Identifying the Most Significant Microbiological Foodborne Risks to Public Health: A New Risk-Ranking Model

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Introduction

The National Academies of Science, federal food safety agencies, the US General Accounting Office and numerous other expert bodies embrace the goal of a science- and risk-based food safety system (NRC 1998, 2003; GAO 1997, 2001). In such a system, risk managers prioritize food safety hazards and preventive interventions using the best available data on the distribution of risk and on how risk can be reduced most effectively and efficiently (Taylor and Hoffmann 2001). This requires taking a more integrated systems approach to reducing foodborne illness; regulators must understand the many factors that contribute to the causation and prevention of foodborne illness from the point of production to the point of consumption and must be able to systematically target efforts in ways that contribute most effectively to risk reduction.

This approach to food safety requires decision tools and data that, with few exceptions, do not currently exist (Taylor et al. 2003). Specifically, decision makers need tools to: (1) identify the most significant risks from a public health perspective; (2) prioritize opportunities to reduce risk, taking into account the feasibility, effectiveness, and cost of possible interventions; and (3) allocate their efforts and resources accordingly.

To address the first need, we created the Foodborne Illness Risk Ranking Model (FIRRM), an analytical software tool designed to enable decision makers to identify, compare, and rank the relative public health impact of twenty-eight foodborne pathogens. Specifically, FIRRM is intended to rank pathogen-food combinations according to five measures of public health impact, including estimated number of cases, hospitalizations, and deaths, as well as estimated economic impact and loss of Quality Adjusted Life Years (QALYs). FIRRM is the first comprehensive model to attribute estimates of microbiological foodborne illness to specific pathogen-food combinations, to employ economic and QALY valuation, and to utilize Monte Carlo simulation to quantify uncertainty.

In doing so, the model combines and furthers much of the research on the topic including: estimates of the incidence of foodborne illness by the Centers for Disease Control and Prevention (CDC) (Mead et al. 1999); cost-of-illness studies by the USDA's Economic Research Service (ERS) (Buzby et al. 1996, Buzby and Roberts 1996, Buzby and Roberts 1997, Frenzen 1999, ERS 2003); risk assessments by the Food and Drug Administration (FDA), USDA's Food Safety and Inspection Service (FSIS), and others (CFSAN 2000, CFSAN 2003, FSIS 1998, FSIS 2001); and a dataset created by the Center for Science in the Public Interest (CSPI) in which outbreaks are linked to causal food vehicles (DeWaal and Barlow 2002).

Materials and Methods

Presently, FIRRM focuses solely on microbiological foodborne hazards. It excludes chemical risks as well as waterborne and environmental microbiological risks. These latter risks are clearly important, and can be incorporated into the model later; however, for the initial effort we elected to concentrate on microbiologic risks. From a regulatory and policy perspective, it is essential that we know which foods are responsible for specific illnesses as well as the relative contribution of these foods to the total disease burden associated with specific foodborne pathogens. Consequently, the model addresses pathogen-food combinations rather than pathogens. Incidence estimates alone are not sufficient for the comparison of illnesses due to the different symptoms and severities associated with different pathogens. The model therefore includes economic and QALY valuation, which incorporate public preferences, to provide a way of comparing different illnesses using a common metric. Finally, the model builds uncertainty into its input variables and results through Monte Carlo simulation, as point estimates exaggerate confidence and may misrepresent the true state of knowledge.

We created FIRRM using Analytica software, a visual modeling and Monte Carlo simulation environment in which mathematical models are developed using functional influence diagrams. Analytica was explicitly designed for risk analysis and risk-informed decision making and is therefore well suited to our functional model needs. Analytica's visual approach and features also meet our usability objectives of transparency, flexibility, adaptability, and accessibility.

Modeling Approach: FIRRM utilizes a "top-down" epidemiological approach rather than a "bottom-up" microbiological approach to estimating illnesses. To estimate illnesses due to pathogen-food combinations, FIRRM uses surveillance data on pathogen illnesses and then traces these illnesses back to food origin. This is distinguished from conventional risk assessment approaches, which use food contamination data, predictive microbiology, and consumption patterns to estimate illnesses.

As we are most concerned with ranking public health impacts, we want to start with observable data gathered as close to these health outcomes as possible, rather than rely on predictions of illnesses based on modeling of microbial risk. In addition, utilizing a predictive microbiological approach would imply performing separate risk assessments on thousands of individual pathogen-food combinations, a frankly impossible task. Finally, for the purpose of risk ranking, computations and data should be consistent across ranked items. A top-down approach ensures identical methodology across pathogen-food combinations; individual risk assessments are not nearly so directly comparable. Although this approach is preferable for a big-picture comparison of foodborne risks, it is inadequate to isolate the causes of illness along the farm to table pathway.

