# Background Paper on Decision Making

*Prepared for the 2014 Advancing Alternatives Analysis Workshop*

This background paper offers an overview of decision-making in alternatives analysis (AA). Following a brief introduction to the nature and challenges of decision-making in the AA context, the paper focuses on two topics: decision frameworks in AA and available decision methods and tools. (The paper assumes a basic knowledge of AA; for more information on AA see the *Background Paper on Alternatives Analysis*.)

## INTRODUCTION

Alternatives analysis (AA) can present regulators, businesses and non-governmental organizations (NGOs) with difficult choices. For example, in our case study the City of Beachside must identify safer, viable alternatives to copper-based paint for boats. In comparing the alternatives, an AA considers multiple criteria, including environmental effects, human health impacts, technical performance, and economic feasibility. And each of those criteria implicates a number of sub-criteria. For example, human health impacts may include considerations of carcinogenicity, endocrine disruption, developmental toxicity, neurotoxicity.

The complexity of such an analysis is increased by several factors. First, in many cases the data regarding toxicity, exposure, functionality and economic impact will be incomplete and highly uncertain. Second, the data that are available will be quite diverse in nature; some will be qualitative and other quantitative, and much will be incommensurable. And finally, selecting among alternatives can present thorny trade-offs. So, for example, how does one make the choice between an endocrine disrupting chemical in one product and a carcinogen in another? Third, in the regulatory setting in particular, concerns regarding consistency and transparency are also raised; good governance calls for similar treatment of similar cases and openness regarding the decision-making process.

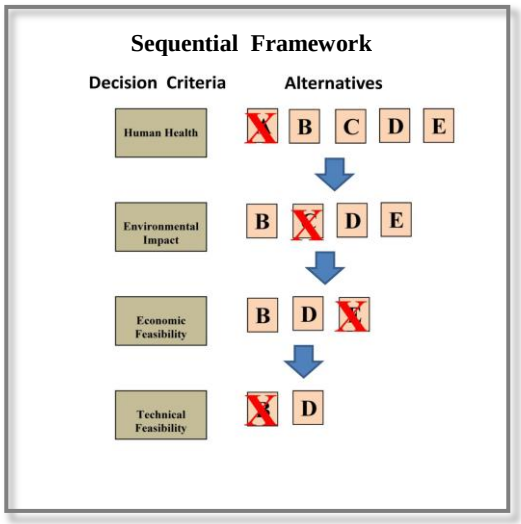
The field of decision analysis can assist policy-makers, businesses, and other stakeholders in this process. Decision analysis is "a systematic approach to evaluating complex problems and enhancing the quality of decisions."[1] It offers a variety of frameworks, tools and methods that are applicable to AA, to which we now turn. Keep in mind that an AA includes a number of decision points, including identifying an initial set of potential alternatives, screening that initial set to choose a smaller set for more comprehensive analysis, and ultimately selecting a safer, viable alternative(s).

## DECISION FRAMEWORKS

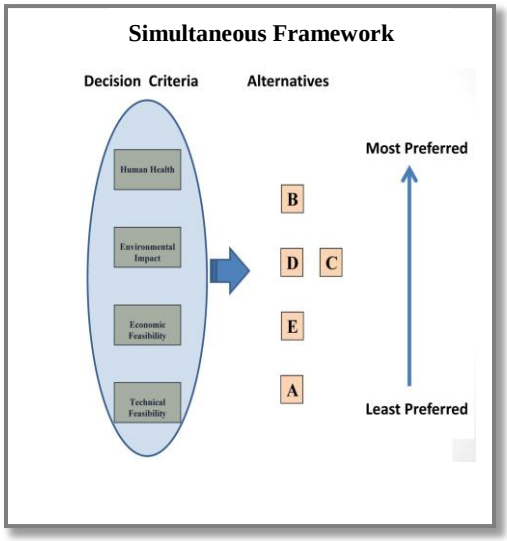
### Mixed Framework

[1] Tarsha Eason, *et al.*, GUIDANCE TO FACILITATE DECISIONS FOR SUSTAINABLE NANOTECHNOLOGY 54, EPA/600/R-11/107 (2011).

