The Use of Multi-criteria Decision Analysis in Food Safety Risk-benefit Assessment

Juliana M. Ruzante,[1]* Khara Grieger,[1] Katherine Woodward,[1] Elisabetta Lambertini[1] and Barbara Kowalcyk[1]

[1]RTI International, 3040 East Cornwallis Road, Research Triangle Park, NC 27709–2194, USA

SUMMARY

Complex decisions call for a wide set of decision-support tools. Risk-benefit assessment (RBAs) is an emerging topic in the area of food safety as decision makers begin to realize that a unilateral focus on risks might be insufficient to make effective decisions in real-world situations. However, existing RBA approaches focus only on the adverse or beneficial health impacts of changes in policies and interventions and lack a more comprehensive and pragmatic evaluation of other criteria, beyond public health, that might influence the risk manager's decision. Multi-criteria decision analysis (MCDA) methods are a promising alternative for handling complex decisions that need to account for multiple, diverse, and potentially conflicting criteria. In the past decade, MCDA has been used to explicitly balance the risks and benefits associated with drugs and medical devices, as well as with certain environmental decisions, but it has not yet been used in the area of food safety. Therefore, this paper presents an MCDA approach, illustrated by a hypothetical case study, that could be used to assess the risk and benefits of selected food safety interventions.

OVERVIEW

Risk-benefit assessment (RBA) is an emerging topic in the area of food safety. Food safety authorities, industry, producers, and consumers are realizing that a unilateral focus on only the risks or benefits associated with policy changes selection of control measures to improve food safety, consumption of food products and dietary choices, is insufficient when making decisions. According to the European Food Safety Authority (EFSA), risk-benefit assessment (or benefit-risk assessment) is "the weighting of probability of an adverse health effect against the probability of benefit as a consequence of exposure, if both are known to be present" *(10)*. RBA is interdisciplinary by nature, requiring a multi-disciplinary approach, and the engagement of a diverse range of experts such as nutritionists, epidemiologists, modelers, toxicologists and microbiologists to be conducted.

* Author for correspondence:
Phone: +1 919.316.3163
E-mail: jruzante@rti.org

In recent years, frameworks such as the ones described in EFSA's Guidance on human health risk-benefit assessment of foods *(10)*, the Benefit–Risk Analysis for Foods (BRAFO) *(3, 21)*, and tools such as Quality of Life — Integrated Benefit and Risk Analysis (QALIBRA) *(20)* have been developed to facilitate the evaluation of the risks and benefits associated with consumption of certain foods. The EFSA and BRAFO frameworks use a stepwise approach that increases, as needed, in complexity and utilizes single health metrics such as disability adjusted life year (DALY) or quality adjusted life years (QALYs) to aggregate and balance opposing health impacts; these well designed frameworks have been applied to address several risk management questions *(2, 22, 36, 42, 43, 45)*. QALIBRA is a tool that complements BRAFO, facilitates the calculation of DALYs and QALYs , and allows for the incorporation of uncertainty and variability in estimates; the tool is user-friendly and can be downloaded free of charge at http://www.qalibra.eu/ *(18)*. Other approaches have also been described in the literature to balance risks and benefits in the area of nutrition and food safety *(12, 14, 15, 29, 32, 33)*, although their focus has been solely on health impacts.

In reality, decisions and policy considerations need to account for several factors beyond the net benefit to public health. Consider, for instance, the selection of food safety interventions. A risk manager will consider how efficient different intervention options are in reducing contamination but also might contemplate how consumers will accept the different options, their associated cost(s), and if there are any potential trade impacts that might result from the adoption of one intervention option versus another.

To address in a systematic and transparent manner those complex decisions that involve value trade-offs and in which a single best course of action may not exist, there are a suite of methods under the umbrella of multi-criteria decision analysis (MCDA). MCDA methods have been utilized to support a range of multifaceted decision problems in several areas, from emerging technologies *(1)* to the selection of contaminated waste management and treatment facilities

(27). In food safety, MCDA has been used to prioritize foodborne hazards *(35, 40)*, to prioritize low-moisture foods *(13)*, in the inspection of egg farms for monitoring compliance *(41)*, and to guide the selection of food safety interventions *(11)*. MCDA is able to aggregate heterogeneous data (i.e., qualitative, semi-quantitative and quantitative) to produce a single metric that can be used to rank the options available given a set of criteria and preferences, making it a useful method of balancing risks and benefits. While MCDA has been used to conduct RBA in other fields *(24, 38, 39)*, its application has been limited in the food safety arena. The goal of this paper is to illustrate how MCDA could be applied to conduct RBA in the context of food safety. To demonstrate its applicability, a hypothetical case study is presented.