Model Design: FIRRM is composed of three major modules: incidence, economic and QALY valuation, and food attribution. In the first module, the annual number of cases, hospitalizations, and deaths from 28 foodborne pathogens are estimated from public health surveillance data; this module includes estimates for the U.S. as well as for the state of Maryland. In the second module, the economic cost and QALY loss associated with a single case of illness are computed for individual pathogens. The third module consists of pathogen-specific food attribution percentages; illnesses from each pathogen are attributed, by percentage, to some set of food "vehicles." As discussed in depth at a recent FSRC workshop (FSRC 2003), a fully adequate source for such food attribution data does not currently exist. Consequently, the model includes two approaches and data sources: 1) outbreak data, which are easily accessible but can offer a distorting picture of risks as cases not tied to an outbreak are ignored; and 2) an expert elicitation, which develops attributions based on judgments of food safety experts and may, to some extent, depend on outbreak data (see FSRC 2003 for more detail on these approaches). We have also worked on development of an algorithm to estimate food attribution percentages based on levels of microbial contamination and food consumption. At its current state of development (and reliance on the inconsistent data on food contamination available from published sources) the algorithm does not provide useable solutions.

Estimates of National Incidence: Estimates of the national incidence of pathogen-specific foodborne illnesses are based on the data and methods described in detail in Mead et al. (1999). Mead's approach relies heavily on parameters representing his best judgment on underreporting. Rather than include only Mead's final estimates, Mead's approach and data were built into the model to allow these parameters to be changed, data to be updated, and to allow for the incorporation of uncertainty into Mead point estimates.

Mead bases his estimates on incidence data on 28 bacterial, viral, and parasitic pathogens (*see* Table 1) from active, passive, and outbreak surveillance sources. The average values of this data are then multiplied by under-reporting factors to obtain estimates of the annual number of cases, hospitalizations, and deaths associated with each pathogen.[1] These estimates are multiplied by the percent of illnesses due to each pathogen estimated to be due to foodborne sources. Thus, following the Mead approach, annual foodborne cases of illness ($fbcases_p$) of pathogen p can be expressed as

$$fbcases_p = repcases_p * curf_p * surf_p * pctfb_p\,, \tag{1}$$

where $repcases_p$ is the average annual number of reported cases of illness cause by pathogens, $curf_p$ is the pathogen-specific under-reporting factor based on illness symptom severity, $surf_p$ is a sporadic under-reporting factor for illnesses estimated from outbreak data, and $pctfb_p$ is the percent of total illnesses estimated to be due to foodborne sources. Similarly, hospitalizations ($fbhosps_p$) and deaths ($fbdeath_p$) due to these foodborne pathogens can be represented by

$$fbhosps_p = repcases_p * rephrate_p * hurf_p * pctfb_p, \quad \text{and} \tag{2}$$

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[1] Of 28 pathogens included, estimates for 11 are based on active surveillance data, 7 are based on passive surveillance data, 6 are based on outbreak surveillance data, and 4 are based on non-surveillance data. Estimated annual cases due to *Toxoplasma gondii*, Norovirus, Rotavirus, and Astrovirus are based on estimated infection rates applied to the U.S. population. Hospitalizations and deaths for these four pathogens plus *Giardia lamblia* are

$$fbdeath_p = repcases_p * repdrate_p * durf_p * pctfb_p, \tag{3}$$

where $rephrate_p$ is the reported hospitalization rate ($hurf_p$) is the hospitalization under-reporting factor ($repdrate_p$) is the reported death rate, and $durf_p$ is the under-reporting factor for deaths.

Mead uses point values for all estimates and thus excludes uncertainty from the analysis. For example, Mead reports the range of under-reporting associated with *Escherichia coli* O157:H7 cases to be between 13 and 27, but only uses the midpoint of 20 in calculations. As a result, although Mead estimates 62,458 annual cases of foodborne *E. coli* O157:H7, the uncertainty associated with the under-reporting factor implies a possible range of cases from 41,598 to 84,318, or a range of plus-or-minus 35% around the point estimate. Placeholder variables for uncertainty are built into the structure of the model, but as Mead does not report uncertainty values for many key parameters, these variables are largely devoid of values. Using the model's default settings, therefore, estimates of national foodborne incidence are point estimates.

Estimates of Maryland Incidence: The model estimates incidence of nine pathogens for the state of Maryland based on active surveillance data collected as part of the CDC's FoodNet program (CDC 1997, 2003).[2] This sub-module was designed to provide an example of how annual FoodNet data could be used to produce constantly updated estimates of incidence, in contrast to Mead's snapshot estimates (1999).

The dataset included over 1500 entries of culture-confirmed cases in 1998 and 1999, cleaned of personal identifiers, with the following variables: isolate, serotype, sex, age, sample location, sample source (stool, blood, etc), month, dates of hospitalization, and outcome (recovered, died,

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similarly computed from non-surveillance data. Incidence estimates based on non-surveillance data do not use under-reporting factors.

[2] The nine FoodNet pathogens are: *Campylobacter* spp., *Cryptosporidium* spp., *Cyclospora*, *E. coli* O157:H7, *Listeria monocytogenes*, non-typhoidal *Salmonella*, *Shigella* spp., *Vibrio* spp., and *Yersinia enterocolitica*.

unknown). From these data, we counted the annual number of total reported cases, reported hospitalized cases, reported physician visits, and reported cases resulting in death. To estimate illnesses from reported data, we used under-reporting factors taken from the national 1998 FoodNet Physician Survey and the national 1998-99 FoodNet Community Survey (Imhoff et al. 2000). Whereas Mead's under-reporting factors are pathogen-specific but static over time, FoodNet under-reporting factors change over time but are not pathogen-specific.

