A Paradigm Shift continued: An Application of Structured Decision Making for Sustainable Waste Management - 16486

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ABSTRACT

Structured decision making presents an opportunity for DOE and others engaged in solving complex environmental and waste management problems to find solutions that are stakeholder engaged and cost effective. This approach represents a paradigm shift that was introduced in a series of papers and a panel session at the WM2015 Symposium. The advantages of structured decision making over less formal approaches to decision making include technical defensibility, traceability and transparency. Structured decision making also overcomes the limitations of misapplication of conservatism in modeling, addresses stakeholder concerns and competing objectives directly, and provides a formal method through which internal and external stakeholders are encouraged to collectively and carefully consider all relevant attributes of solving complex problems. The first requirement of this paradigm shift is a realization and recognition that the problems faced are inherently decision problems, and that there is a formal theory of decision analysis that can, and should, be used to support finding the best solutions. Structured decision making is, very simply, formalized common sense. The formalities include: framing the problem; identification of objectives and measures for valuing those objectives; costs or values associated with those objectives; management options or alternatives for taking action that are tied directly to the objectives; and, science-based models to evaluate the options. Decision analysis is used to evaluate objectives and choose management options by balancing probability and consequence. The science-based models are built probabilistically based on expectation and uncertainty, and costs and value judgments are used to fulfill addressing stakeholder concerns. Consequently, this approach avoids misplaced conservatism in science-based modeling and properly places values in the objectives component of a decision model. This approach honestly addresses uncertainty and value judgments and balances these competing components to find the most effective decision.

A software framework program called Guided Interactive Statistical Decision Tools (GiSdT – pronounced “gist”) is used to support an application of this paradigm shift towards structured decision making. In this application objectives and management options for a waste disposal problem at the Los Alamos National Laboratory are identified, and features, events and processes are described and defined to form the basis of a conceptual site model. This establishes the decision model structure. Objectives are addressed through the three pillars of sustainability – economic, environmental, and social – and also address regulatory concerns or constraints. Management options include removal of waste to another location and engineering designs for leaving waste in place. Using structured decision making, the relationship between objectives, management options, and the conceptual site model is made clear, and leads to a comprehensive, defensible, transparent and traceable approach to effective decision making.

INTRODUCTION

The vast majority of remediation and waste management decisions are made without quantitative consideration of economic and socio-political factors. They are made instead based on quantitative metrics of human health risk. Sustainable decisions need to be made based on all three "pillars of sustainability" (economics, environment and social), and require understanding and characterization of the costs and values associated with each pillar. In addition, such decisions need to conform to regulatory or other legal requirements, which often constrains the decision space of interest. Although efforts are often made to include factors across all three pillars (for example, decisions made under CERCLA), these efforts are usually qualitative, and hence difficult to defend. They lack technical defensibility, transparency and traceability. The purpose of Structured Decision Making (SDM) is to provide a quantitative framework whereby all aspects of a decision problem can be addressed quantitatively, and hence, defensibly, transparently and traceably.

Most decision-makers do not currently have access to useful or usable methods and approaches when presented with choices that have significant impacts across all three pillars of sustainability. The goal of SDM is to provide that access by identifying or developing effective and user-friendly decision methods and approaches that empower decision-makers to explicitly and routinely incorporate all aspects of sustainability into their decision-making. To identify and develop these methods and approaches, SDM provides the tools needed for decision-makers and stakeholders to understand and characterize their knowledge of their current decision-making processes, and methods and approaches they need to proactively and quantitatively address all aspects of sustainability in their decisions.

In the past decades addressing DOE's environmental issues has focused primarily on modeling fate and transport of contaminants and human health risk assessment. Most often these modeling activities are carried out in a conservative fashion, where the conservatism is supposedly justified in the context of "protection of human health and the environment". Conservatism also surfaces in the regulations and associated guidance through use of very protective compliance limits, and the way in which data or model results are compared to the compliance limits. Although these multiple levels of conservatism, or protection, might be applied to relatively simple problems without significant downside, the same cannot be said for complex problems. For example, multiple levels of conservatism might sometimes be sufficient for compliance-based decisions for which a simple screening risk assessment is applied. It is certainly the case that such approaches to decision-making are sub-optimal, but under limited circumstances they might be sufficient. When the decision problems are complex, involving projections into the distant future or addressing large and complex engineering and environment, taking such simple screening approaches with the appearance of being conservative or protective is counter-productive, and often leads to unnecessarily costly remediation and waste management, and under-utilization of the nation's relatively few radioactive waste disposal facilities.

