An Approach to Ranking Microbial Foodborne Hazards

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Food Safety Research Consortium
A MULTI-DISCIPLINARY COLLABORATION TO IMPROVE PUBLIC HEALTH
Overview

- Background on the FSRC
- Conceptual Framework for Priority Setting
- The Foodborne Illness Risk Ranking Model
- Specific challenges:
  - Food categories
  - Food attribution approaches
  - Uncertainty and dependencies
Towards Risk-Based Food Safety

- Foodborne illness is a complex problem:
  - Many hazards in many foods
  - Diversity of health outcomes
  - Long production chain from farm to fork
  - Many players involved throughout chain
  - Complicated regulatory structure

- Numerous bodies (e.g. NAS/IOM, GAO) have called for a more science- and risk-based food safety system in the United States
In Turn, A Need for Tools

- Risk-based decision-making and priority setting rely on data-driven tools and analyses that treat the system as a whole.

- Tools needed for:
  - Ranking risks
  - Prioritizing opportunities to reduce risk
  - Assessing the effectiveness of interventions
  - Allocating resources to maximize risk reduction

- Data access and integration at national and local level are key challenges.
The Food Safety Research Consortium

- Formed in 2002 to develop analytic and decision tools towards a more risk- and science-based food safety system

- Interdisciplinary collaboration between 7 institutions, with steering committee members from each:

  University of Maryland, Baltimore
  - Mike Taylor (Chair)
  - Glenn Morris Jr.
  - Mike Batz (Executive Director)

  University of California at Davis
  - Juliana Ruzante

  University of Georgia
  - Mike Doyle

  Iowa State University
  - Helen Jensen

  University of Massachusetts
  - Julie Caswell

  Michigan State University
  - Ewen Todd

  Resources for the Future
  - Alan Krupnick
The Priority Setting Challenge

- Given a complex problem and finite resources, how best to target interventions and allocate resources to reduce illness?

- A Conceptual Framework for Food Safety Priority Setting: A set of principles set down to organize and guide decision tools and how they might fit together in a science-informed food safety system
The Conceptual Framework...

- Was developed through five focused workshops with researchers, decision makers and stakeholders from all sectors
- Is NOT methodologically prescriptive
- Is NOT intended to displace the other factors (social, political, market) that will continue to play a role in decisions
Some Key Principles

- **Systems perspective**
  - Foodborne illness results from the interaction of numerous factors, arising from farm to table, that affect both causation and prevention

- **Practicality:**
  - Needs of decisionmakers
  - Limitations of data
  - Financial and time costs of analysis

- **Within the bounds of practicality:**
  - Best available science
  - Transparency in assumptions & limitations
  - Flexible

- **Re-evaluation:**
  - Continuous or iterative evaluation
A Range of Decision Contexts

- **Purpose 1**: *broad, public sector*
  “resource allocation” – how to expend dollars, personnel, and other resources towards large array of hazards

- **Purpose 2**: *specific, public & private*
  “targeted risk management” – where and how best to act to reduce specific risks

- Approaches require different types of analysis and degrees of data-intensity
Four Analytical Elements

1. Risk Ranking
   Identify the most significant hazards from a public health perspective

2. Intervention Assessment
   Identify interventions and estimate their feasibility, effectiveness, and cost

3. Health Impact Estimation
   Compute public health effectiveness and benefits of interventions

4. Combined Evaluation
   Integrate information from other elements to inform decisions
The Conceptual Framework

Risk Ranking (FIRRM)
- Health outcomes
- Health valuation

Intervention Assessment
- Feasibility
- Costs
- Define surrogate
- Local effectiveness (surrogate)

Health Benefit Estimation
- Dose-response modeling
- Health outcomes
- Health valuation

Priority Setting Decision
Purpose 1: Public, Broad:
(e.g. resource allocation, data, research, education)
Purpose 2: Public/Private,
Specific: (e.g. regulatory action, private intervention)

Combined Evaluation
- Cost-effectiveness (surrogate)
- Cost-effectiveness (pub hlth)
- Cost-benefit analysis