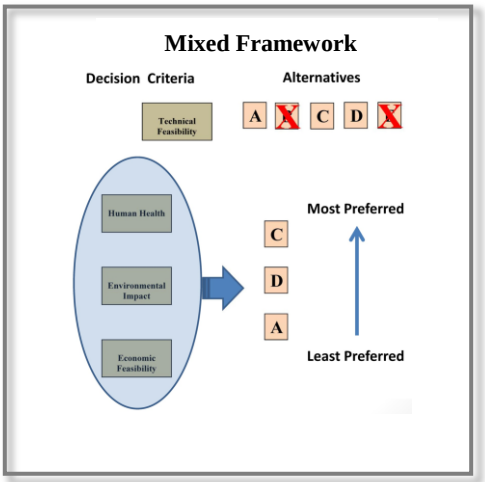
For our purposes the term "decision framework" means the overall structure or order of the decision-making. Existing AA approaches that explicitly address decision-making use any of three general decision frameworks: sequential, simultaneous, and mixed.[2] The **sequential framework** includes a set of attributes, such as human health, environmental impacts, economic feasibility, and technical feasibility, which are addressed in succession. The first attribute addressed is often human health or technical feasibility, as it is assumed that any alternative that does not meet minimum performance requirements should not proceed with further evaluation. Only the most favorable alternatives proceed to the next module for evaluation.




The ***simultaneous framework*** considers all or a set of attributes at once, allowing good performance on one attribute to offset less favorable performance on another for a given alternative. Thus, one marine paint's lackluster performance in terms of cost might be offset by its superior ability to minimize buildup of barnacles. This type of trading off is not generally available in the sequential framework across major decision criteria. That said, it is important to note that even within a sequential framework, the simultaneous framework may be lurking where a major decision criterion consists of sub-criteria. For example, in most AA approaches the human health criterion has numerous sub-criteria reflecting a various forms of toxicity such as carcinogenicity, acute toxicity, and neurotoxicity. Even within a sequential framework, the decision-maker may consider all those sub-criteria simultaneously when comparing the alternatives with respect to human health.




The ***mixed framework***, as one might expect, is a combination of the sequential and simultaneous approaches. So, for example, if technical feasibility is of particular importance to you, you may screen out certain alternatives on that basis, and subsequently apply a simultaneous framework to the remaining alternatives regarding the other decision criteria.




A recent study of 21 existing AA approaches noted that ten adopt no decision framework. Seven adopted the mixed framework, using different frameworks for screening potential alternatives and for generating a ranking of alternatives or preferred alternative,

[2] Interstate Chemicals Clearinghouse (IC2). ALTERNATIVES ASSESSMENT GUIDE (2013) (http://www.newmoa.org/prevention/ic2/IC2_AA_Guide-Version_1.pdf) (accessed Sept. 10, 2014); Timothy F. Malloy, *et al.*, DEVELOPING REGULATORY ALTERNATIVES ANALYSIS METHODOLOGIES FOR THE CALIFORNIA GREEN CHEMISTRY INITIATIVE (UCLA Sustainable Technology and Policy Program 2011) (stpp.ucla.edu/sites/default/files/Final%20AA%20Report.final%20rev.pdf ) (accessed Sept. 10, 2014).