Screening approaches, such as those often used for CERCLA and RCRA cleanup decisions might be sufficient for compliance-based decisions, but it is not sufficient for optimization, which can lead to far more cost-effective decisions. Approaches to optimization must also demonstrate compliance, because this is a requirement or a constraint on the decision space. However, optimization within the compliance constraints needs to be supported with different approaches than screening. Optimization in principle is the same as the concept of "as low as reasonably achievable" (ALARA). To properly implement ALARA, or optimal decision making, a more complete decision analysis system is needed. This is the intent of an SDM approach to problem solving that was introduced in various papers and a panel session at WM2015 (P. Black et al. [1], P. Black et al. [2], and K. Black et al. [3]).

Compared to the upcoming complex problems faced by DOE, both in terms of waste disposal and remediation, human health risk assessment decisions under CERCLA and RCRA focus on shorter-term decision-making because long term fate and transport modeling is usually not considered necessary. However, some more complex contamination problems suffer from the same basic issues as radioactive waste disposal in terms of the need for complex fate and transport modeling and subsequent risk assessment. At least CERCLA addresses a form of "optimization" in the feasibility study, but it does not address how to perform that optimization in the face of uncertainty or stakeholders who have different competing objectives. Instead the CERCLA nine criteria involve a mix of quantitative and qualitative factors, with no system for organizing their relative importance or of formally supporting decisions that are made.

Other environmental issues that fall outside the realm of DOE Orders, NRC regulations, and regulations such as CERCLA and RCRA, have found the SDM path towards effective decision-making. This includes land reuse, watershed management, coral reef management, resiliency planning, and community redesign decisions, for which there is a focus on sustainability, including climate change, and on stakeholder involvement throughout the decision making process. These same tools and approaches can be applied to the types of environmental and waste management decisions that need to be made by DOE and NRC. SDM provides a formal process for capturing not only the science side of the problem, but also the costs and value judgments of the stakeholders, to help reach an optimal solution. This approach requires a paradigm shift within the DOE and NRC environmental and waste management programs, and it requires a willingness to engage a new technical approach that will provide a path towards effective optimization in the decision-making process. Because of the current nature of problem solving for these types of problems, which involves many layers of conservatism, this SDM path towards optimization will also realize substantial cost savings, while maintaining or improving defensibility and transparency in the decision making process.

The intent of SDM is fully consistent with the original goals of EPA's Data Quality Objectives (DQO) process. Indeed, it is reasonable to claim that SDM properly operationalizes the DQO process. The DQO process, whereas philosophically reasonable, was not connected with the right technical methods for statistics or decision analysis, which made application to other than very simple problems very difficult. SDM addresses that concern, because it uses the right technical approach for both statistics and decision analysis components of effective decision making. Also, in so doing, it is fully consistent with the intent of the Scientific Method.

The SDM approach to assessing decision risk is supported with a software framework program called Guided Interactive Statistics and Decision Tools (GiSdT– pronounced "gist"). GiSdT is an open source, interactive, web-based program that is used to document stakeholder inputs during decision model development. GiSdT presents a relatively new approach to addressing the stakeholder involvement in the context of solving complex decision problems, and involves organizing stakeholder values and objectives prior to addressing decision options that might be available for optimization. That is, GiSdT can be used to address the costs and values side of a decision problem, and then interfaces with science-based models so that a proper decision analysis is performed that balances stakeholder concerns with the probability of human health risk or dose.

In this application objectives and management options for a waste disposal problem at the Los Alamos National Laboratory are identified, and features, events and processes are described and defined to form the basis of a conceptual site model. This establishes the decision model structure. Objectives are addressed through the three pillars of sustainability – economic, environmental, and social – and also address regulatory concerns or constraints. Management options include removal of waste to another location and engineering designs for leaving waste in place. Using SDM, the relationship between objectives, management options, and the conceptual site model is made clear, and leads to a comprehensive, defensible, transparent and traceable approach to effective decision making.