Public Health Surveillance & Animal/Food Data

Post-Hoc Evaluation
Risk Ranking

- A first step in broad priority setting
- A risk ranking should be:
  - Data-driven when possible
  - Focused on public health endpoints
  - Based on integrated measures of public health impact (such as dollars or QALYs)
  - Inclusive of hazards - avoid the “streetlamp” effect of excluding hazards prematurely
  - Consistent across risk categories
Foodborne Illness Risk Ranking Model

- Need for a systematic approach to identify microbial hazards with the greatest public health impact
- FIRRM Project team:
  - UMB: Glenn Morris, Mike Taylor, Mike Batz, others
  - RFF: Alan Krupnick, Sandy Hoffmann, others
  - Iowa State: Helen Jensen
- Funded by RWJ (v1) and USDA CSREES (v2)
A Very Brief History of Risk Ranking

- Also known as Comparative Risk Assessment
- Historically, a deliberative process
  - Small number of experts/decision-makers
  - Diverse set of risk domains (health, ecosystem, socio-economic)
  - Use consensus to aggregate experts’ preferences
- Unfinished Business (US EPA, 1987)
  - Ranked 31 National environmental issues
  - Followed by 8 EPA Regions, and most states
  - Fairly quiet for the past 10 years or so...
FIRRM Is Unlike Traditional CRA

- Empirical not deliberative
- Quantitative not qualitative
- Fewer and more similar risk domains
- Focus on differentiation within a single risk domain (microbial illness)
- Use of expert judgment is quite different
  - Used for input parameters only
  - Large panel survey for data, not consensus
Basics of FIRRM

- Ranks pathogen-food combinations, pathogens, and foods (summed over pathogens):
  - 28 pathogens
  - 13 food categories (46 sub-categories)
    - (11 food categories in v2)
  - 5 measures of annual public health impact:
    - Cases
    - Hospitalizations
    - Deaths
    - Monetary cost ($)
    - QALY loss
FUNCTIONAL INFLUENCE DIAGRAM OF MODEL

As with all Analytica models, the Foodborne Illness Risk Ranking Model is composed of functional influence diagrams of model inputs, constants, assumptions, and outputs. Modules are composed of sub-diagrams that may include further modules. Arrows indicate data flow; an arrow from one variable to another indicates that the former is an input to the latter. Arrows between modules indicate that a variable, or variables, in one module are inputs to a variable or variables in another module. Not all data flow arrows are visible in all sub-diagrams, to make them easier to follow. Relationships between variables can still be followed through each variable’s object window.
Model Design

- “Top-down” model that takes an epidemiological approach, working backwards from observed cases of disease to the hazard
- Integrates data from multiple sources:
  - Estimates of incidence of 28 pathogens based upon disease surveillance and underreporting factors
  - Health outcome trees of pathogen-associated illnesses, including hospitalization and death as well as chronic sequelae
  - Valuation, in dollars and QALYs, of health states in outcome trees
  - Attribution of pathogen-specific illnesses to food categories based on outbreak data and expert elicitation
Model Characteristics

- Not a predictive model
- Does not point to specific interventions
- Does not include chemical or other risks
- Built in Analytica
  - Graphical interface: point-and-click
  - Changeable assumptions
  - Uncertainty (Monte Carlo)
  - Documentation
  - Adaptability
  - Transparency (no secrets)
- Open and free to download/use/change
Incidence by Pathogen

- Estimates of incidence of 28 pathogens based upon disease surveillance and underreporting
- Based on data from FoodNet surveillance and studies, notifiable disease data, outbreak data, and from studies found in literature (e.g. Mead et al. 1999)

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Parasites</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus cereus</em></td>
<td><em>Salmonella Typhi</em></td>
</tr>
<tr>
<td><em>Brucella</em></td>
<td><em>Salmonella nontyphoidal</em></td>
</tr>
<tr>
<td><em>Campylobacter</em></td>
<td><em>Shigella</em></td>
</tr>
<tr>
<td><em>C. botulinum</em></td>
<td><em>Staphylococcus</em></td>
</tr>
<tr>
<td><em>C. perfringens</em></td>
<td><em>Streptococcus</em></td>
</tr>
<tr>
<td><em>E. coli</em> O157:H7</td>
<td><em>Vibrio cholerae toxigenic</em></td>
</tr>
<tr>
<td><em>E. coli</em> nonO157 STEC</td>
<td><em>Vibrio vulnificus</em></td>
</tr>
<tr>
<td><em>E. coli</em> enterotoxigenic</td>
<td><em>Vibrio other</em></td>
</tr>
<tr>
<td><em>E. coli</em> other diarrheogenic</td>
<td><em>Yersinia enterocolitica</em></td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td></td>
</tr>
</tbody>
</table>
Integrated Measures of Health Impact

- Cases, hospitalizations, and fatalities are insufficient for comparing pathogens.