The total number of annual cases of illness ($cases_{pt}$) for pathogen p and year t is defined as

$$cases_{pt} = hvis_{pt} + phvis_{pt} + nophvis_{pt} \,. \tag{4}$$

For pathogen p and year t annual physician visits ($hvis_{pt}$) are estimated by multiplying the number of reported physician visits by an under-reporting factor to account for the fact that doctors don't submit samples for every case of diarrheal illness. This under-reporting factor is defined as a uniform distribution between two estimates: one drawn from the physician survey and one drawn from the community survey (Imhoff et al. 2000). According to the community survey, a small percent of physician visits result in hospitalization (Imhoff et al. 2000). Annual hospitalizations ($phvis_{pt}$) are therefore defined as a uniform distribution with this value as the upper bound and reported hospitalizations as the lower bound. Estimated cases with no medical attention ($nophvis_{pt}$) are estimated by multiplying estimated physician visits by an under-reporting factor based on the community survey which estimates the number of illnesses in the community for each illness that results in physician care.

FoodNet collects no data on under-reporting of deaths, therefore estimated deaths ($death_{pt}$) is assumed equal to reported deaths.

As Maryland FoodNet data was collected in 1998 and 1999 only for the Baltimore metropolitan area, incidence estimates are scaled up to statewide estimates using U.S. Census county-level population data. Estimates of total annual foodborne cases ($fbcases_p$) may be therefore be expressed as

$$fbcases_p = pctfb_p * \frac{1}{T}\sum_{t}^{T} cases_{pt} * \frac{PopM_t}{PopB_t}, \tag{5}$$

where $PopM_t$ is the population of Maryland in year t, $PopB_t$ is the population of Baltimore for the same year, $pctfb_p$ is the estimated percent foodborne, as drawn from Mead, and T is the total number of years of data. Foodborne hospitalizations ($fbhosps_p$) and deaths ($fbdeath_p$) are calculated similarly. While national incidence estimates are point values, Maryland incidence estimates are distributions.

Economic Valuation of Health Effects: FIRRM includes two alternative measures of the economic value of avoiding adverse health effects: cost-of-illness (COI), and willingness-to-pay (WTP). COI is defined as the direct market costs of illness, primarily medical costs and labor market productivity losses. It is widely used in regulatory analysis because it is easy to estimate, but economists agree that it undercounts the economic value of avoiding illness. WTP is generally recognized by economists as a more complete health valuation measure. It measures the value that individuals place on specific risk reductions in order to obtain the benefits of such risk reductions (Freeman 2003).

COI and WTP measures are used to value outcomes from health-outcome trees developed in studies from the USDA Economic Research Service (ERS) on the costs of bacterial foodborne disease (Buzby et al. 1996, Buzby and Roberts 1996, Buzby and Roberts 1997, Frenzen 1999, ERS 2003). In these health-outcome trees, total cases of illnesses from a particular pathogen are mapped by symptom, severity, and medical attention required into health-outcome trees unique to each pathogen. Rates of hospitalization, death, and other health effects are used to estimate the annual number of cases of each health state in the outcome tree. For each health state *i*, the number of cases is multiplied by the economic value per-case of avoiding that health state ($valperhs_i$). Thus, the economic impact of foodborne illnesses due to pathogen p ($fbval_p$) may be expressed as

$$fbval_p = fbcases_p \sum_{i}^{I} (valperhs_i * pcths_i)\,, \tag{6}$$

where $fbcases_p$ is the number of foodborne cases of pathogen p as defined in equations (1) and (4), and $pcths_i$ is the likelihood of health state i. The total number of health states (I) varies by pathogen.

FIRRM includes health-outcome trees for four pathogens - *Campylobacter*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, and non-typhoidal *Salmonella* - drawn directly from ERS studies. We did not create health-outcome trees for additional pathogens due to resource limitations. Although most data in the health-outcome trees are drawn from ERS studies, the two major exceptions are the hospitalization rate and fatality rate. Both national and Maryland estimates of these rates are derived from incidence estimates. Some assumptions in FIRRM also differ from ERS assumptions. These differences are described in detail in internal model documentation and can easily be changed in the model by the analyst to match ERS assumptions.

COI and WTP estimates for the economic impact of foodborne illness are drawn from existing studies. Cost-of-illness estimates are drawn from ERS studies. Estimating WTP values is highly resource-intensive and therefore estimates are not available for all health states. Estimates of WTP to reduce mortality risk are much more common than those for morbidity. Estimates of

WTP to reduce mortality risk (commonly referred to as the "value of a statistical life" (VSL)) are taken from several studies, some of which vary by age and some of which do not (Krupnick et al. 2002; Landefeld and Seskin 1982; Mrozek and Taylor 2002; Viscusi 1993; EPA 1997, 1999). These include studies used by ERS and the Environmental Protection Agency in their regulatory benefits analysis. For health states without available WTP values, empty placeholder variables are built into the model; COI estimates are used as default values. Further research is needed to provide estimates of WTP to fill in these placeholder variables.

QALY Valuation of Health Effects: FIRRM also includes valuation of health effects in Quality Adjusted Life Years (QALY), an alternative to economic valuation commonly used in the public health community (Gold 1996). QALY loss is computed in the model similarly to economic cost; health states in a pathogen's health-outcome tree are individually valued and summed. Thus, the QALY loss of foodborne illnesses ($fbqaly_p$) due to pathogen p, may be expressed as

$$fbqaly_p = fbcases_p \sum_{i}^{I} (qalyperhs_i * pcths_i), \tag{7}$$

where $qalyperhs_i$ is the per-case QALY loss of a health state i, and the remaining variables are the same as defined in equation (6).