Completion of these initial model structuring steps in the application will set the stage for evaluating the decision system by building a complete radiological risk assessment that addresses each of the management options explicitly, and developing value functions that address each of the objectives. This holistic stakeholder driven system focuses on forming agreements on inputs from which outputs and results are consequences of the inputs and assumptions made. This leads to decision endpoints that are agreed upon by all included stakeholders and sets the stage for effective model evaluation that evaluates the sensitivity of the model results to both the science-based components, costs and stakeholder values. This is a technically defensible and very effective approach to complex decision making that avoids misplaced conservatism in science-based models, appropriately addresses costs and values, and addresses stakeholder concerns directly.

DESCRIPTION

SDM was introduced in several papers and a panel session at WM2015 [1, 2, 3]. The introduction showed the basic process with a primary focus on stakeholder involvement leading to creating an objectives hierarchy, identifying measures for each objective so the objectives can be evaluated, developing value (utility) functions, and weighting the objectives. The next step is to demonstrate application of SDM to a specific problem and demonstrate how and why using SDM to support decision making adds value to the decision making process. The particular application presented involves a decision regarding transuranic (TRU) waste currently contained in shafts at the Los Alamos National Laboratory's (LANL) Material Disposal Area (MDA) G. Possible fundamental objectives include: minimizing costs; minimizing impact on human health and ecological risks; satisfying preferences of the local communities, including the Native American communities; and satisfying regulatory requirements. Basic management options are to exhume the waste and dispose at another facility, or leave the TRU waste in place, perhaps including some re-engineering of the current disposal system. The application is presented for the first steps of the SDM process, including developing objectives, identifying options that could achieve the objectives, and showing how and where science-based models are used to evaluate the options through the objectives. The science-based models are not developed, but a conceptual model for the connections between objectives and options is developed. The completed application will be developed over the course of the next year. The descriptions presents the general technical approach, and then reports on potential application of the approach to the LANL MDA G TRU Waste decision problem. Note that the example is meant to be illustrative. It is not intended to suggest a decision path to the best solution at this time. It is, however, the path that will be followed to find the best long-term disposition option.

SDM provides a decision analysis framework for defensibly merging stakeholder concerns, costs and value judgments, and technical science-based input enabling decision-makers and stakeholders to:

(1) understand the underlying context of the decision;

(2) define desired outcomes and measurable objectives;

(3) identify options (actions) for achieving desired outcomes;

(4) evaluate options using applicable data and models; and

(5) take appropriate action when significant uncertainty exists.

These five steps form the core of a decision model for environmental and waste management decisions. They begin with a shared understanding of the problem and development of a set of objectives that it would be desirable to achieve. At that time, the possible actions that could be taken are identified. It is then possible to consider how well each option (or combinations of options) achieves the desired objectives. The set of options that maximizes how fully the objectives are achieved is then identified as the optimal solution. From that point, various methods can be utilized to determine whether additional information might be valuable for increasing confidence that the optimal decision has been identified, to determine which additional information would be most valuable, and to establish a plan for revisiting the decision in the future as conditions change, as appropriate.

Further technical details are provided in the WM2015 papers (15236, 15649, 15650, and 15651). The purpose here is to demonstrate applicability of SDM through the LANL TRU waste application. In particular, structuring the decision model is addressed. This includes the following components:

1. Objectives hierarchy with associated measurable attributes
2. Management options that are associated with the objectives
3. A conceptual site model that addresses evaluation of each management option

TECHNICAL APPROACH

The technical approach that serves as the basis for the paradigm shift can be termed stakeholder engaged structured decision-making (SDM). SDM came to the fore in Gregory et al's [4] book of the same name. Gregory et al took a value-focused approach to decision making, which can be differentiated from traditional approaches to decision analysis that focus first on decision options. Value-focused thinking was first described by Keeney [5], and was intended to make decision analysis more tractable, useful, and accessible to decision makers. The steps involved in this stakeholder engaged structured decision-making approach can be summarized as follows:

1. Understand context
    a. Regulatory, social, and environmental setting
    b. Scientific setting
    c. Decision landscape
    d. Conceptual model
    e. Social network analysis
2. Define objectives
    a. Fundamental objectives
    b. Measurable attributes
    c. Value functions
    d. Objectives preference weighting
3. Identify decision options
    a. Define options
    b. Tie options to objectives
    c. Develop management scenarios (combinations of options)
4. Evaluate decision options
    a. Develop science-based models (probabilistic modeling) for each option and measurable attribute
    b. Perform uncertainty analysis
    c. Perform sensitivity analysis
5. Take action
    a. Choose optimal decision option or collect more data/information (including model refinement as necessary)
    b. Iterate if necessary