MCDA FRAMEWORK FOR FOOD SAFETY RBA

MCDA aims to quantitatively assess complex decisions where there are competing interests and no clear best option. This is often the case in food safety problems, where preventing and eliminating product contamination often must be balanced against other individual and societal risks and benefits. MCDA, which is best suited to help select one out of a set of possible actions, commonly involves breaking down a complex scenario into variables that can be independently assessed and evaluated, and then synthesizing the information to help in selecting the best option(s). Typical MCDA steps include: (1) defining the decision problem and the set of alternatives; (2) identifying the evaluation criteria (i.e., the risks and benefits criteria of interest that the alternative actions will be measured against; (3) collecting data and evaluating alternatives' performance against each criterion; (4) defining the weight of each criterion; (5) analyzing and synthesizing the alternatives' performance based on steps 3 and 4; and 6) reporting and visualizing results. This section describes, in the context of a hypothetical decision on food safety interventions, methodological options for each step. The steps illustrated here are adapted from MCDA and RBA methods previously described in the literature *(11, 21, 24, 26, 28, 37)*.

Step 1: Define the decision problem and the set of alternatives

As with a risk assessment or an RBA that focuses only on health impacts, the definition of the decision problem is a crucial step of the process. The basic principles for this step are well described by others *(3, 10, 21, 27)*. In brief, decision makers and risk managers work with the risk-benefit assessors and other relevant experts to identify and define the issue(s) of concern, and what is being considered for the decision (e.g., selection of interventions, new policy evaluation). It is also important to consider the types of scenarios or alternatives that will be evaluated, and the target population.

To demonstrate this, a hypothetical case study will be used *(Table 1)*. In this case study, risk-benefit assessors need to choose the best chemical intervention strategy to control pathogen A in food B, out of five potential alternatives. In this first step, alternatives need to be well characterized so they can be evaluated in later steps. For example, the specific concentrations of the chemicals and mode of application/use for each of the chemical interventions need to be carefully described, so that during data collection it is clear what type of intervention needs to be measured.

Step 2: Identify the evaluation criteria

In this step, risk managers and decision makers need to identify the relevant criteria or factors against which each alternative (i.e., intervention) will be evaluated. Criteria represent an adverse (risk) or a beneficial (benefit) outcome. The adverse outcomes could be financial, psychological, social, environmental, and/or linked to the harmful health effects caused by or related to the alternatives. Beneficial outcomes, on the other hand, could be related to positive gains that are associated with the adoption of the alternatives, such as prevention of foodborne illness and increased consumer confidence. For example, a proposed intervention could lead to reduced pathogen concentration and/or improved shelf life for the food.

A multidisciplinary team of risk assessors, nutritionists, economists, epidemiologists, food and social scientists, microbiologists, toxicologists, and decisions makers should

TABLE 1. Decision problem and alternatives for the hypothetical case study

Background	Recent multi-state outbreak of pathogen A in food B has raised concerns among consumer and public health agencies. Industry needs to choose a new or different intervention strategy for processing of food B
Decision problem	Industry needs to select one chemical intervention to reduce contamination with pathogen A of food B during processing
Alternatives	The evaluation of five different chemical interventions to reduce the level of pathogen A in food B
Target population	General population consuming food B

be engaged to identify the potential risks and benefits associated with each alternative. The composition of the team will vary with the decision at hand; for example, economists and social scientists will be needed if trade impact and public acceptance are part of the relevant criteria being considered. In addition to input from experts, it is crucial to review peer-reviewed and grey literature (and potentially social media as well) to identify the potential adverse and beneficial effects. It might also be important to engage different stakeholder groups in order to understand and address their concerns.

In this step, it may be helpful to develop a risk-benefit tree to comprehensively and systematically identify the potential risks and benefits. In the hypothetical case study, a list of criteria was developed based on feedback from a multidisciplinary team, and a risk and benefit tree was developed to transparently reflect the main adverse and beneficial effects associated with each of the five options to control pathogen A in food B *(Fig. 1)*.

In this step, it is also important to identify the boundaries of the decision problem to clearly delineate which factors or categories of factors will be included in the analysis (in terms of both benefits and risks). For instance, in addition to public health and business viability factors, risk and benefit variables may include energy inputs, a range of environmental impacts, food production/security, and consumer and community behavior change, but not all of those would be relevant to the decision maker. As discussed in the next step, this is not meant to be the final list of criteria that will be included in an analysis; the criteria will be further evaluated based on several factors, such as their relevance to the decision makers, the availability of data to quantify each of the effects, level of evidence for the association, and resources available to conduct the RBA.