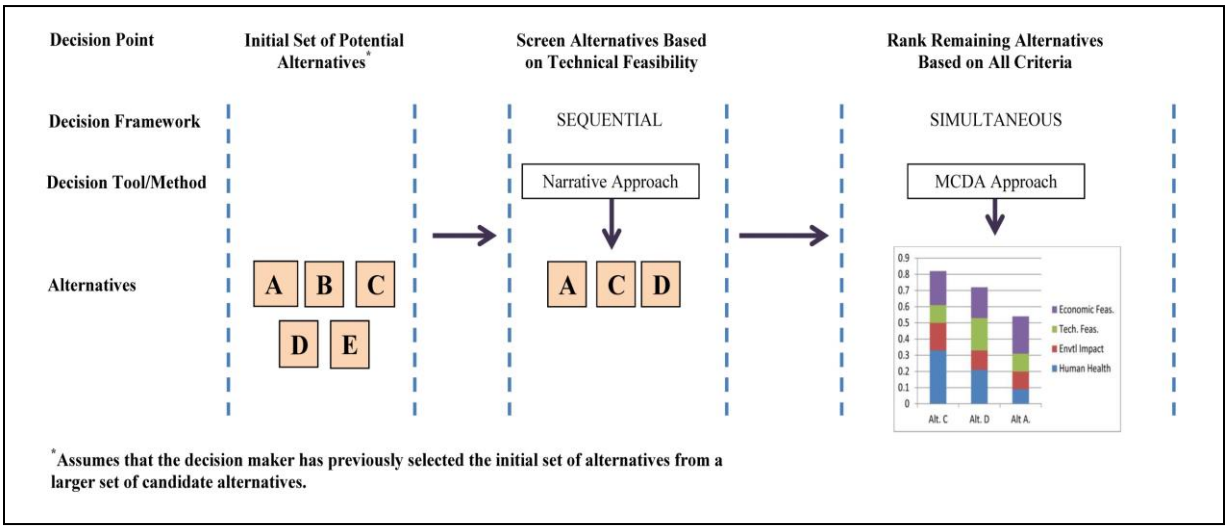
respectively. Three other frameworks applied the simultaneous approach exclusively, while one framework applied only the sequential approach. Lastly, the IC2 and the UCLA approaches presented the sequential, simultaneous and mixed frameworks as a menu of choices without expressing a preference. The UCLA approach applied the various frameworks in two case studies to illustrate how the choice of decision framework can affect the outcome of the AA.[3]

## DECISION TOOLS/METHODS

Decision tools or methods are formal and informal aids, rules or techniques that guide specific decisions. In the case of AA the particular decision may vary depending upon their needs and/or the requirements of the regulatory program. For example, the goal may be to identify a single optimal alternative, to rank the entire set of alternatives, or to simply differentiate between acceptable and unacceptable alternatives.[4]

There are a wide range of decision tools and methods, ranging from informal rules of thumb to highly complex, statistically-based methodologies.[5] These diverse approaches have distinctive theoretical bases, and handle uncertainty, weighting of decision criteria and other issues differently. (See Appendix I for a general comparison of the methods/tools). For our purposes, they can be broken into four general types: the narrative, structured, MCDA-assist, and robust scenario approaches. Each type can be used for various decisions in an AA, such as winnowing down the initial set of potential alternatives or for ranking the alternatives. As Figure 1 illustrates, in the context of a mixed decision framework, two different decision tools/methods could even be used at different decision points within a single AA.

**Figure 1**
**Example of a Mixed Framework**




[3] Molly Jacobs, *et al.*, *Alternatives Assessment Frameworks: A Literature Review to Identify Gaps and Research Needs for the Informed Substitution of Hazardous Chemicals* (draft on file).
[4] Igor Linkov *et al*, *From Comparative Risk Assessment to Multi-Criteria Decision Analysis and Adaptive Management: Recent Developments and Applications*, 32 ENVIRONMENT INTERNATIONAL 1072, 1075 (2006).
[5] *See* Joanne Shatkin and S. Qian, *Classification Schemes for Priority Setting and Decisionmaking: A Selected Review of Expert Judgment, Rule-Based, and Prototype Methods*, in Igor Linkov and A. Bakr Ramadan *(eds.)*, COMPARATIVE RISK ASSESSMENT AND ENVIRONMENTAL DECISION MAKING 213 (2004).