This process is depicted in Figure 1. Note the off-ramp in Figure 1. SDM is applied from the starting point of understanding the context of the problem. The basic intent is to characterize the decision problem in terms of uncertainty and possible consequences. The decision is made when uncertainty is sufficiently reduced that the decision can be made. The off-ramp is taken if uncertainty is sufficiently small. This is consistent, or operationalizes, the Scientific Method. That is, collect information, evaluate information, and iterate (Step 5b above) unless uncertainty is sufficiently reduced that the decision can be made with sufficient confidence. Uncertainty is evaluated against the costs and values specified in the decision model. Uncertainty is small enough if there is insufficient value in collecting additional information, or the cost/value of collecting additional information will not result in sufficient reduction in uncertainty in the decision.

GiSdT provides a software platform for capturing inputs provided for each of these steps, which allows the decision model to be fully transparent and traceable. Technical defensibility is obtained by completing the SDM process. GiSdT forces quantification at each step (e.g., value functions, weights, probability distributions), requiring stakeholder engagement for specification of value functions and weights. GiSdT implementation of SDM is essentially an implementation of Bayesian statistical decision analysis. This addresses multi-attribute utility and uncertainty characterized using probability distributions. This approach, using GiSdT technology, has been used by EPA on watershed management, brownfields revitalization, and coral reef management projects, and by other federal agencies such as FDA (food safety), DoD (unexploded ordnance risk), and NASA (climatology), as well as for some commercial applications. It is perhaps time to bring the same technology into DOE decision-making. This approach changes the focus of modeling from one of conservatism to optimization, which supports better decision-making. It engages stakeholders more effectively, so that value judgments and assumptions are addressed as inputs instead of as endpoints, and provides a structure to support decision-making that allows decisions to be defensible, transparent and traceable. The main steps are described in greater detail in each subsection that follows, including general discussion followed by specifics of the example used in the panel session mock demonstration.