Step 3: Collecting data and evaluating alternatives' performance against each criteria

At this stage, analysts will need to consider how to measure each of the alternatives against the criteria identified in the risk and benefit tree and build a performance matrix *(Table 2)*. MCDA methods have the ability to handle a variety of heterogeneous qualitative and quantitative data, giving a wide range of possibilities for criteria metrics. The metric used to measure the criteria and how it will be expressed will depend on the type of the alternatives being considered, criteria selected to evaluate the alternatives, and availability and quality of data. The sources of data can also be diverse, ranging from quantitative risk assessments, surveillance reports, and meta-analysis to results from focus groups.

Once the data have been collected, data gaps are expected. Expert elicitation can be used to fill data gaps, and several recognized methods can be used to formally elicit expert opinion *(4, 5, 6, 19, 23)*. These range from individual interviews or online surveys to face-to-face meetings. Some methods aim to arrive at a general consensus among experts, while other methods handle diverging opinions among experts. However, there are limitations to using expert elicitation, as it does not provide empirical data, and results can be biased by a number of factors such as the

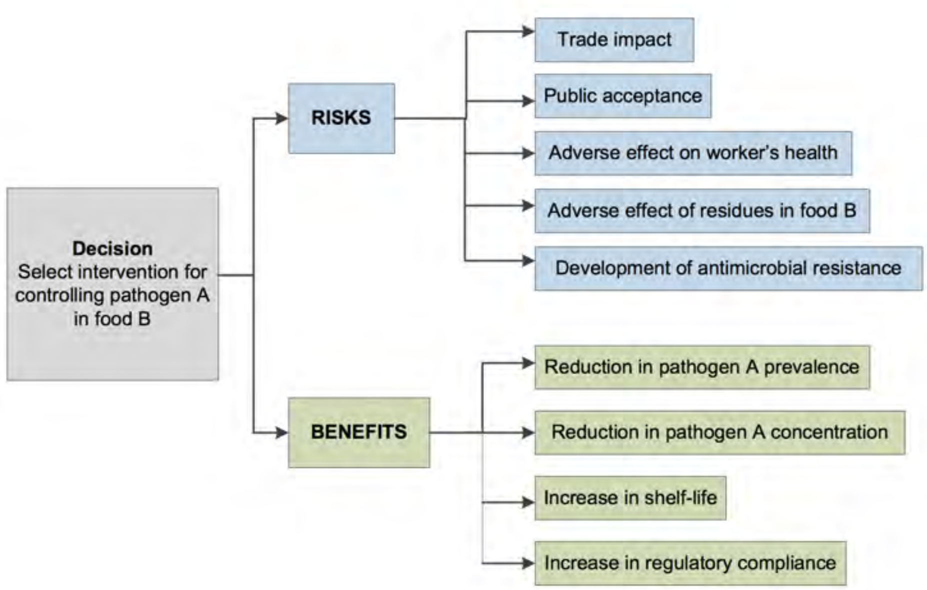

Figure 1: Risk and benefit tree for the hypothetical case study

TABLE 2. Hypothetical performance matrix for the hypothetical case study

	Criterion	Food Safety Interventions[a]					Scenarios[b]		
		1	2	3	4	5	A	B	C
Risks	Trade impact	yes	no	no	yes	no	0	30	20
	Public acceptance	yes	yes	no	no	yes	20	30	20
	Effect on workers	likely	unlikely	unlikely	unlikely	likely	30	5	20
Benefits	Reduction in pathogen concentration	4	1.5	0.5	2	3	50	30	20
	Increase in shelf life (days)	3.8	0	0	2.3	1.5	0	5	20

[a]Each cell represents how each intervention option performed when evaluated against each criterion. Different criteria may have different evaluation scales and can be qualitative, semi-quantitative or quantitative.

[b]Each scenario represents a different weighting scheme assigned to the criteria, such that the sum of weights equals 100.

background and scientific expertise of the experts *(30)* or "loudest voice in the room." For those reasons, the expert elicitation process should be designed and conducted using best practices.