- Pathogens have distinct:
  - Symptoms, severities, treatments
  - Hospitalization and fatality rates
  - Chronic sequelae

- The solution is valuation of health states using dollars or Health-Adjusted Life Years (HALYs):
  - Can aggregate across health states, compare distinct syndromes
  - Captures preferences about alternative health states
  - Can estimate the economic impact of foodborne illness
Valuation: *Vibrio vulnificus* example

Note: Because *V. vulnificus* infection results in severe symptoms, all symptomatic persons are assumed to receive medical treatment.
**Estimating QALYs**

- Track HRQOL through stages of disease – compute loss of QALYs from population baseline (area between the curves)
- Multiple indices available to estimate HRQOL (we use QWB in version 1 and EuroQOL in version 2)

**HRQOL (Health-Related Quality of Life)**

- **Excellent Health**
- **Baseline health**
- **Perfect health**

**Time**

- **Onset of symptoms**
- **Dead**
- **Person 1**: mild acute illness, then recovery (to baseline)
- **Person 1**: severe illness, partial recovery with chronic sequelae
- **Person 3**: severe illness, hospitalization, complications, death
Our definition of “food attribution” is broad: for each pathogen, determine proportion (percentage) of foodborne cases in each food category.

<table>
<thead>
<tr>
<th>Food</th>
<th>Proportion (%)</th>
<th>Path-Food</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food 1</td>
<td>10%</td>
<td>Food A1</td>
<td>100</td>
</tr>
<tr>
<td>Food 2</td>
<td>5%</td>
<td>Food A2</td>
<td>5</td>
</tr>
<tr>
<td>Food 3</td>
<td>30%</td>
<td>Food A3</td>
<td>300</td>
</tr>
<tr>
<td>Food 10</td>
<td>15%</td>
<td>Food A10</td>
<td>150</td>
</tr>
<tr>
<td>Food 11</td>
<td>10%</td>
<td>Food A11</td>
<td>100</td>
</tr>
</tbody>
</table>

**TOTAL** 100% = **TOTAL** 1000
Food Attribution for Risk Ranking

- The systems approach: for broad prioritization (e.g. resource allocation), need to capture a broad coverage of foods

- Comparability: apples to apples
  - Consistency with attribution method across hazards
  - Use consistent food categories across combinations
  - Don’t exclude important categories or foods

- Many approaches to attribution, but few data available for large number of pathogens and foods, leaving us with 2 primary sources:
  - Outbreak data
  - Expert judgment
Outbreaks and Experts

- **Outbreak Attribution:**
  - Pros: large dataset for many pathogens, straightforward data, can aggregate by decision rules
  - Cons: misrepresents sporadic cases, geographic & temporally inconsistent, driven by large events, selection bias in food identification

- **Expert Judgment:**
  - Pros: can reconcile disagreeing data & fill gaps, increasingly accepted as valid
  - Cons: not “data driven” in traditional sense, hard to detect biases, potential for circularity

- **Exposure Assessment:**
  - We attempted a simplified approach using contamination and consumption data, but data was too sparse across our scope of pathogens and foods
Food Categories

- Want risk categories to be logically consistent, administratively compatible, equitable, and compatible with cognitive biases*

- But food categories are non-obvious because there are many different ways to group things
  - Ultimately want to get at the many “contributing factors” along the farm-to-fork continuum but the big-picture view needs to simplify the picture into pathogens and foods

Additional Food Categorization Factors

- **Complex foods:**
  - Foods as eaten usually include multiple ingredients - do we organize foods by complete dishes or composite ingredients?