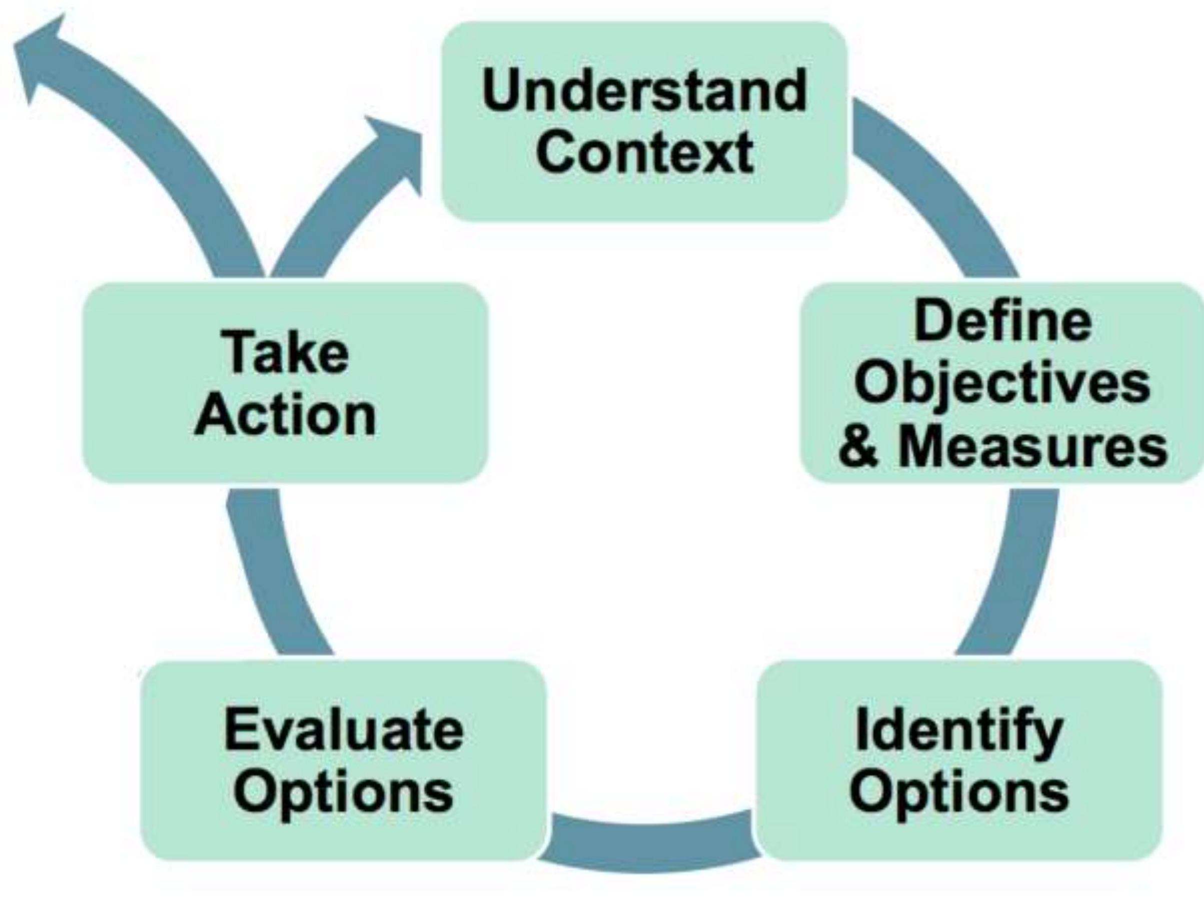


Figure 1: Structured decision making steps

APPLICATION

Understand Context

Remote handled transuranic (TRU) waste is currently contained in 33 shafts at the Los Alamos National Laboratory (LANL) Material Disposal Area (MDA) G. The long-term disposition of the waste is of interest. The principal decision regarding the disposition of the remote handled (RH) TRU is whether it should be exhumed (and processed and disposed somewhere else) or disposed in place. However, there are various manifestations of these basic decisions that are of importance when considering the entirety of the decision problem. For example, if the waste is left in place, then consideration could be given to how the waste is contained, and whether further engineering of the system is needed. Or, if the waste is to be exhumed, then which options exist for offsite disposition, and what type of waste processing is needed?

Figure 2 shows the general spatial and scientific setting. MDA G is on Mesita del Buey, a mesa that is within the boundary of the Los Alamos National Laboratory. MDA G has been used to dispose of radioactive waste for more than 50 years. The remote handled TRU waste that is of concern is contained in 33 shafts near the southern edge of Mesita del Buey (denoted approximately by the "star" on Figure 2). There are many more pits and shafts in which radioactive waste is disposed at MDA G. The shafts are located next to fill material that has been used to partially fill the smaller canyon to the west and south of the shafts that feeds into the main Pajarito Canyon.

Figure 2: Location of remote handled TRU shafts are MDA G, Los Alamos National Laboratory

Figure 3 provides a depiction of the stable subsurface of volcanic tuff and the fill material located in the canyon near the shafts. The location of the fill material is uncertain, and research is underway to determine if any of the shafts are drilled into fill material.