In the hypothetical case study, metrics need to be selected for each of the identified criteria. Since the interventions under consideration are used for processing and certain countries may not allow or be comfortable with a novel intervention technologies used on foods, the possibility of food B being rejected by importing countries was selected as the metric. Therefore, the trade impact for each intervention could be qualitatively measured using a "yes or no" scale (e.g., yes there is a chance it will be rejected; no there is not a chance it would be rejected) using information from previous trade incidents and the input from economists and trade experts. Alternatively, a semi-quantitative scale (such as an ordinal scale from 1 to 5 representing very likely, likely, neutral, unlikely, very unlikely) could be used to measure the criterion. In contrast to this, the criterion for reducing the concentration of pathogen A in food B could be measured as the average log reduction achieved in randomized field trials; peer-reviewed papers, systematic reviews and/or meta-analysis could be used as data sources. Overall, it is important to clearly document the assumptions behind each metric and be aware of the limitations of using qualitative and semi-quantitative scales *(6, 7)*.

Not all the risks and benefits identified in step 2 will be included in the final assessment and need to be carefully evaluated. It is possible that there are either no data available or the quality of the data is too poor to support the inclusion of the criterion. Boobis et al. (2013) *(3)* discussed the challenges in evaluating the level of evidence for health risks and benefits in the same manner. According to the authors, only health effects with convincing or at least probable effects (as defined by existing guidelines, such as WHO, 2003 *(44)*) should be included in the assessment. However, effects with lower levels of evidence but with potential significant impact might need to be included as well. Whether a criterion is included or excluded, it is important to clearly define and document those parameters so that it is defensible and reproducible. For example, in the current case study, there may be conflicting information and evidence regarding how the different interventions impact antimicrobial resistance. In this case, analysts and decision makers may exclude this criterion from the analysis for the time being. The performance matrix described in *Table 2* shows the final list of criteria and how they were measured for the hypothetical case study.

Step 4: Defining the weights of the criteria

Another advantage of MCDA methods is that it allows users to assign criteria weights to reflect the relative importance or stakeholder preferences for each criterion. This is because different stakeholders often have different value judgments or preferences, which can be captured by preferentially assigning different weights to the criteria. For example, consumer advocates may consider certain criteria to be more important in terms of ensuring a safe food supply, while other stakeholder groups, such as industry, may feel that other criteria are more important. Stakeholder preferences may be particularly important for a given decision context, and there are various approaches to assigning preference weights. On one end of the spectrum, a decision maker, risk assessor, or researcher conducting the MCDA can select criteria weights based on their own preferences or assumptions. On the other end of the spectrum, there are more formalized methods and approaches to determining and assigning criteria weights, including quantitative methods *(8)*, semi-quantitative approaches such as swing weighting *(25)*, or other methods that rely on resource allocations to determine weights *(34)*. While there are many different proposed approaches to determining the criteria weights in the literature, it is generally recommended that the method selected be simple, intuitive, and robust *(17)*.

In order to evaluate how these criteria weights may impact the overall risk ranking results, scenario analyses can be performed whereby the criteria weights can be adjusted and the resulting rankings compared. In our example, we consider three scenarios (A, B, and C) to represent the different criteria weighing schemes from three different stakeholder groups (see last three columns in the performance matrix) *(Table 2)*, where values represent the relative weights assigned to each criterion, totaling 100.

Step 5: Analyzing and synthesizing the alternatives' performance

As mentioned, a suite of MCDA methods is available (e.g., outranking, multi-attribute utility theory, linear additives models, analytical hierarchy process) that can be used to synthesize all risks and benefits and produce a single metric that can be used to rank the considered food safety interventions in order of overall performance *(16)*. For the case study we chose to use the outranking method, which is robust and available online *(31)*. Data from the performance matrix was entered into the software, which summarizes the risks and benefits of the interventions into a single score, the net flow (Φ); the higher the net flow, the better the alternative's overall performance. The PROMETHEE algorithm and more details about the method can be found in Fazil et al. (2008) and PROMETHEE-GAIA *(11, 31)*.

As one can expect, these complex models may contain a great deal of variability and/or uncertainty which can potentially result in significant variations in the outputs. Several methods have been developed to formally describe and account for uncertainty in MCDA models, e.g., using full probability distributions, summary risk measures such as ranges and quantiles, and scenarios *(9)*. In our case study, we did not account for uncertainty or variability, but those could have been addressed in a deterministic fashion through the development of more scenarios with different input variables.

Step 6: Reporting results

The aggregated measure (net flow) is the output from MCDA that gives analysts and decision makers the ranking of the alternatives being considered. Results can be visualized in tables and several types of graphs for one or all of the scenarios being evaluated. A narrative should follow the tabular and graph results, stating clearly the assumptions, limitations, uncertainties and variability associated with analysis.