QALYs are estimated for a health state by multiplying a health index (between 0 for death and 1 for perfect health) by the duration of the health state in years. There are numerous health indices available to estimate QALYs based on different approaches and assumptions. FIRRM uses the Quality of Well-Being (QWB) index, which is based on four component scores -- Mobility, Physical Activity, Social Activity, and Symptom/Problem Complex -- that are computed for each health state (Kaplan et al. 1979, Kaplan et al. 1998). The QWB index was selected for ease of use and due to resource limitations that precluded the extensive research required to implement the Health Utility Index (Feeny et al. 1996; Furlong et al. 1998) or other indices.

QALY loss is defined as the difference between a baseline health index and the health index associated with a particular health state, multiplied by the average duration of the health state. Thus, the per-case QALY loss ($qalyperhs_i$) of health state i, as required for equation (7), can be expressed as

$$qalyperhs_i = (qwb_{baseline} - qwb_i) * dur_i , \tag{8}$$

where $qwb_{baseline}$ and qwb_i are the QWB scores for the baseline health state and a health state, i, respectively, and dur_i is the duration of that health state.

Food Categories for Food Attribution: To attribute illnesses to foods, FIRRM relies on a two-tier food categorization scheme developed and used by Center for Science in the Public Interest in their analyses of outbreak data from CDC and other sources (DeWaal and Barlow 2002). We modified the CSPI food categorization scheme to make it more appropriate for the model; the final scheme is shown in Table 2. The model's food categories are explained in more detail in FSRC (2002) and in internal model documentation.

Food Attribution from Outbreak Data: The outbreak method of food attribution is based on analysis of CSPI's compilation of outbreak data, in which each outbreak has been traced to an implicated food vehicle. These data include primarily unpublished CDC data obtained through FOIA requests, but also include additional outbreak reports collected and verified by CSPI. Of the 2,472 outbreaks listed in the September 2002 Outbreak Alert, 300 or 12.1% were not from CDC sources (DeWaal and Barlow 2002). After pathogens not in FIRRM were excluded, the dataset contained entries for 1,977 outbreaks, representing 83,619 individual cases of foodborne illness.

The food vehicles in the outbreak attribution dataset were categorized into the two-tier scheme previously discussed. For each pathogen, food attribution percentages were computed by dividing the number of cases due to each pathogen-food combination by the total number of cases due to that pathogen. Food attribution percentages therefore sum to 100% for a single pathogen across all food categories.

Food Attribution from Expert Elicitation Results: We designed and implemented an expert elicitation survey, in which experts were asked to estimate, for each pathogen, the percentage of illnesses attributable to each food ”vehicle”. The survey was developed, with the aid of Dr. Paul Fischbeck, Carnegie-Mellon University, a recognized expert in the field of expert elicitation, using standard methodologies found in the literature (Morgan et al. 1990; Cooke 1991). The survey included 11 major pathogens and elicited uncertainty bounds around responses.[3] The survey was sent to a peer-reviewed list of 101 scientists, public health officials, and food safety policy experts; we received 45 responses. The model includes an average of experts' best judgment estimates of attribution percentages. Work is underway to further analyze survey results.[4]

Computing Rankings: To compute risk rankings, the model combines results from the three aforementioned modules. For each pathogen, foodborne incidence from the first module and

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[3] The survey asked respondents to give low, high, and best-guess estimates, and asked them to rate their expertise on individual pathogens and individual food categories on a scale from 1 to 5.

[4] The model also includes the option of using the results of a series of risk assessments on *Listeria monocytogenes* in 23 ready-to-eat (RTE) foods performed by FDA, USDA, and CDC (CFSAN 2003). The risk assessments estimated the number of annual illnesses due to Listeria in each food item, which were classified into the major food categories in the model. Food attribution percentages were computed by dividing the number of estimated cases in each food category by the total estimated cases of Listeria from all twenty-three risk assessments.

valuation of health outcomes from the second module are multiplied by the food attribution percentages from the third module to obtain incidence and valuation by pathogen-food combination. The primary output of the model is a risk ranking of pathogen-food combinations, sorted by one of the five measures of public health burden: annual estimated cases, hospitalizations, deaths, economic cost, and QALY loss.

Results and Discussion

The results produced by FIRRM are only preliminary. There are a significant number of areas in which data are missing or thin; there are other modules, namely in valuation and food attribution, that have yet to be fully designed and programmed; and uncertainty is not fully incorporated into many model input variables. These issues make it impossible for us to draw strong policy conclusions from the ranking results produced by the model. Nonetheless, results strongly support the value of the underlying methodology to food safety policy analysis and highlight the importance of some key attributes of the model.

Pathogen-Food Combinations: The results show quite clearly how risk rankings are sensitive to whether pathogens or pathogen-food combinations are being ranked. Table 3 shows that while only three pathogens cause the vast majority of annual foodborne hospitalizations, these illnesses are spread across a large number of foods. The top-ranked pathogen may be Norovirus, but Salmonella in egg dishes is the most significant pathogen-food combination. This type of ranking enables the comparison of specific disease pathways in the food safety system and points towards development of more efficient intervention strategies.