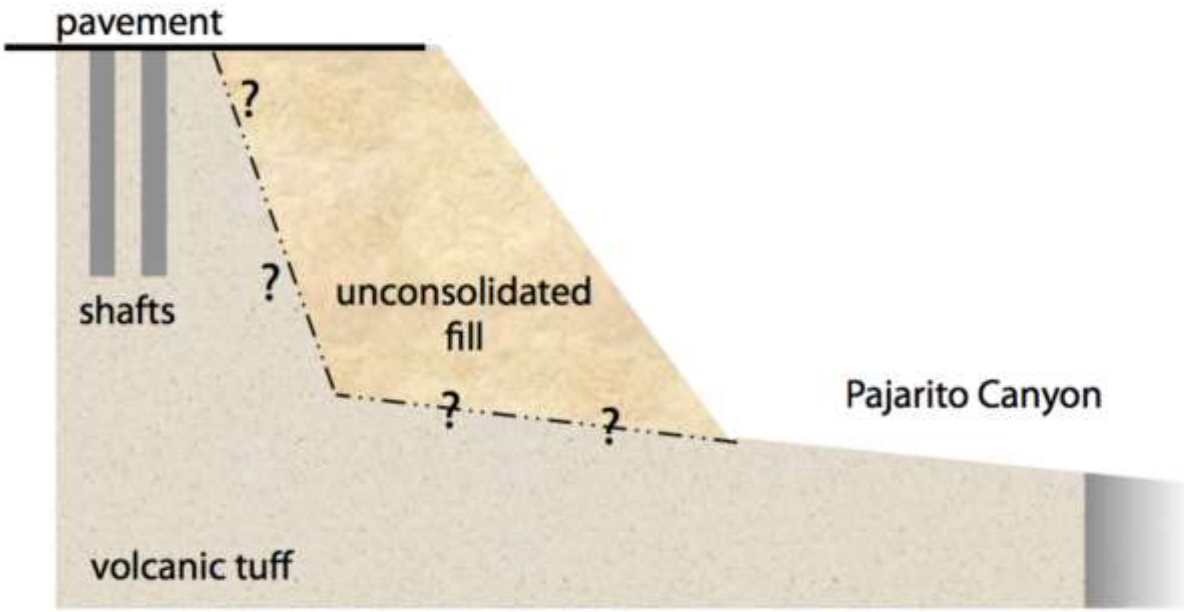


Figure 3: Depiction of shafts relative to fill material and native tuff bedrock

There are three types of shafts. Configuration A contains one-gallon drums stored in one vertical chain. The shaft is about 12 inches wide (diameter), and is filled with concrete to increase the total diameter to about 36 inches. It also has a concrete cap that completely overlaps the shaft. Configuration C is similar, except there is no concrete fill, and the cap is a steel lid. Configuration B, which consists of only one shaft, contains a LAMPRE reactor vessel. The inventory includes various TRU radionuclides, including plutonium and americium isotopes, fission products such as cesium and strontium, and various other radionuclides including isotopes of uranium.

Radionuclides left behind in a closed Area G disposal facility will eventually (i.e. over a period of thousands of years) migrate via a variety of processes from the disposed wastes, through engineered materials containing them, and into the surrounding environmental media where they could come into contact with future humans. These exposure media include rocks, soils, water, air, dust, and plants and animals that people might use for food or medicine. Such exposures may result in unacceptable risks, both to humans and to the plants and animals that constitute the local ecosystem. In order to evaluate the significance of different environmental transport pathways and materials, a conceptual model of the local environment is constructed

From a regulatory perspective, all radioactive wastes generated by the DOE, including those at Area G, are regulated under DOE Order 435.1, *Radioactive Waste Management* (DOE 2001a). The predecessor order, DOE O 5820.2A, came into effect on 26 September 1988, and 435.1 retains this date for applicability to the timing of waste disposals. Order 435.1 distinguishes between waste classifications, relegating

TRU waste to EPA's 40 CFR 191, and high-level waste to a geologic repository. LLW is addressed in the Order itself, as well as the accompanying DOE Manual 435.1 (DOE 2001b) and the DOE Guidance 435.1 (DOE 1999). Performance Assessments under DOE O 435.1 consider only LLW disposed after the effective date of the order. Other regulations that are of interest for the remote handled TRU waste include the New Mexico Hazardous Waste Act (20 NMAC 4.1), RCRA, NRC's 10 CFR 61, and the National Environmental Policy Act (NEPA).

The decision landscape falls into two major parts in terms of options: risks from leaving waste in place; and, risks from exhuming the waste and transporting the waste to another site. The decision landscape also needs to address potential objectives, which might include aspects of human health risk, ecological risk, groundwater concentrations, air concentrations, migration of contaminants onto other properties, waste processing risks, transportation risk, costs of taking action, public acceptance, affect on local economy including jobs, tourism, etc. Human health and ecological risks are associated with long term fate and transport consequences of the disposed waste, but also as a comparison with other risks at the site (from the other wastes that are already disposed). That is, considering the large amount of LLW and TRU waste disposed in the immediate vicinity, a natural risk management question is how the risk from the RH TRU alone compares to the risk from the entire site. The relative and incremental risks posed by the RH TRU, as compared to the risks related to all radiological waste disposed at MDA G, could inform risk management decisions for the RH TRU.

The stakeholders affected by the decisions that are made include DOE, NMED, EPA, other regulators (BLM, Fish & Wildlife, Forest Service), owners of adjacent properties, local residents (Los Alamos, White Rock), downstream residents (Espanola, Santa Fe), Native American groups (local Pueblos), and activist groups (Sierra Club, NRDC). DOE has decision making authority, but the various stakeholders are likely to have different and competing objectives that can be captured in the SDM approach. The GiSdT tools include a social network analysis that addresses how the various stakeholder groups interact.

