this value was appropriate for the normal sub-population, but we had no explicit data or survey results to describe the uncertainty around this estimate. We are aware of no published estimate of this parameter for the susceptible sub-populations, and the value of this estimate for the susceptible sub-population will vary widely within the susceptible sub-population depending on their particular health status and underlying medical problems and age.

(2) The other conditional probabilities for both normal and susceptible sub-populations suffer from the same lack of published data or information. Within the susceptible sub-populations, the probability of specific outcomes will vary considerably given the age and medical status of the individual.

(3) There is evidence that the conditional probabilities of specific clinical outcomes for an ill individual is functionally related to the number of organisms ingested.

Evidence suggests that with an increasing dose of the enteric pathogen the incubation period is shorter after exposure and the symptoms are more severe; It is believed that as the ingested dose of the enteric pathogen increases, the probability of a physician visit and subsequent hospitalization increases. Because of lack of data, we did not incorporate this belief into the computation of the probability of specific clinical outcomes. As public health investigators collect more data during outbreak investigations pertaining to the likely numbers of pathogens ingested, ingested dose can be correlated to clinical outcomes, and this correlation can be included in future modeling efforts.

d. Probability of long-term sequelae to illness.

Although a number of to infection with SE have been identified, we estimated the frequency of only one long-term sequelae, and that is reactive arthritis. We are not aware of epidemiologic evidence or data which quantifies the rate of reactive arthritis at different levels of exposure to SE. Such epidemiologic data would be used in validating the results of the model. A complicating factor is the observation that reactive arthritis can arise from exposure to several other foodborne pathogens as well as other non-food related causes.

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Research Needs

Risk assessments function not only to characterize factors leading to higher or lower risk, but also to identify where information is missing. Missing information identified during the modeling process targets the areas with priority for research. For the SE risk assessment, assumptions were stated throughout the text; these assumptions indicate additional places where data is needed. In this section, the most prominent research needs are summarized. Prioritization of these needs across modules was not attempted, as each module could significantly contribute to the public health outcomes depending on a given pathway or scenario.

Egg Production Module

The annual production of SE-positive eggs in the USA is estimated in the Production Module. Much of the data in the module needed to be adjusted for sampling size, the seasonal and temporal patterns of SE prevalence, and variability of SE prevalence associated with flock size strata (i.e. SE prevalence varies with the size of the flock). Research is needed to generate more data in these areas so that in the future, models can incorporate the actual observed data as opposed to the data generated by the algorithms currently in the module.

Egg production begins on the farm, yet little is known about farm environmental and/or management risk factors associated with SE-positive flocks or within-flock prevalences (i.e. proportion of SE-positive birds in SE-positive flocks). The effects of manure management and feeding practices may provide some examples of factors leading to an increase or decrease in SE-positive flocks and within-flock prevalence. Other examples of environmental and management risk factors include vaccination of flocks, rodent control in and around layer houses, cleaning/disinfection of layer houses, and the use of bacterial competitive exclusion techniques to prevent the colonization of the intestinal tract of hens with SE.

The size of the flock may also affect the probability that a flock is SE-positive. In the spent hen surveys (see page 32), the size of SE positive flocks was not documented. It is possible that flock size is correlated with whether or not a flock is SE-positive and with the within-flock prevalence of SE-positive hens. Future surveys should document and analyze the effect(s) of flock size.

A seasonal pattern to the proportion of flocks found to be SE-positive has been suggested (page 32 of Production Module). The number of positive flocks increases from March (11%), to April (29%), to May (39%) according to the 1991 spent hen survey. However, it is not known whether this increase is due to a true increase in SE-positive flocks or an increase in the prevalence within flocks associated with the season of the year. Studies should be conducted to confirm the seasonal pattern as well as to distinguish between the two possibilities. Likewise, longitudinal studies which document temporal and seasonal patterns of SE prevalence within positive flocks should be conducted.

Research Needs

The Production Module categorized flocks into either high or low prevalence SE-positive flocks by using SE contamination in the flock environment as an indicator of the status of the flock. An important question which should be addressed is whether or not these high prevalence flocks represent a constant proportion of SE-positive flocks (i.e. in other words, is there a seasonal or temporal change in the number of SE-positive flocks which are high prevalence?). This information would greatly enhance the value of survey data.

Other factors which should be investigated in future research projects include: (1) the association between severity of SE infection and specific strains of SE, (2) positive egg frequencies from geographically diverse SE-positive flocks, and (3) the efficacy of various molting strategies on SE infection.