Measures of Public Health Burden: The results show that rankings are sensitive to the outcome measure. For the four pathogens for which economic and QALY valuation were completed, table 4 shows that while Campylobacter causes more cases of foodborne illness than any of the other pathogens, Salmonella causes the most hospitalizations and deaths, and is likewise the most expensive. Economic valuation is driven largely, though not entirely, by the value of statistical life (VSL) used to value mortality risks. The default VSL is $2.39 million (2001$), drawn from Mrozek and Taylor (2002); if a significantly lower VSL is chosen, such as Krupnick's $720,000 (2001$) estimate (2002), Campylobacter becomes the most expensive pathogen due to its greater incidence. Salmonella and Listeria have similar economic costs because although Salmonella is associated with far more hospitalizations, Listeria hospitalizations are far more severe and costly. Estimates of QALY loss for Salmonella and Listeria differ greatly because of their age-distributions; those who die from Salmonella are, on average, much younger than those who die from Listeria, and therefore have greater loss of life-years.

Food attribution complicates the matter. Table 5 shows the same pathogen-food combinations shown in Table 3 for all five health-outcome measures, sorted by hospitalizations. There is little agreement as to which is the most significant public health risk; Salmonella from egg dishes, Norovirus from shellfish, and Listeria from luncheon meats all rank highest by different outcome measures. As valuation was only completed in the model for four pathogens, economic valuation of some key pathogen-food combinations could not be computed. Indeed, these missing values suggest the importance of completing economic valuation for both Norovirus and Toxoplasma.

Methods of Food Attribution: Table 6 shows food attribution percentages for Campylobacter and Listeria using the expert elicitation, outbreak data and a series of Listeria risk assessments. According to outbreak data, only 16% of Campylobacter illnesses are due to Poultry. Experts note the limitations of outbreak data for a largely sporadic illness with few outbreaks and estimate that percentage to be nearly 70%, citing a reliance on case control data. Percentages for Listeria show greater similarities across attribution methods, though they still differ. Listeria outbreaks were recorded only in four food categories, whereas experts associate at least minor Listeria risk with every food category. Food attribution percentages drawn from the CFSAN/FSIS risk assessment on *Listeria monocytogenes* are also shown for comparison although they are not directly comparable to the other two approaches, as they were only performed on 23 ready-to-eat (RTE) food items in only five of the model's food categories. Nonetheless, the risk assessments agree with the two other approaches that luncheon meats and dairy are the two most important food categories for Listeria.

Uncertainty: Although the model includes various measures of uncertainty, too little statistical information on uncertainty about model inputs is currently available to make extensive analysis of uncertainty meaningful. In order to report uncertainty associated with rankings, it is imperative to be able to characterize uncertainty about national incidence of illness and death; further research is required to define uncertainty distributions around Mead's reported estimates and under-reporting multipliers. Similarly, further analyses are required to define uncertainty around outbreak estimates and mean values obtained from expert elicitations of food attribution. Currently, the primary driver of uncertainty bounds around model outputs is uncertainty associated with per-case valuation estimates. Analysis of the consequences of this source of uncertainty on model results suggests how further information on uncertainty can clarify what we do and do not know about the impacts of foodborne illness. Under default settings, the estimated annual mean cost of foodborne Salmonella and Campylobacter are $1.6 billion and $1.4 billion, respectively. The 5th and 95th percentile values for Salmonella COI are $1.4 billion to $1.8 billion. Those for Campylobacter COI are far broader -- $730 million to $2.0 billion. The uncertainty around these mean values will increase when uncertainty associated with incidence estimates is added.

Conclusion: Although FIRRM is in a preliminary stage of development and is too incomplete to use to make policy recommendations, the ranking results highlight both the long-term potential of the model as a policy tool, and the areas in which there is a critical need for further data collection and parameter estimation. In making Mead's incidence estimates transparent, the model underscores the need for explicitly considering uncertainty about under-reporting multipliers. The model demonstrates how active surveillance data from FoodNet might be used to produce continually updateable estimates of incidence at a state or national level, and provides a tool for comparing FoodNet data with incidence estimates derived using Mead's methodology. The model demonstrates the importance of economic valuation of illnesses, as the most costly illnesses may not be those that are the most common, while also showing that the costs of illness vary greatly depending on assumptions about the value of reducing mortality risk. Perhaps most strikingly, the model highlights the inadequacy of existing food attribution data and shows explicitly how different attribution methods and data sources can lead to profoundly different outcomes. Overall, however, the model successfully integrates disparate data sources in a transparent and straightforward manner, and will have increasing utility as additional (and better) data are added, and the model structure is further refined.