This provides the basic decision landscape or understanding of the problem. Each of the sub-steps described in the Understand Context step under the Technical Approach above is addressed in turn and collectively. The purpose at this time, is simply to provide an illustration. The level of information provided here might be used to facilitate discussion with the stakeholders so that decision landscape can be more fully understood.

Objectives Hierarchy

The next step in the SDM process is to develop an objectives hierarchy that addresses the concerns and values of the stakeholders. This stars with a discussion with the stakeholders about their concerns. Developing an objectives hierarchy is more of an art than a science. The intent is to help stakeholders think through all aspects of the problem and put all stakeholder concerns, desires, and preferences on the table for consideration. The stakeholders are encouraged to address what matters to them with respect to the environmental contamination or waste management problem at hand. For example, stakeholders might express concerns about the effect on human health, ecological health or systems, land values, costs of disposal. Figure 4 presents an initial objectives hierarchy that has been developed for this particular decision problem. In this initial example, the hierarchy is structured around the three pillars of sustainability, although this is not necessary. It also introduces aspects of the regulatory landscape. These objectives are tied to measures and value function as described in [1, 2, 3].

Figure 4: Example objectives hierarchy for the LANL TRU waste decision problem

Options

Once the objectives hierarchy, objectives measures, and values for those measures have been addressed, then the next step is to identify options that might achieve the objectives. As noted earlier, for the LANL remote handled TRU waste issue, the basic options appear to be: leave the waste in place; or, exhume waste and transport to another location. However, there are potentially other options to consider, or, at least, manifestations of these two primary options. Figure 5 shows a high-level influence diagram that shows the relationship between objectives and options. This figure focuses only on the high-level options of: leave waste in place; and, move waste to another site. However, a more complete objectives hierarchy and options breakdown would show more connections.

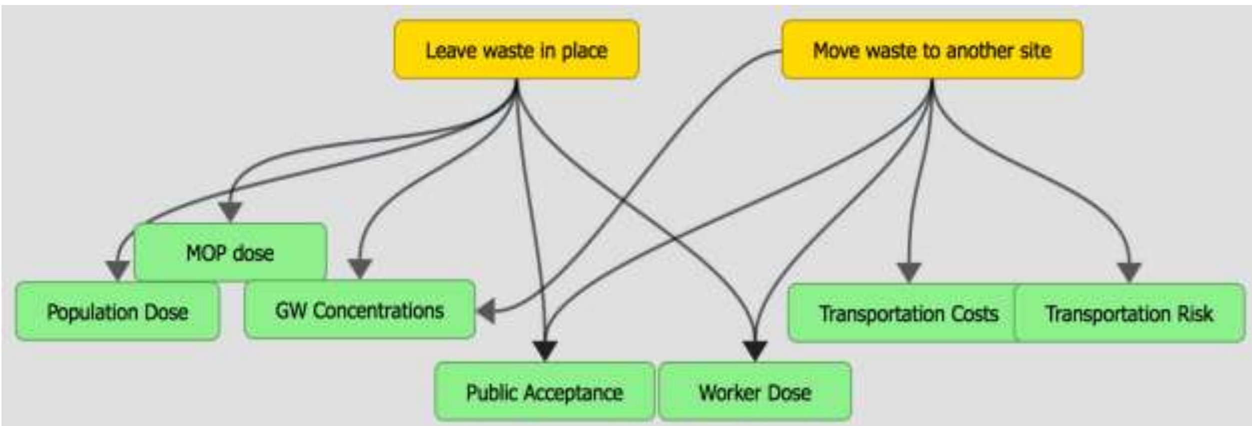


Figure 5: Depiction of relationships between options and objectives

Note that the relationships expressed in Figure 5 show that the "leave waste in place" option is connected to various risk and concentration endpoints, and also to public acceptance, and worker dose objectives. However, it is not connected to transportation costs and transportation risk (although leaving waste in place implies a transportation cost of zero). The intent of the figure and example is not to claim that these connections are complete, it is meant to illustrate how the connections between options and objectives are made in the SDM approach.

The connectors, or arrows, in the influence diagram (Figure 5) imply models that are used to evaluate the options by measuring the effect of the options on the objectives. Figure 6 provides a more detailed example for the LANL remote handled TRU waste problem that shows the models that need to be developed for each connection. For example, an option might include institutional control, which might affect human health dose to a receptor of interest (farmer in this example). There are many possible institutional controls, that might include fencing the site, placing sign posts, deed restrictions, etc. Each type of institutional control should be evaluated. The institutional control model could be used to modify dose or address costs directly. However it is set up, a model is needed to evaluate the effect of institutional control on the system.