Random surveys of eggs for the presence of SE and the number of SE bacteria in SE-positive eggs will be important in order to validate the numbers obtained from this module and future models. These surveys should occur on a national scale.

Shell Eggs Processing and Distribution Module

The Shell Eggs Processing and Distribution Module is the next module, following the Egg Production Module, in the SE farm-to-table risk assessment model. It calculates the likelihood of various numbers of SE bacteria in SE-positive shell eggs. Research needs which were identified from the Shell Eggs Processing and Distribution Module of the SE risk assessment model include the following:

Number of *Salmonella* Enteritidis in an infected egg

There are only two studies on the numbers of SE inside infected eggs at the time of laying. Both of these studies contain limited data. Gast and Beard (1992) used artificially infected hens which had been challenged with high numbers of SE. Humphrey (1994) describes an initial one log of growth in the number of SE before the pH of the egg increases and the albumen becomes inhibitory to growth. In addition, the two studies do not agree very well. These limitations and the conflicting results indicate that more research is needed to quantify the number of SE bacteria inside SE-positive eggs. It is preferably that these studies be conducted with naturally infected eggs.

Inhibition of *Salmonella* Enteritidis growth inside the egg

After the first day, the albumen is an excellent inhibitor of SE growth. This inhibition is maintained until the yolk membrane loses its ability to keep apart the SE in the albumen and the yolk contents. The time to yolk membrane breakdown depends upon the temperature storage: typical values are 17 days before yolk membrane breakdown when the egg is stored at 20° C and only 4 days before yolk membrane breakdown when the egg is stored at 35° C. This essential information comes from a single study. This single study needs to be validated by independent replication of the study.

Research Needs

Growth rates of *Salmonella* Enteritidis in eggs

Only two studies were found with significant information on the growth rates of SE in blended whole eggs at different temperatures (page 105). Blended whole eggs serve as an experimental approximation of the events following the breakdown of the yolk membrane and the utilization of yolk contents by SE in the albumen. Several experiments should be conducted on SE growth rates under various conditions in order to more accurately model the growth of SE in eggs.

Improved model for egg cooling

It would be very useful to have the ability to predict the temperature of an egg at a specified time given the initial temperature of the egg, the ambient air temperature, and the packaging characteristics . Only a few cooling curves have been published on the internal temperature of the egg over time, and no modeling or engineering studies are available. Studies are needed which correlate the internal egg temperature of an egg to the type of packaging material used, the position of the egg in a pallet of stacked cartons of eggs, and the ambient storage temperature.

Role of *Salmonella* contamination on the exterior of the shell

This model does not consider the role of SE or other *Salmonella* species found on the egg's exterior in producing human illness. Studies have shown that the bacteria on the exterior of the egg can potentially cross the shell and the two egg shell membranes, but the frequency or importance of this route of contamination for eggs in commercial channels has not been established. This route may not be significant in causing human illness; however, the question frequently arises as to the role and the significance of the exterior contamination of the egg shell in human illness. More research is needed to determine the role and the significance of exterior contamination of the egg shell in human illness .

Information about storage times and temperatures.

The sensitivity analyses indicate that storage times and temperatures are important risk factors (see page 108 of the Shell Eggs Processing and Distribution Module). More extensive surveys of industry practices (e.g. storage time after processing) should be conducted to streamline the distributions for these parameters. Industry and regulatory agencies should collaborate in these efforts.

As with the Production Module, validation of the Shell Eggs Processing and Distribution Module results is an important research need. Random egg surveys on the number of SE bacteria in SE-positive eggs should be conducted for eggs subjected to various processing, storage, and transportation scenarios.

Research Needs

Egg Products Processing Module

Sensitivity analysis of variables in the Egg Products Processing Module indicates that the number of SE bacteria in liquid egg before pasteurization is more highly correlated with the number of organisms remaining after pasteurization than any other variable tested. This relationship is true for whole egg, albumen, and yolk. This information has two implications. First, reduction in the number of bacteria in liquid egg prior to pasteurization will result in a reduction in the number of bacteria post pasteurization. Plant sanitation including washing and sanitizing of incoming eggs, and prevention of cross contamination from breaking machinery, machine operators, airborne *Salmonella*, and the surface of the shell in the breaking process are the most promising means of reducing *Salmonella* in the final product. Second, refining our estimate of the number of organisms before pasteurization would allow us to predict with greater certainty the number remaining after pasteurization.