- **Species vs Product:**
  - Should turkey slices be grouped with “poultry” or “luncheon meat?”
  - Is a tomato a fruit or a vegetable?

- **Origin of production:**
  - Do we need separate categories for imports?

- **Processing and preparation conditions:**
  - For ranking, does it matter how the food was produced (raw, fresh-cut, canned, etc), prepared (home, restaurant, caterer), or eaten (raw, cooked, reheated) at the big-picture level?

- **Fuzzy boundaries:**
  - Do you treat sprouts as a legume or similar to salad greens?

- **One size does not fit all:**
  - The best categories for ranking hazards may not match up to categories used in other data (e.g. food consumption data)
<table>
<thead>
<tr>
<th>Poultry</th>
<th>Chicken</th>
<th>Fruit</th>
<th>Citrus Fruit</th>
<th>Melons and Berries</th>
<th>Other Fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other Poultry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poultry Dishes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Turkey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef</td>
<td>Beef Dishes</td>
<td>Vegetables</td>
<td>Bean Dishes</td>
<td>Canned Vegetables</td>
<td>Herbs and Spices</td>
</tr>
<tr>
<td></td>
<td>Ground Beef</td>
<td></td>
<td></td>
<td></td>
<td>Legumes and Nuts, and Seeds</td>
</tr>
<tr>
<td></td>
<td>Other Beef</td>
<td></td>
<td></td>
<td></td>
<td>Mixed Produce</td>
</tr>
<tr>
<td></td>
<td>Raw or Cured Beef</td>
<td></td>
<td></td>
<td></td>
<td>Other Vegetables</td>
</tr>
<tr>
<td>Pork</td>
<td>Bacon / Ham</td>
<td></td>
<td></td>
<td>Salad Greens and Sprouts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pork</td>
<td></td>
<td></td>
<td>Tomatoes &amp; Mixtures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pork Dishes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Meats</td>
<td>Other / Unknown Meat</td>
<td>Sweets &amp; Beverages</td>
<td>Alcoholic beverages</td>
<td>Fruit Juices</td>
<td>Non-alcoholic beverages</td>
</tr>
<tr>
<td></td>
<td>Other Meat Dishes</td>
<td></td>
<td></td>
<td></td>
<td>Sugars and Sweets</td>
</tr>
<tr>
<td></td>
<td>Sausages &amp; Deli Meats</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Game</td>
<td>Game</td>
<td>Grain &amp; Bakery</td>
<td>Bread</td>
<td>Cakes and Pastries</td>
<td>Other grain flour items</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rice</td>
</tr>
<tr>
<td>Seafood</td>
<td>Finfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other Seafood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seafood Dishes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shellfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy Products</td>
<td>Cheese</td>
<td>Complex Foods</td>
<td>Deli Salads</td>
<td>Desserts</td>
<td>Other Complex Foods</td>
</tr>
<tr>
<td></td>
<td>Ice Cream</td>
<td></td>
<td></td>
<td></td>
<td>Other Meat Dishes</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
<td></td>
<td></td>
<td></td>
<td>Other Meat Dishes</td>
</tr>
<tr>
<td></td>
<td>Other Dairy</td>
<td></td>
<td></td>
<td></td>
<td>Pasta and Pizza</td>
</tr>
<tr>
<td>Eggs</td>
<td>Egg Dishes</td>
<td></td>
<td></td>
<td></td>
<td>Sandwiches</td>
</tr>
<tr>
<td></td>
<td>Eggs</td>
<td></td>
<td></td>
<td></td>
<td>Saucess, Dressings, Oils</td>
</tr>
</tbody>
</table>
Food Categories and Binning Outbreaks

- Many foods as consumed are “complex” in that they include multiple ingredients - for some pathogens, as many as 50% of outbreaks may be due to complex foods

- How to handle? Sensitivity analysis approach:
  - Complex foods category: include or exclude
  - Binning choices: bin all multi-ingredient dishes into complex food category, or use less conservative approach to bin eligible outbreaks into the primary ingredient in the dish (e.g. omelette as egg)?
## Complex Foods Example: Salmonella