In our example, PROMETHEE provides a series of graphic results and comparisons that can be used to discuss findings with the decision makers and assessors. Results can be presented in bar graphs *(Fig. 2)*, tables (not shown) and GAIA webs (not shown). Decision makers can quickly visualize how the five interventions compare with each other in a specific scenario *(Fig. 2)* and/or evaluate the impact of the different scenarios in the final ranking (i.e., different value judgments from stakeholders) *(Fig. 3)*.

In our case study, interventions 1 or 5 seem to have the best ratio of risk and benefits and are the top two choices for the three scenarios evaluated. They are followed by intervention 2 that, independently of the value judgement from stakeholders, is consistently in third place. Interventions 3 and 4 seem to perform much worse than any of the other three, regardless of the scenario considered. These types of outputs can be extremely valuable when discussing the potential options with the different stakeholders. For instance, in this hypothetical example the top 3 and the bottom 2 interventions are consistent across the different scenarios, demonstrating that there is some overall agreement between the values and weights of the three stakeholder groups.

FINAL CONSIDERATIONS

RBA is an emerging topic in the area of food safety. The goal of this paper was to first illustrate how one RBA approach using MCDA could be applied to systematically identify and evaluate a wide range of risks and benefits in the context of food safety. In order to demonstrate its applicability, a hypothetical case study that focuses on different types of interventions to control pathogen A in food B was presented. Three criteria related to risk and two criteria related to benefits were identified. These criteria were used to evaluate five hypothetical intervention strategies using the PROMETHEE method and online software MCDA tool. Two of the five interventions provide the best balance for minimizing risks and maximizing benefits. This hypothetical case study demonstrated the potential utility of RBA and MCDA for decision-making in food safety. The same approach can be applied to a similar decision context using real data, evaluation criteria, and stakeholder preferences as reflected in criteria weights.

MCDA is equipped to address a larger set of criteria that are often not formally included in RBA, which traditionally focuses only on public health effects. The set of criteria (i.e., risks and benefits) is flexible and can be customized to the needs of specific decision makers and stakeholders, if necessary. MCDA could be seen as a more comprehensive and transparent assessment of the risks and benefits associated with a specific risk management decision with broader boundaries of the study system and a broader set of analytical tools to choose from.