Table 1: Pathogens in FIRRM (Mead Pathogens)

Bacteria		**Parasites**
Bacillus cereus	*Salmonella* Typhi	*Cryptosporidium parvum*
Brucella spp.	*Salmonella* nontyphoidal	*Cyclospora cayetanensis*
Campylobacter spp.	*Shigella* spp.	*Giardia lamblia*
Clostridium botulinum	*Staphylococcus* spp.	*Toxoplasma gondii*
Clostridium perfringens	*Streptococcus* spp.	*Trichinella spiralis*
E. coli O157:H7	*Vibrio cholerae* toxigenic	**Viruses**
E. coli non-O157 STEC	*Vibrio vulnificus*	*Norovirus*
E. coli enterotoxigenic	*Vibrio*, other	Rotavirus
E. coli other diarrheogenic	*Yersinia enterocolitica*	Astrovirus
Listeria monocytogenes		Hepatitis A

Table 2: Food Categories used in the Foodborne Illness Risk Ranking Model

Major category	**Sub-category**	**Major category**	**Sub-category**
Seafood	Finfish	Breads and Bakery	Breads
	Molluscan Shellfish		Bakery
	Other Seafood		Breads and Bakery Combo
	Seafood Dishes	Game	Game
	Seafood Combo	Beef	Ground Beef
Eggs	Eggs		Other Beef
	Egg Dishes		Beef Dishes
	Eggs Combo	Poultry	Chicken
Produce	Fruits		Turkey
	Vegetables		Other Poultry
	Produce Dishes		Chicken Dishes
	Produce Combo		Turkey Dishes
Beverages	Juices	Pork	Ham
	Other Beverages		Other Pork
	Beverage Combo		Pork Dishes
Dairy	Milk	Luncheon/ Other Meats	Luncheon Meats
	Cheese		Other Meats
	Ice Cream		Other Meat Dishes
	Other Dairy	Multi-Source	USDA
	Dairy Combo		FDA
Multi-Ingredient	Salads		Both USDA/FDA
	Rice/Beans/Stuffing/Pasta Dishes	Unattributable	Unattributable and Other
	Sandwiches		
	Sauces/Dressings/Oils		
	Other Foods		
	Multi-Ingredient Combo		

Table 3: Top Pathogens and Pathogen-Food Combinations, Ranked by Estimated Annual Hospitalizations, Using Default Model Settings

Rank	Pathogen	Hospitalizations[a]	Pathogen-Food Combination	Hospitalizations[b]
1	*Norovirus*	20,000	*Salmonella* nontyphoidal / Egg dishes	4,219
2	*Salmonella* nontyphoidal	15,610	*Norovirus* / Molluscan shellfish	3,247
3	*Campylobacter*	10,540	*Norovirus* / Multi-Ingredient salads	3,053
4	*Toxoplasma gondii*	2,500	*Norovirus* / Produce dishes	2,963
5	*Listeria monocytogenes*	2,298	*Campylobacter* / Vegetables	2,623
6	*E. coli* O157:H7	1,843	*Toxoplasma gondii* / Unattributable food	2,500
7	*Staphylococcus*	1,753	*Campylobacter* / Milk	2,045
8	*Shigella*	1,246	*Norovirus* / Fruits	1,881
9	*Yersinia enterocolitica*	1,105	*Campylobacter* / Chicken	1,522
10	*E. coli* non-O157 STEC	921	*Norovirus* / Vegetables	1,299
11	Hepatitis A	542	*Campylobacter* / Produce dishes	1,148
12	Rotavirus	500	*Salmonella* nontyphoidal / Vegetables	1,085
13	*Giardia lamblia*	500	*Listeria monocytogenes* / Luncheon meats	990
14	*Salmonella* Typhi	494	*Norovirus* / Bakery	937
15	*Streptococcus*	356	*E. coli* nonO157 STEC / Unattributable food	921

[a] Mean estimated annual foodborne hospitalizations for the United States.

[b] Mean estimated annual foodborne hospitalizations for the United States, attributed to food sub-categories using outbreak data. The food category "Unattributable food" implies that there were not enough outbreaks of that pathogen in the outbreak dataset to attribute estimated illnesses from that pathogen to food categories.

Table 4: Measures of Public Health Burden for Four Major Pathogens, Using Default Model Settings[a]

Pathogen	Cases	Hospital-izations	Deaths	Cost ($Millions)	QALY Loss
Campylobacter	1,963,141	10,539	103	1,397	8,727
E. coli O157:H7	62,458	1,843	52	232	2,003
Listeria monocytogenes	2,493	2,298	499	1,604	8,795
Salmonella nontyphoidal	1,341,873	15,608	551	1,607	14,400

[a] Mean annual foodborne estimates for the United States. Costs are in 2001 dollars.

Table 5: Rankings of Pathogen-Food Combination by Measures of Public Health Burden, Sorted by Hospitalizations, Using Default Model Settings[a]

Pathogen-Food Combination	Hospital -izations	Cases	Deaths	Cost[b]	QALY[b]
Salmonella nontyphoidal / Egg dishes	1	10	3	3	1
Norovirus / Molluscan shellfish	2	1	19	N.A.	N.A.
Norovirus / Multi-Ingredient salads	3	2	24	N.A.	N.A.
Norovirus / Produce dishes	4	3	25	N.A.	N.A.
Campylobacter / Vegetables	5	6	12	4	4
Toxoplasma gondii / Unattributable food	6	25	1	N.A.	N.A.
Campylobacter / Milk	7	9	20	5	5
Norovirus / Fruits	8	4	33	N.A.	N.A.
Campylobacter / Chicken	9	12	28	7	6
Norovirus / Vegetables	10	5	38	N.A.	N.A.
Campylobacter / Produce dishes	11	17	34	8	9
Salmonella nontyphoidal / Vegetables	12	28	6	9	8
Listeria monocytogenes / Luncheon/other meats	13	160	2	1	2
Norovirus / Bakery	14	7	41	N.A.	N.A.
E. coli nonO157 STEC / Unattributable food	15	60	13	N.A.	N.A.