***Narrative Approaches.*** In the narrative approach, as known as the "*ad hoc"* approach,[6] the decision-maker engages in a holistic, qualitative balancing of the data and associated trade-offs to arrive at a selection. In some cases the decision-maker may rely upon explicitly stated informal decision principles, or expert judgment to guide the process. No quantitative scores are assigned to alternatives for purposes of the comparison. Likewise no explicit quantitative weighting is used to reflect the relative importance of the decision criteria, although in some instances qualitative weighting may be provided for the analyst. Often the weight given to the relevant decision criteria is left to the discretion of the analyst, and is often unstated.[7]

The narrative approach is widely used in regulatory decision-making. For example, the federal Superfund statute and implementing regulations use it in selecting cleanup remedies for hazardous waste sites. Remedy selection is driven through a qualitative balancing of five criteria: long-term effectiveness, reduction of toxicity through treatment, short-term effectiveness, implementability, and cost-effectiveness.[8] The narrative approach has also been used under the name of the verbal-argumentative approach in comparative life cycle assessment,[9] and by the European Chemicals Agency (ECHA) in prioritizing chemicals for regulations under the European Union's REACH program.[10]

***Structured Approaches.*** Structured approaches, also known as elementary approaches, apply a more systematic overlay to the narrative approach, providing the analyst with specific guidance about how to make a decision. Such approaches provide an observable path for the decision process, but typically do not require sophisticated software or specialized expertise. The structure may take the form of a decision tree which takes the analyst through an ordered series of questions. Alternatively, it may offer a set of checklists, specific decision rules, or simple algorithms to assist the analyst in framing the issues and guiding the evaluation.[11] Structured approaches can make use of both quantitative and qualitative data, and may incorporate implicit or explicit weighting of the decision criteria.

For example, Clean Production Action's Green Screen is an open source screening tool used by businesses and regulators to classify chemicals according to four categories of concern (low, medium, high, very high) for various health, environmental and physical hazards. Green Screen also sets out decision rules for determining whether and to what extent a particular chemical should be used in a product.[12] Similarly, the Eco-Value Analysis method for eco-design generates a matrix

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[6] Eason, *et al.*, *supra*, n. 1.

[7] Igor Linkov, *et al*., Multi-Criteria Decision Analysis: A Framework for Structuring Remedial Decisions at Contaminated Sites, in Igor Linkov and Abou Bakr Ramadan, eds., COMPARATIVE RISK ASSESSMENT AND ENVIRONMENTAL DECISION MAKING 15 (2005).

[8] Each of these criteria is further broken down into underlying factors or sub-criteria. 40 CFR Section 300.430

[9] Göran Finnveden, *A Critical Review of Operational Valuation/Weighting Methods for Life Cycle Assessment* (1999).

[10] European Chemicals Agency, GENERAL APPROACH FOR PRIORITISATION OF SUBSTANCES OF VERY HIGH CONCERN (SVHCS) FOR INCLUSION IN THE LIST OF SUBSTANCES SUBJECT TO AUTHORISATION (May 2010)

[11] Linkov, *et al*., Structuring Remedial Decisions, *supra* n. 7.

[12] Brandon Kuczenski and Roland Geyer, CHEMICAL ALTERNATIVES ANALYSIS: METHODS, MODELS, AND TOOLS. (2010); *see also* Steffen Foss Hansen, Keld Alstrup Jensen, Anders Baun, *NanoRiskCat: A Conceptual Tool for Categorization and Communication of Exposure Potentials and Hazards of Nanomaterials in Consumer Products*, 16 J. NANOPART. RES. 2195 (2014) (setting out a structured decision tool for characterizing the hazard and exposure potential of nanomaterials in consumer products).

displaying the technical, environmental and economic performance of potential product designs, supplemented by simple rules of thumb for product optimization.[13]

***MCDA-Assist Approaches.*** The MCDA-Assist approach couples a narrative evaluation with a mathematically-based formal decision analysis tool such as multi-criteria decision analysis (MCDA).[14] The output of the MCDA analysis is intended as a guide for the decision-maker and a reference for stakeholders affected by or otherwise interested in the decision.[15] MCDA consists of a range of different methods and tools, reflecting various theoretical bases and methodological perspectives. Accordingly, they tend to assess the data and generate rankings in different ways.[16] They generally share certain common features which set them apart from the type of informal decision making present in the narrative approach. Each MCDA approach provides a systematic, observable process for evaluating alternatives in which an alternative's performance across the decision criteria is aggregated to generate a partial or complete ranking. In most, the relative importance of the decision criteria and sub-criteria is quantified, and used to weight the performance of each alternative on each criterion.[17]