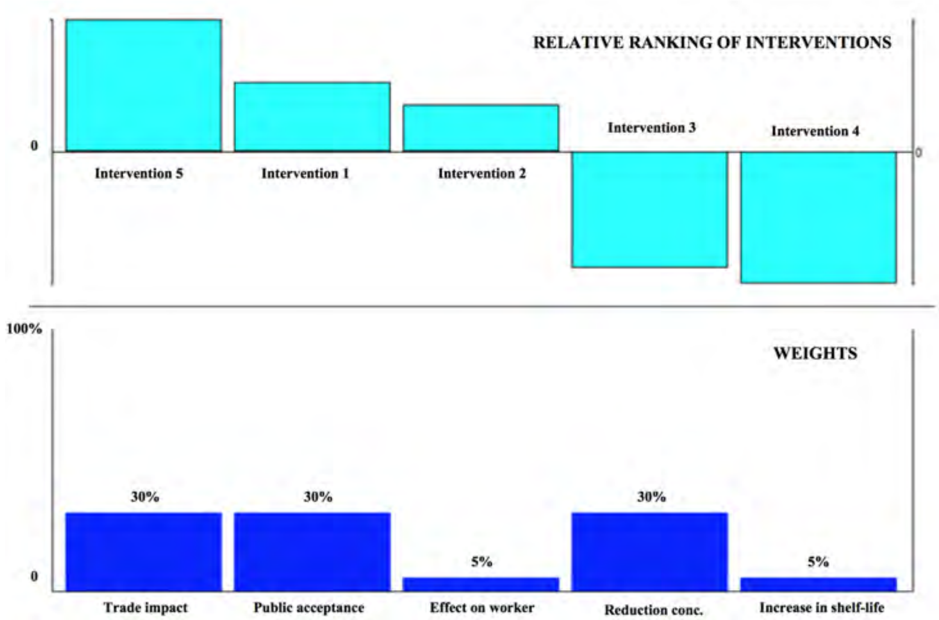

Figure 2: Bar graph for Scenario B of the hypothetical case study

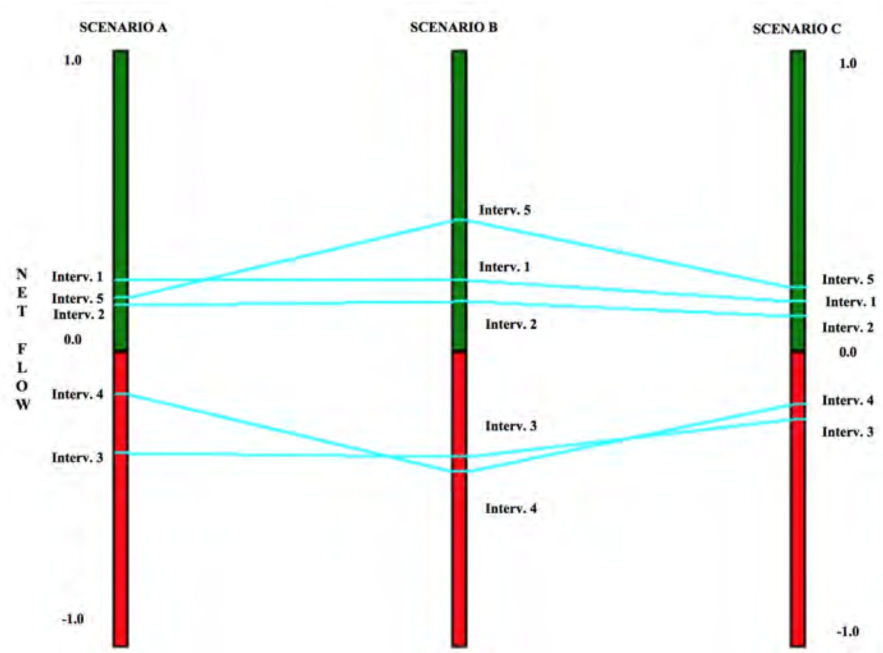

Figure 3: Scenario comparison of the hypothetical case study

ACKNOWLEDGMENTS

The research team acknowledges the technical advice of Archana Lamichhane from RTI International and Aamir Fazil from the Public Health Agency of Canada.