<table>
<thead>
<tr>
<th>Include/exclude?</th>
<th>With Complex Category</th>
<th>No Complex Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binning option:</td>
<td>As Complex Food</td>
<td>By Primary Ingredient</td>
</tr>
<tr>
<td>Beef</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>Poultry</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>Pork</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Other Meats</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Seafood</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Game</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Dairy Products</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>Eggs</td>
<td>5%</td>
<td>19%</td>
</tr>
<tr>
<td>Fruit</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Vegetables</td>
<td>14%</td>
<td>18%</td>
</tr>
<tr>
<td>Grain &amp; Bakery</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Beverages</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Complex Foods</td>
<td>41%</td>
<td>12%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Multi-Source outbreaks excluded (single food vehicle only), 1990-2004
Uncertainty Due to Binning: Salmonella

Multi-Source outbreaks excluded, “complex foods” dropped from percentages.
Food Attribution from Experts

- FSRC expert elicitation performed in 2003
  - 11 pathogens: FoodNet + Noro + Toxo
  - Best estimates, also low/high estimates
  - Self-assessed expertise, confidence in answers

- Survey administration
  - Mail survey, peer-reviewed set of respondents
  - 101 contacted, 45 completed: State/Federal Government (24), Academia/Research (14), Industry (3), Other (3)

- Forthcoming articles
  - “Using Expert Elicitation to Link Foodborne Illness in the U.S. to Food” Hoffmann S, Fischbeck P, Krupnick A, McWilliams M. Journal of Food Protection
Comparing Outbreaks and Experts

- For some pathogens, percentages are quite similar
- For others, percentages significantly different
- Outbreak data might have informed expert opinion
- Expert opinions might also reflect other data, such as case-control studies
**Campylobacter: Experts & Outbreak**

*Campylobacter* spp.

μ = mean of expert attribution  
ο = mean of outbreak attribution

Major differences between outbreak data and expert judgments for *Campylobacter*

Note: preliminary data shown for illustrative purposes only
### Attribution Affects Rankings: Example

<table>
<thead>
<tr>
<th>Ranking pathogen-food combinations by number of annual hospitalizations</th>
<th>Using Outbreak Data</th>
<th>Using Expert Judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norwalk-like viruses / Produce</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Norwalk-like viruses / Unattributable or Other</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Salmonella nontyphoidal / Eggs</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Campylobacter / Produce</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Norwalk-like viruses / Seafood</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Salmonella nontyphoidal / Poultry</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Toxoplasma gondii / Unattributable</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>Salmonella nontyphoidal / Produce</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Campylobacter / Dairy</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>Campylobacter / Poultry</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Norwalk-like viruses / Breads and Bakery</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Listeria monocytogenes / Luncheon/Other Meats</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: Preliminary results, shown for illustrative purposes only. Toxoplasma cannot be attributed via outbreaks (1 outbreak in dataset), but can be attributed via experts, thus the large number of unattributable hospitalizations by outbreaks are broken up by expert attribution.
Uncertainties and Dependencies

- Ranking results have wide uncertainty bands
  - Some pathogen-food combinations likely to be robust at top of list
  - But wide ranges may make it difficult to truly distinguish between “worst” and “almost worst”

- But distributions may be highly correlated
  - For example, underreporting multipliers may be very uncertain but are driven by the same variables across pathogens (e.g. likelihood of patient to see a physician, likelihood of stool sample, etc)
Conclusions

- Significant uncertainties, data gaps, and areas requiring subjective judgment
  - Food categories
  - Expert judgment for attribution
  - Choices of attribution approach
  - Valuation of mortality (VSLs)

- Nonetheless, we expect results to be informative and useful

- What is “good enough?”
Take Home Messages

- We should be striving for data-driven, empirical, and quantitative approaches
  
  - But incorporation of uncertainty is critical
  
  - We can learn a lot about future data collection needs and gaps in knowledge

- Consistency is crucial

- For microbial hazards, categorization and attribution to foods are major hurdles

- Expert judgment can be utilized in a focused manner to fill data gaps
Thanks

For more information on the Foodborne Illness Risk Ranking Model, including a downloadable version, visit the FSRC website:

http://www.rff.org/fsrc/

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