Some MCDA-based tools, such as Multi Attribute Utility Theory (MAUT), are *optimization tools* that seek to maximize achievement of the decision maker's preferences. The preferences for each of the decision criteria are represented by utility functions, dimensionless scales that range from 0 to 1. This method converts the measured performance of an alternative for a given decision criterion to a score between 0 and 1, multiplies that score by the weight assigned to that criterion. It aggregates the weighted scores to arrive at a total score for the alternative.[18]

In contrast, outranking methods do not create utility functions or seek optimal alternatives. Instead outranking methods seek the *dominant* alternative rather than the optimal one. Such methods directly compare the performance of two alternatives on each criterion, one at a time, to ascertain which one alternative out-performs the other. In a sense, it is as if all the alternatives are engaged in a tournament of one on one contests over each criterion, with the alternative having the best overall record prevailing. The value awarded for each "win" is weighted to reflect the importance of that criterion to the decision maker.[19]

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[13] Christof Oberender and H. Birkhofer, *The Eco-Value Analysis: An Approach to Assigning Environmental Impacts and Costs to Customers' Demands*, Proceedings of the International Design Conference (2004).

[14] Igor Linkov and Emily Moberg, MULTI-CRITERIA ANALYSIS: ENVIRONMENTAL APPLICATIONS AND CASE STUDIES (2012).

[15] Stefan Hajkowicz, *A Comparison of Multiple Criteria Analysis and Unaided Approaches to Environmental Decision Making*, 10 ENVIRONMENTAL SCIENCE & POLICY 177 (2007).

[16] Gregory A. Kiker, *et al.*, *Application of Multicriteria Decision Analysis in Environmental Decision Making*, 1INTEGRATED ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 95 (2005).

[17] Valerie Belton and Theodor J. Stewart, MULTIPLE CRITERIA DECISION ANALYSIS: AN INTEGRATED APPROACH (2002).

[18] Linkov and Moberg, *supra* n. 14.

[19] Timothy F. Malloy, *et al.*, *Use of Multi-Criteria Decision Analysis in Regulatory Alternatives Analysis: A Case Study of Lead Free Solder*, 9 INTEGRATED ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 652 (2013). Analytical Hierarchy Process (AHP) is a third family of widely used MCDA methods which also uses pair-wise comparisons. AHP relies upon a ratio scale ranging from 1 to 9 to measure an alternative's relative performance on each criterion as compared to another alternative. The results of these comparisons are entered into a matrix, from which a preference vector is constructed to analyze the overall relative performance. Belton and Stewart, *supra* n. 17.

***Robust Scenario Approaches.*** Robust scenario analysis is particularly useful where a decision-maker faces deep uncertainty, meaning situations in which the decision-makers do not know or cannot agree upon the likely performance regarding important criteria.[20] In the case of alternatives analysis, such uncertainty may exist regarding the probability that some chemical will turn out to be toxic, or that a particular exposure may occur. Narrative and structured approaches tend to use simple heuristics to deal with such uncertainties, while MCDA approaches may integrate probability distributions into their predictions of overall performance. Rather than generating probability distributions to identify an optimal alternative, robust scenario analysis uses large ensembles of scenarios to visualize all plausible, relevant futures for each alternative. With this range of potential futures in mind, it helps decision-makers to compare the alternatives in search of the most *robust* alternative. A robust alternative is one that performs well across a wide range of plausible scenarios even though it may not be optimal or dominant in any particular one.[21]

Robust decision making consists of four iterative steps. First, the decision makers define the decision context, identifying goals, uncertainties and potential alternatives under consideration. Second, modelers generate ensembles of hundreds, thousands or even more scenarios, each reflecting an outcome flowing from different plausible assumptions about how each alternative may perform. Third, quantitative analysis and visualization software is used to explore the benefits and drawbacks of the alternatives across the range of scenarios. Finally, trade-off analysis is used to evaluate the alternatives and identify a robust strategy.[22]

## CONCLUSION

AA requires balancing numerous, incommensurable decision criteria and evaluating the trade-offs among those criteria presented by multiple alternatives. While narrative and formal decision analysis methods and tools suitable for such situations are well developed, little sustained, rigorous attention has been paid to their use in alternatives analysis practice. The range of decision approaches and decision analysis tools is quite broad, requiring development of principles for selecting and implementing the most appropriate approaches and tools for this regulatory setting.