AUTHOR INFORMATION

Phone: +1 919.316.3163
E-mail: jruzante@rti.org

REFERENCES

1. Bates, M. E., K. D. Grieger, B. D. Trump, J. M. Keisler, K. J. Plourde, and I. Linkov. 2016. Emerging technologies for environmental remediation: integrating data and judgment. *Environ. Sci. Technol.* 50:349–358.
2. Berjia, F. L., R. Andersen, J. Hoekstra, M. Poulsen, and M. Nauta. 2012. Risk-benefit assessment of cold-smoked salmon: microbial risk versus nutritional benefit. *EJFRR*. 2:49–68.
3. Boobis, A., A. Chiodini, J. Hoekstra, P. Lagiou, H. Przyrembel, J. Schlatter, H. Verhagen, and B. Watzl. 2013. Critical appraisal of the assessment of benefits and risks for foods, 'BRAFO Consensus Working Group'. *Food Chem. Toxicol.* 55:659–675.
4. Cooke, R. M. 1991. Experts in uncertainty: opinion and subjective probability in science. Oxford University Press, Oxford, UK.
5. Cooke, R. M., and L. H. J. Goossen. 2007. TU Delft Expert Judgment Data Base. *Reliab. Eng. Sys. Safe.* 93:657–674.
6. Cox, L. A. Jr. 2008. What's wrong with risk matrices? *Risk Anal.* 20:497–512.
7. Cox, L. A. Jr., D. Babayev, and W. Huber 2005. Some limitations of qualitative risk rating systems. *Risk Anal.* 25:651–662.
8. Diakoulaki, D., G. Mavrotas, and L. Papayannakis. 1995. Determining objective weights in multiple criteria problems: the critic method. *Computers Opt. Res.* 22:763–770.
9. Durbach, I. N., and T. J. Stewart. 2012. Modeling uncertainty in multi-criteria decision analysis. *Europ. J. Oper. Res.* 223:1–14.
10. European Food Safety Authority Scientific Committee. 2010. Guidance on human health risk-benefit assessment of foods. Available at: http://www.efsa.europa.eu/en/efsajournal/pub/1673. Accessed 15 August 2016.
11. Fazil A., A. Rajic, J. Sanchez , and S. McEwen. 2008. Choices, choices: the application of multi-criteria decision analysis to a food safety decision-making problem. *J. Food Prot.* 71:2323–2333.
12. Food and Agriculture Organization and World Health Organization. 2010. Report of the joint FAO/WHO expert consultation on the risks and benefits of fish consumption. Rome, January 25–29, 2010. FAO Fisheries and Aquaculture Report No. 978. Available at: http://www.fao.org/docrep/014/ba0136e/ba0136e00.pdf. Accessed 15 August 2016.
13. Food and Agriculture Organization and World Health Organization. 2014. Ranking of low moisture foods in support of microbiological risk management. Preliminary report. Available at: http://ucfoodsafety.ucdavis.edu/files/209893.pdf. Accessed 3 September 2016.
14. Ginsberg, G. L., and B. F. Toal. 2009. Quantitative approach for incorporating methylmercury risk and omega-3 fatty acid benefits in developing species-specific fish consumption advice. *Environ. Health Perspect.* 117:267–275.
15. Gochfeld, M., and J. Burger. 2005. Good fish/bad fish: a composite benefit-risk by dose curve. *NeuroToxicol*. 26:511–520.
16. Greco, S., M. Ehrgott, and J. R. Figueira (ed.). 2016. Multiple criteria decision analysis. Springer, New York, NY.
17. Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson. 2012. Structured decision making: a practical guide to environmental management choices. Wiley-Blackwell, Oxford, UK.
18. Gunnlaugsdottir, H., A. Hart, and A.K. Danielsdottir. 2010. Quality of Life — Integrated Benefit and Risk Analysis: Web-based tool for assessing food safety and health benefit (N° 022957). Available at: http://www.qalibra.eu/showFile.cfm?filename=final_summary_report.pdf. Accessed 30 September 2016.
19. Hald, T., W. Aspinall, B. Devleesschauwer, R. Cooke, T. Corrigan, A. H. Havelaar, H. J. Gibb, P. R. Torgerson, M. D. Kirk, F. J. Angulo, R. J. Lake, N. Speybroeck, and S. Hoffmann. 2016. World Health Organization estimates of the relative contributions of food to the burden of disease due to selected foodborne hazards: a structured expert elicitation. *PLoS ONE.* 11:1–35.
20. Hart, A., J. Hoekstra, H. Owen, M. Kennedy, M. J. Zeilmaker, N. de Jong, and H. Gunnlaugsdottir. 2013. Qalibra: A general model for food risk-benefit assessment that quantifies variability and uncertainty. *Food Chem. Toxicol.* 54:4–17.
21. Hoekstra, J., A. Hart, A. Boobis, E. Claupein, A. Cockburn, I. Knudsen, D. Richardson, B. Schilter, K. Schütte, P. R. Torgerson, H. Verhagen, B. Watzl, and A. Chiodini. 2012. BRAFO tiered approach for benefit-risk assessment of foods. *Food Chem. Toxicol.* 50 (Suppl 4):S684–S698.
22. Hoekstra, J., J. Verkaik-Kloosterman, C. Rompelberg, H. van Kranen, M. Zeilmaker, H. Verhagen, and N. de Jong. 2008. Integrated risk-benefit analyses: Method development with folic acid as example. *Food Chem. Toxicol.* 46:893–909.
23. Hoffmann. S., P. Fischbeck, A. Krupnick, and M. McWilliams. 2007. Using expert elicitation to link foodborne illnesses in the United States to Foods. *J. Food Prot.* 70:1220–1229.
24. Hsu, J., D. Tang, and C. Lu. 2015. Risk-benefit assessment of oral phosphodiesterase type 5 inhibitors for treatment of erectile dysfunction: a multiple criteria decision analysis. *Int. J. Cl. Pract.* 69:436–443.
25. Kirkwood, C. W. 1997. Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets. Duxbury Press, Belmont, CA.
26. Linkov, I. 2011. Coupling multi-criteria decision analysis, life-cycle assessment, and risk assessment for emerging threats. Environ. *Sci. Technol.* 45:5068–5074.
27. Linkov, I., F. K. Satterstrom, G. Kiker, T. P. Seager, T. Bridges, K. H. Gardner, S. H. Rogers, D. A. Belluck, and A. Meyer. 2006. Multicriteria decision analysis: a comprehensive decision approach for management of contaminated sediments. *Risk Anal.* 26:61–78.
28. Mussen, F., S. Salek, and S. Walker. 2007. A quantitative approach to benefit-risk assessment of medicines — part 1: The development of a new model using multi-criteria decision analysis. *Pharm. Drug Safety.* 16: S2–S15.
29. Nesheim, M. C., and A. L Yaktine (ed). 2007. Seafood choices: balancing benefits and risks. NAP Press, Washington, D.C.
30. Pires, S. M., A. R. Vieira, T. Hald, and D. Cole. 2014. Source attribution of human salmonellosis: an overview of methods and estimates. *Foodborne Pathog. Dis.* 11:667–676.
31. PROMETHEE-GAIA software. Available at: http://www.promethee-gaia.net/software.html. Accessed 30 September 2016.
32. Renwick, A. G., A. Flynn, R. J. Fletcher, D. J. G. Müller, S. Tuijtelaars, and H. Verhagen. 2004. Risk-benefit analysis of micronutrients. *Food Chem. Toxicol.* 42:1903–1922.
33. Rheinberger, C., and J. Hammitt. 2012. Risk trade-offs in fish consumption: A public health perspective. *Environ. Sci. Technol.* 46:12337–12346.
34. Riabacke, M., M. Danielson, and L. Ekenberg. 2012. State-of-the-art prescriptive criteria weight elicitation. *Adv. Dec. Sci.* 1:9.
35. Ruzante, J. M., V. Davidson, J. Caswell, A. Fazil, J. Cranfield, S. Henson, S. Anders, C. Schmidt, and J. Farber. 2010. A multifactorial risk prioritization framework for foodborne pathogens. *Risk Anal.* 30:724–742.
36. Schütte, K., H. Boeing, A. Hart, W. Heeschen, E. H. Reimerdes, D. Santare, K. Shog, and A. Chiodini. 2012. Application of the BRAFO tiered approach for benefit–risk assessment to case studies on heat processing contaminants. *Food Chem. Toxicol.* 50:S724–S735.
37. Tervonen, T., H. Naci, G. van Valkenhoef, A. E. Ades, A. Angelis, H. L. Hillege, and D. Postmus. 2015. Applying multiple criteria decision analysis to comparative benefit-risk asessment: choosing among statins in primary prevention. *Med. Decis. Making.* 35:859–871.
38. Tervonen, T., G. van Valkenhoef, E. Buskens, H. L. Hillege, and D. Postmus. 2011. A stochastic multicriteria model for evidence-based decision making in drug benefit-risk analysis. *Stat. Med.* 30:1419–1428.