Our sources of data for the number of organisms in liquid egg before pasteurization have significant shortcomings. The 1991 and 1995 liquid egg surveys (Ebel, 1991 and Hogue, 1997) provide no information on the number of organisms because samples were only analyzed for the presence or absence of SE and other *Salmonella*. The 1969 survey (Garibaldi, 1969) includes the number of *Salmonella* organisms present but the information is nearly thirty years old and is not specific to *Salmonella* Enteritidis. Significant changes have occurred in the egg products industry over the last 30 years. A current survey of the level of *Salmonella* in liquid egg prior to pasteurization including the variation in *Salmonella* across breaker plants nationwide would provide information useful in predicting the number of organisms likely to remain after pasteurization.

The uncertainty in our estimates of the logs of bacteria reduced in liquid egg pasteurized according to FSIS regulations is large (Table 7). The 95% confidence interval for whole egg and yolk extends from about five to more than 20 and albumen is about one to 16. The reason for this large uncertainty is that our estimates were made by regression of data from all current experimental pasteurization studies on egg products. Variation within studies is generally low but variation between studies is large (see regression charts for whole egg [page 130], yolk [page 136], and albumen [page 132]). Minor differences in methods between studies do occur but no single variable has been identified as responsible for the lack of repeatability of pasteurization studies between laboratories. Egg may, by its composition (high fat and globular), provide less repeatable results, or the conditions under which bacteria are grown prior to inoculation into the egg may influence experimental results. In any case, a better understanding of the reasons for the lack of repeatability in experimental pasteurization studies on liquid egg is essential in accurately predicting the number of bacteria remaining in liquid egg after pasteurization.

Table 7. Estimates of the reduction in *Salmonella* Enteritidis from pasteurization

Product	FSIS minimum pasteurization requirements	Expected logs of SE reduced	95% confidence interval
whole egg	60°C for 3.5 minutes	8.1	5.2-17.8
yolk	60°C for 6.2 minutes	7.8	4.7-19.6
	61.1°C for 3.5 minutes	8.2	5.4-22.5
albumen (pH=8.3)	55.6°C for 6.2 minutes	3.6	1.1-15.7
	56.7°C for 3.5 minutes	3.7	1.1-16.0

pH is inversely correlated with the number of bacteria in albumen after pasteurization (i.e. the higher the pH of albumen, the greater the reduction in the number of SE during pasteurization). The pH of egg albumen increases from about 7.8 to 9.3 over the first three or four days after lay. FSIS requirements for pasteurization are based on a pH for albumen of about nine. FSIS minimum time and temperature requirements for egg white pasteurization were adequate in the late 1960's when the regulation was enacted because eggs generally took more than four days to reach breaker plants. The industry in 1998 includes in-line operations where eggs generally reach the breaker plant in less than 24 hours and thus have a lower initial pH. Also, restricted eggs currently make up a smaller proportion of the eggs broken than in 1969 because of the growth of the egg products industry. Since restricted eggs are sorted during grading and diverted to pasteurization, they are generally older when they arrive at breakers.

Information used in this model about the pH of albumen in breaker plants across the U.S. comes largely from the opinion of industry experts and experimental studies on the change in pH of egg white over time. More accurate survey information about the pH of albumen in breaker plants and how pH varies across breaker plants nationwide will reduce the uncertainty in our estimate of the number of SE in egg white after pasteurization.

Preparation and Consumption Module

The purpose of the Preparation and Consumption Module is to determine the number of egg containing servings which are contaminated with SE and the extent of this contamination. Due to a lack of sufficient data, the Preparation and Consumption Module estimated several preparation and consumption variables in both the home setting and in the institutional settings. Storage times and temperatures, probability of eggs being pooled or non-pooled, thoroughness of cooking, and the number of eggs consumed as “eggs” versus “eggs as ingredients” were estimated from the results of limited surveys or by members of the core group of the SE risk assessment team. Much research is needed in these areas, as preparation and consumption variables have significant effects on public health outcomes.