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[20] Robert J. Lempert and Myles T. Collins, *Managing the Risk of Uncertain Threshold Responses: Comparison of Robust, Optimum and Precautionary Approaches*, 27 RISK ANALYSIS 1009 (2007).
[21] Nidhi Kalra, *et al.*, AGREEING ON ROBUST DECISIONS: NEW PROCESSES FOR DECISION MAKING UNDER DEEP UNCERTAINTY (June 2014).
[22] RAND Corporation, MAKING GOOD DECISIONS WITHOUT PREDICTIONS: ROBUST DECISION MAKING FOR PLANNING UNDER DEEP UNCERTAINTY (undated).

## Appendix I
## Comparison of Decision Methods/Tools

| Method | Standard for Comparison of Alternatives | Compensatory Nature | Approach to Uncertainty | Weighting of Criteria |
|---|---|---|---|---|
| **Narrative** | **Varied:** The standard may be unspecified or may be explicitly or implicitly set out in informal decision principles or guidance. | **Varied:** Extent to which good performance on one criterion can offset poor performance on another depends upon the discretion of the decision-maker or upon informal decision principles or guidance, if any exist. | **Varied:** The standard may be unspecified or may be explicitly or implicitly set out in informal decision principles or guidance. For example, where data is uncertain the decision-maker might assume the worst possible performance for the relevant criteria. | **Varied:** Relative importance of criteria may be unspecified or qualitative weighting may be explicitly or implicitly set out in informal decision principles or guidance. |
| **Structured** | **Varied:** The standard may be explicitly or implicitly set out in decision rules or structure. | **Varied:** Extent of compensation depends upon explicit or implicit direction set out in decision rules or structure. | **Varied:** The standard may be explicitly or implicitly set out in decision rules or structure. | **Varied:** Relative importance of criteria may be explicitly or implicitly set out in decision rules or structure as qualitative weights. |
| **MCDA-MAUT** | **Optimization:** Uses numerical scores to quantify and rank the overall performance of each alternative on a single dimensionless scale. | **Compensatory:** Because MAUT methods aggregate performance across all criteria, poor performance on one criterion can be fully compensated for by good performance on others. | **Probabilistic:** Rather than assigning a single value for performance or preferences, the method assigns a distribution of values so that uncertainty is explicitly reflected. A variety of probabilistic approaches | Explicit, quantitative weighting of criteria. |

| Method | Standard for Comparison of Alternatives | Compensatory Nature | Approach to Uncertainty | Weighting of Criteria |
|---|---|---|---|---|
| | | | have been used, including Monte Carlo analysis, fuzzy sets, and Bayesian networks. | |
| **MCDA-Outranking** | **Dominance:** Orders alternatives based on the extent to which they dominate one another; that is where one alternative outperforms the other on some criteria and does not significantly underperform on other criteria, taking into account the criteria's relative importance. | **Partially compensatory:** Outranking methods allow for some compensation, but do not necessarily reflect the magnitude of relative underperformance in a criterion versus the magnitude of over-performance in another criterion. Thus an alternative gets the same "credit" for performing slightly better on a one criterion as it does for performing substantially better on another. | **Probabilistic:** Rather than assigning a single value for performance or preferences, the method assigns a distribution of values so that uncertainty is explicitly reflected. A variety of probabilistic approaches have been used, including Monte Carlo analysis, fuzzy sets, and Bayesian networks. | Explicit, quantitative weighting of criteria. |
| **Scenario Analysis** | **Robustness:** Seeks to identify the alternatives that perform well over a wide range of possible future scenarios. | **No Compensation**: No mechanism for compensation, although individual decision-maker may engage in compensation in evaluating a scenario's outcome. | **Scenarios**: Rely upon large number of plausible scenarios to identify and evaluate the range of outcomes. | **No weighting:** No mechanism for weighting although individual decision-maker may use weighting in evaluating outcomes in the scenarios. |