39. Tsang, M. P., M. E. Bates, M. Madison, and I. Linkov. 2014. Benefits and risks of emerging technologies: Integrating life cycle assessment and decision analysis to assess lumber treatment alternatives. *Environ. Sci. Technol.* 48:11543–11550.

40. U.S. Food and Drug Administration. 2015. Multicriteria-based ranking model for risk management of animal drug residues in milk and milk products. Available at: http://www.fda.gov/downloads/Food/FoodScienceResearch/RiskSafetyAssessment/UCM443965.pdf. Accessed 15 August 2016.

41. U.S. Food and Drug Administration. 2011. Multi-criteria decision analysis methodology used to prioritize inspection of subject: egg farms for monitoring compliance with the egg safety rule. Available at: http://www.fda.govdownloads/Food Compliance Enforcement/UCM267597.pdf. Accessed 15 August 2016.

42. Verhagen, H., R. Andersen, J. M. Antoine, P. Finglas, J. Hoekstra, A. Kardinaal, H. Nordmann, G. Pekcan, K. Pentieva, T. A. Sanders, H. van den Berg, H. A. van Kranen, and A. Chiodini. 2012. Application of the BRAFO tiered approach for benefit-risk assessment to case studies on dietary interventions. *Food Chem. Toxicol.* 50:S710–S723.

43. Watzl, B., E. Gelencser, J. Hoekstra, S. Kulling, E. Lydeking-Olsen, I. Rowland, B. Schilter, J. van Klaveren, and A. Chiodini. 2012. Application of the BRAFO-tiered approach for benefit-risk assessment to case studies on natural foods. *Food Chem. Toxicol.* 50:S699–S709.

44. World Health Organization. 2003. Diet, nutrition and the prevention of chronic diseases. Available at: http://apps.who.int/iris/bitstream/10665/42665/1/WHO_TRS_916.pdf. Accessed 30 September 2016.

45. Xiong, G. Y., Z. H. Xia, L. J. Guang, Z. Lei, Y. X. Wei, H. J. Lu, S. X. Hong, Z. Y. Feng, and W. Y. Ning. 2015. The benefit risk assessment of consumption of marine species based on benefit-risk analysis for foods (BRAFO)-tiered approach. *Biomed. Environ. Sci.* 28:243–252.