[a] Mean annual foodborne estimates for the United States, attributed to food sub-categories using outbreak data. The food category "Unattributable food" implies that there were not enough outbreaks of that pathogen in the outbreak dataset to attribute illnesses to food categories.

[b] Economic valuation and QALY loss are currently estimated in FIRRM only for four pathogens, and therefore rankings by dollars and QALYs are "Not Available (N.A.)" for *Norovirus*, *Toxoplasma gondii*, and *E. coli* non-O157 STEC.

Table 6: FIRRM Food Attribution Percentages for Illnesses from Foodborne *Campylobacter* and *Listeria monocytogenes*

	Campylobacter		***Listeria monocytogenes***		
Food Category	**Outbreak Cases**	**Expert Elicitation**	**Outbreak Cases**	**Expert Elicitation**	**RTE Risk Assessments**[a]
Seafood	9.1	0.9	0.0	6.8	1.3
Eggs	0.0	2.3	0.0	0.3	N.A.
Produce	39.3	5.1	0.0	8.4	14.1
Beverages	0.0	0.0	0.0	0.2	N.A.
Dairy	21.0	7.4	32.0	22.8	24.5
Breads and Bakery	0.0	0.0	6.3	0.2	N.A.
Multi-ingredient/Other	6.8	3.9	0.0	3.7	0.1
Game	0.0	1.9	0.0	0.3	N.A.
Beef	5.0	4.2	0.0	1.5	N.A.
Poultry	16.4	69.4	4.3	2.6	N.A.
Pork	0.7	4.1	0.0	1.2	N.A.
Luncheon/Other Meats	1.8	0.9	57.3	52.1	60.1
Total	100.0	100.0	100.0	100.0	100.0

[a] CFSAN/FSIS risk assessments for Listeria were solely for ready-to-eat foods, and therefore did not include foods in all categories (CFSAN 2003). As a result, food attribution percentages are "Not Available (N.A.)" for certain food categories.

References:

Buzby, J. C., T. Roberts, C. T. J. Lin, and J. M. MacDonald. 1996. Bacterial Foodborne Disease: Medical Costs and Productivity. Economic Research Service, U.S. Department of Agriculture. Agricultural Economics Report No. 741, August 1996.

Buzby, J. C., and T. Roberts. 1996. ERS Updates U.S. Foodborne Disease Costs for Seven Pathogens. *FoodReview*, Economic Research Service, U.S. Department of Agriculture, 19(3, September):20-25.

Buzby, J. C., and T. Roberts. 1997. Guillain-Barré Syndrome Increases Foodborne Disease Costs. *FoodReview*, Economic Research Service, U.S. Department of Agriculture, 20(3, September):36-42.

CDC (Centers for Disease Control and Prevention). 1997. Foodborne Diseases Active Surveillance Network. *Morbidity and Mortality Weekly Report*, 46(12):258-261.

CDC (Centers for Disease Control and Prevention). 2003. Preliminary FoodNet Data on the Incidence of Foodborne Illnesses -- Selected Sites, United States, 2002. *Morbidity and Mortality Weekly Report*, 52(15):340-343.

CFSAN (Center for Food Safety and Applied Nutrition). 2000. Draft Risk Assessment on the Public Health Impact of Vibrio parahaemolyticus in Raw Molluscan Shellfish. Food and Drug Administration, United States Department of Health and Human Services, Washington, DC. December.

CFSAN (Center for Food Safety and Applied Nutrition), Consumer Studies Branch. 2002. Food Safety Survey: Summary of Major Trends in Food Handling Practices and Consumption of Potentially Risky Foods. http://vm.cfsan.fda.gov/~dms/fssurvey.html (accessed September 10, 2003).

CFSAN (Center for Food Safety and Applied Nutrition), FSIS (Food Safety and Inspection Service), and CDC (Centers for Disease Control and Prevention). 2003. Quantitative Assessment of Relative Risk to Public Health from Foodborne *Listeria monocytogenes* Among Selected Categories of Ready-to-Eat Foods. United States Department of Health and Human Services and United States Department of Agriculture, Washington, DC.

Cooke, R.M. 1991. Experts in Uncertainty: Opinion and Subjective Probability in Science. Oxford University Press, New York, NY.

DeWaal, C.S. and K. Barlow. 2002, 5th printing. *Outbreak Alert! Closing the Gaps in Our Federal Food-Safety Net*. Center for Science in the Public Interest, Washington, DC.

EPA (U.S. Environmental Protection Agency). 1997. The Benefits and Costs of the Clean Air Act, 1970 to 1990. U.S. EPA, Office of Air and Radiation, Office of Policy, Washington, DC.

EPA (U.S. Environmental Protection Agency). 1999. The Benefits and Costs of the Clean Air Act, 1990 to 2010. U.S. EPA, Office of Air and Radiation, Office of Policy, Washington, DC.

ERS (Economic Research Service). 2003. Foodborne Illness Cost Calculator, Available from: http://www.ers.usda.gov/data/foodborneillness. 2003.

Feeny, D. H., G. W. Torrance, and W. J. Furlong. 1996. Health Utilities Index, p. 239-252. *In* B. Spilker, ed. Quality of Life and Pharmacoeconomics in Clinical Trials. Second Edition. Lippincott-Raven Press, Philadelphia, PA.