## ANNOTATED LIST OF ADDITIONAL RESOURCES

Laure Canis, Igor Linkov, and Thomas P. Seager, *Application of Stochastic Multiattribute Analysis to Assessment of Single Walled Carbon Nanotube Synthesis Processes*, 44 ENVT'L. SCI. TECHNOL. 8704 (2010): **Application of MCDA to evaluation of alternative carbon nanotube production processes using a stochastic approach for dealing with uncertainty.**

Michela Catenacci and Carlo Giupponi, *Integrated Assessment of Sea-level Rise Adaptation Strategies Using a Bayesian Decision Network Approach*, 44 ENVT'L MODELLING & SOFTWARE 87 (2013): **Integration of MCDA and Bayesian networks in decision-making under conditions of deep uncertainty.**

Stefan Hajkowicz, *A Comparison of Multiple Criteria Analysis and Unaided Approaches to Environmental Decision Making*, 10 Environmental Science & Policy 177 (2007): **A comparison of the MCDA-assist approach and the narrative approach as used by 55 decision makers in Queensland, Australia in evaluating environmental projects.**

Steffen Foss Hansen, Keld Alstrup Jensen, Anders Baun, *NanoRiskCat: A Conceptual Tool for Categorization and Communication of Exposure Potentials and Hazards of Nanomaterials in Consumer Products*, 16 J. NANOPART. RES. 2195 (2014): **A structured decision tool for first-tier assessment of the hazard and exposure potential of consumer products containing engineered nanomaterials.**

Interstate Chemicals Clearinghouse (IC2). Alternatives Assessment Guide (2013) (http://www.newmoa.org/prevention/ic2/IC2_AA_Guide-Version_1.pdf): **A guidance document developed by a consortium of regulatory agencies and interested stakeholders setting out background on a menu of decision frameworks for alternatives analysis.**

Nidhi Kalra, *et al.*, AGREEING ON ROBUST DECISIONS: NEW PROCESSES FOR DECISION MAKING UNDER DEEP UNCERTAINTY (June 2014): **Overview of robust decision making approaches in the context of deep uncertainty.**

Gregory A. Kiker, *et al.*, *Application of Multicriteria Decision Analysis in Environmental Decision Making*, 1 INTEGRATED ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 95 (2005): **Overview of the potential applicability of MCDA approaches to environmental decision making, including a review of the then existing literature.**

Brandon Kuczenski and Roland Geyer, CHEMICAL ALTERNATIVES ANALYSIS: METHODS, MODELS, AND TOOLS. (2010): **A report reviewing and evaluating the applicability of various decision making approaches in the context of alternatives analysis.**

Igor Linkov *et al.*, *From Comparative Risk Assessment to Multi-Criteria Decision Analysis and Adaptive Management: Recent Developments and Applications*, 32 ENVIRONMENT INTERNATIONAL 1072, 1075 (2006): **A review of decision-making approaches used by US and European regulatory agencies, and a synthesis of MCDA and adaptive management methods for use in environmental remediation and restoration projects.**

Timothy F. Malloy, *et al.*, *Use of Multi-Criteria Decision Analysis in Regulatory Alternatives Analysis: A Case Study of Lead Free Solder*, 9 INTEGRATED ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 652 (2013): **Application of multi-attribute utility analysis and outranking to an alternatives analysis case study, developing and evaluating a regulatory alternatives analysis methodology and supporting decision-analysis software.**

Sung Jin Park, Oladele A. Ogunseitan, *Dempster-Shafer Theory Applied to a Regulatory Decision Process for Selecting Safer Alternatives to Toxic Chemicals in Consumer Products*, 10 INTEGRATED ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 12 (2013): **Use of a form of Bayesian probability theory to address uncertainty presented by multiple and sometimes conflicting lines of evidence in evaluating the toxicity of chemicals in consumer products.**

RAND Corporation, MAKING GOOD DECISIONS WITHOUT PREDICTIONS: ROBUST DECISION MAKING FOR PLANNING UNDER DEEP UNCERTAINTY (undated): **A short overview of robust decision making approaches in the context of deep uncertainty.**