Research Needs

Specific examples of data needs are as follows:

--Retail storage times and temperatures before cooking
--Home storage times and temperatures before cooking
--Institutional storage times and temperatures before cooking
--Pooling factors in home and institutional settings
--Thoroughness of cooking for pooled vs. non-pooled eggs
--Thoroughness of cooking in home and institutional settings
--Home and institutional storage times and temperatures after pooling
--Home and institutional storage times and temperatures after cooking
--Consumption patterns for institutional and home settings--pooled vs. non-pooled
--Consumption patterns for institutional and home settings--cooked vs. undercooked
--Consumption patterns for institutional and home settings--"eggs" vs "eggs as ingredients"

This information could be obtained through cooperative studies amongst retailers, institutions, and regulatory agencies. Information about home practices could be obtained through surveys conducted by regulatory agencies, retailers, and/or consumer groups.

In addition to preparation and consumption variables, bacterial death rates with respect to cooking times and preparation of various egg dishes have not been well-studied. Results used in the Preparation and Consumption Module are taken largely from one study (Humphrey et al., 1989). Log reduction of bacteria in this study is enumerated for total cooking time on inoculated eggs that are cooked as "eggs", not ingredients. No data exist for bacterial death rates with "eggs as ingredients". Future studies should (1) monitor the log reduction of bacteria for each minute given each style of cooking (e.g. log reduction in bacteria after boiling a shell egg for one minute, after boiling a shell egg for two minutes, after boiling a shell egg for three minutes, and after boiling a shell egg for four minutes--total time 4 minutes); 2) focus on the death rates with respect to "eggs as ingredients", and 3) incorporate naturally infected eggs into the studies.

Results of the Preparation and Consumption data should be validated by surveying homes and institutions for preparation and consumption practices and subsequently sampling egg-containing dishes from the surveyed groups for the presence and enumeration of SE.

Research Needs

Public Health Outcomes Module

The Public Health Outcomes Module links exposure to SE-contaminated foods with adverse health outcomes. Limitations of this module were summarized in the text of the module (see page 252). These limitations are indicators of specific research needs.

Proportion susceptible

Data on the types and numbers of people more susceptible to foodborne pathogens are limited. Currently, the data does not account for differences within the susceptible and "normal" sub-populations, but rather dichotomizes the human population into these two groups. The probability of a certain clinical outcome may be very similar between the most "sensitive" of the "normal" sub-population and the most "robust" of the susceptible sub-population. There is most likely a continuum of susceptibilities in the human population. Future research should focus on further stratification of the susceptible and "normal" sub-populations (i.e. defining subcategories of each of the two groups).

Dose-Response Parameters (probability of illness)

Much of the dose-response data is based upon animal models or human feeding trials using strains other than SE. The human feeding trials are also of limited use because of the small sample sizes, the repeated use of subjects, and the use of a quantitatively large dose as the minimum doses. Given the differences between animals and humans, the variation in human susceptibility, and bacterial strain/species differences, there is a great deal of uncertainty in dose-response calculations, especially in the low dose ranges. Because human studies should not be conducted with pathogenic organisms, research is needed to determine how to deal with this uncertainty. Better quantitative methods (e.g. better functional forms) for modeling the probability of illness are needed.

Dose-response data can be obtained from outbreaks. Epidemiologic investigations which trace the food vehicle and enumerate the number of disease causing organisms in this vehicle should be expanded. Current surveillance efforts (e.g. FoodNet USDA/FDA/CDC) should enhance efforts to track the causative food source.

Probability of clinical outcomes when ill

Important parameters describing probabilities for clinical outcomes of disease often were not described explicitly due to a lack of data. Research is needed to determine these outcome probabilities, particularly with respect to the susceptible sub-population. More extensive surveys of the general population and medical professionals are needed to determine these values.

The number of ingested organisms may be related to the severity of illness due to SE and to the incubation period for a particular illness. Evidence suggests that there is an increase in the probability of treatment by a physician and in the probability of hospitalization when higher doses are ingested. Likewise, with higher doses, the

incubation periods (i.e. the time between infection and the onset of clinical signs) of SE illnesses appear to be shorter. However, because of the lack of data, these relationships were not incorporated into the computation of clinical outcomes. Research is needed to collect more data concerning the relationship between the number of ingested organisms and clinical health outcomes.

Probability of long-term sequelae to illness

Only one long-term sequelae to illness, reactive arthritis, was estimated in the current Public Health Outcomes Module. Several other long-term sequelae of SE infection have been identified; however, information is limited with respect to the proportion of these long-term sequelae that can be attributed to SE. Epidemiologic studies should be expanded to enumerate the long-term sequelae due to foodborne illness and to investigate the food vehicles involved.

End