Freeman, A. M., III. 2003. The Measurement of Environmental and Resource Values: Theory and Methods, Second Edition. RFF Press, Washington, DC.

Frenzen, P. D., T. L. Riggs, J. C. Buzby, et al. 1999. *Salmonella* Cost Estimate Updated Using FoodNet Data. *FoodReview*, Economic Research Service, U.S. Department of Agriculture, 22(2, May):10-15.

Furlong, W. J., D. H. Feeny, G. W. Torrance, et al. 1998. Multiplicative Multi-Attribute Utility Function for the Health Utilities Index Mark 3 (HUI3) System: A Technical Report. McMaster University Centre for Health Economics and Policy Analysis, Working Paper No. 98-11, Ontario. December.

FSIS (Food Safety and Inspection Service). 1998. *Salmonella* Enteritidis Risk Assessment: Shell Eggs and Egg Products: Final Report. United States Department of Agriculture, Washington, DC, August 10.

FSIS (Food Safety and Inspection Service). 2001. Draft Risk Assessment of the Public Health Impact of Escherichia coli O157:H7 in Ground Beef. United States Department of Agriculture, Washington, DC. September 7.

FSRC (Food Safety Research Consortium). 2002. Food Attribution Data and Methodologies in the Foodborne Illness Risk Ranking Model. Washington, DC.

FSRC (Food Safety Research Consortium). 2003. Food Attribution Data Workshop: Draft Discussion Outline. Atlanta, GA. October 31.

GAO (U.S. General Accounting Office). 1997. Food Safety: Fundamental Changes Needed to Improve Food Safety. Report 97-249. Washington, DC.

GAO (U.S. General Accounting Office). 2001. Food Safety and Security – Fundamental Changes Needed to Ensure Safe Food. GAO-02-47T. Washington, DC, October 10.

Gold M. R., D. L. Patrick, G. W. Torrance, and D. G. Fryback. 1996. Identifying and valuing outcomes, p. 82-134. *In* M. R. Gold, J. E. Siegel, L. B. Russle, and M. C. Weinsteing (eds.) Cost-effectiveness in health and medicine. Oxford University Press, New York, NY.

Imhoff, B., J. Hadler, D. Morse, B. Shiferaw, D. Vugia, C. Medus, S. Lance-Parker, T. Karchmer, T. Van Gilder, and the EIP FoodNet Working Group. 2000. The Substantial Burden of Acute Diarrheal Illness in the United States: A Running Total, FoodNet, 1998-1999. Paper presented at the 2nd International Conference on Emerging Infectious Diseases. July 2000, Atlanta, GA.

Kaplan R. M., J. W. Bush, C. C. Berry. 1979. Health status index: Category rating versus magnitude estimation for measuring levels of well-being. *Med Care*, 17:501-525.

Kaplan, R. M., T. G. Ganiats, W. J. Sieber, and J. P. Anderson. 1998. The Quality of Well-Being Scale: critical similarities and differences with SF-36. *International Journal for Quality in Health Care*. 10(6):509-520.

Klatka, L., M. Hawkins, M. Pass, F. Angulo, D. Rohn, J. Morris, and the EIP FoodNet Working Group. 2002. Risk factors for Sporadic *Campylobacter* Infections in Maryland. Conference on Emerging Infectious Diseases. Atlanta, GA, March.

Krupnick, A.J., M. Cropper, A. Alberini, N. Simon, B. O'Brien, and R. Goeree. 2002. Age, Health, and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents. *Journal of Risk and Uncertainty* 24: 161-75.

Landefeld, J. S., and E. P. Seskin. 1982. The Economic Value of Life: Linking Theory to Practice, *Am. J. Public Health*. 6:555-566.

Mead, P.S., L. Slutsker, V. Dietz, L.F. McCaig, J.S. Bresee, C. Shapiro, P.M.Griffin, and R.V. Tauxe. 1999. Food-Related Illness and Death in the United States. *Emerging Infectious Diseases* 5(5): 607-25.

Morgan, M.G., M. Henrion, and M. Small. 1990. Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press, Cambridge.

Mrozek, J. R. and Taylor, L. O. 2002. What determines the value of life? A meta-analysis. *Journal of Policy Analysis and Management*, 21:253-270.

NRC (National Research Council). 1998. Ensuring Safe Food from Production to Consumption. National Academy Press, Washington, DC.

NRC (National Research Council). 2003. Scientific Criteria to Ensure Safe Food. National Academy Press, Washington, DC. May.

Taylor, M.R., and S.A. Hoffman. 2001. Redesigning Food Safety, *Issues in Science and Technology,* 17(4):26-30.

Taylor, M.R., M.O. Glavin, J.G. Morris, C.E. Woteki. 2003. *Food Safety Updated: Developing Tools for a More Science- and Risk-Based Approach*. Milbank Memorial Fund, New York, NY.

Viscusi, W.K. 1993. The Value of Risks to Life and Health. *Journal of Economic Literature* 31: 1912-46.

DECISION ANALYTIC TOOLS FOR FOOD SAFETY REGULATORY PRIORITY SETTING

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Short Summary This paper presents a decision-analytic model for ranking the social burden of foodborne illness. The availability a consistent, transparent model allowing use of alternative ranking criteria and data assumptions will facilitate discussions between agencies committed to different criteria. By use of multiple criteria, the model highlights overlooked food safety problems.

Extended Abstract