Note that the institutional control model has nothing to do with the typical human health risk model that is commonly used as the starting point for evaluating radioactive waste. The SDM approach identified objectives and options and connects the two groups with models. This is a very different approach than simply modeling the human health risk (dose) consequences of leaving the waste in place, which is the typical first step when performing a risk assessment or performance assessment. Given the connections between the objectives and options, it becomes clear that models are needed to address the impacts of different types of public meetings, institutional controls, engineering designs, waste processing, transportation, etc. All of these models are needed. Some such models might be complicated, similar to a performance assessment model. Others might be simple such as a simple cost model, or a purely data-based model.

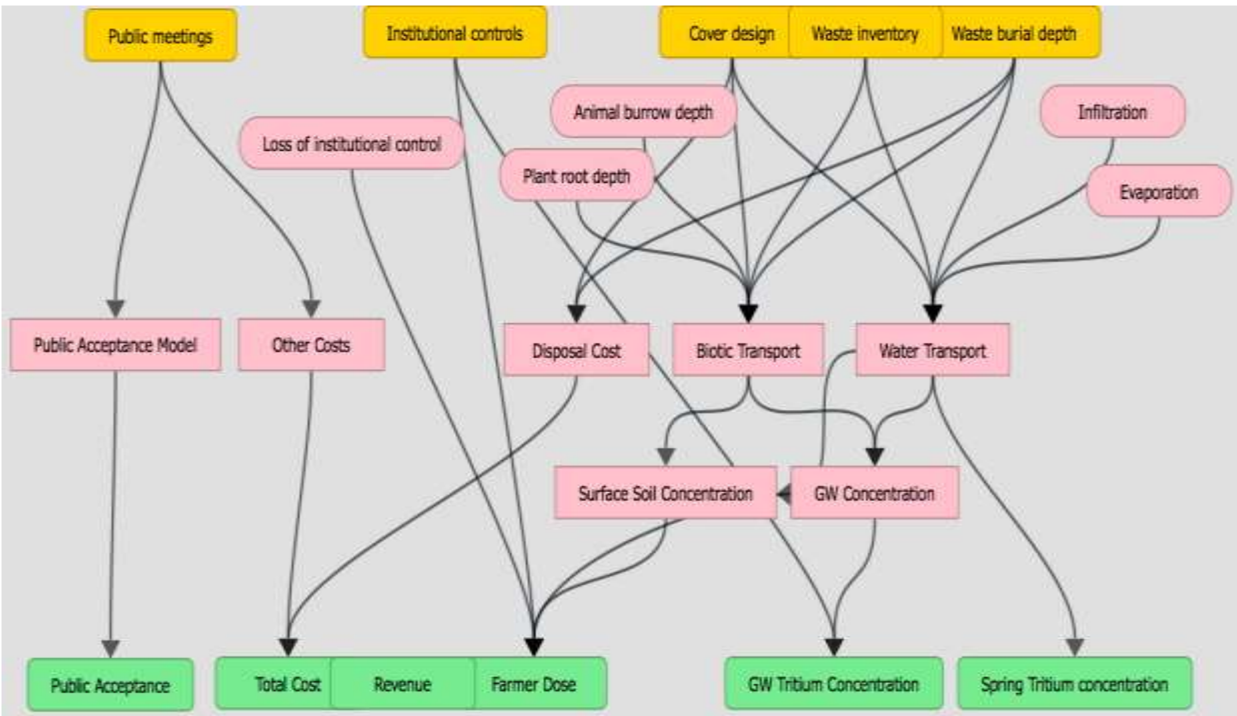


Figure 6: Depiction of models that connect options to objectives

For a problem as complex as LANL remote-handled TRU waste disposition, the number of options and objectives will be large, and the number of models needed will be called out by the influence diagram structure. As noted, the institutional controls options could include many different types of institutional control. Similarly for engineering options, or waste processing options, or transportation options. The SDM approach allows all of the individual options to be evaluated individually or collectively. For example, a combined option of fencing the site, building an ET cover, and having meetings separately with each stakeholder group on a quarterly basis could be considered. In general, it is a combination of options that will prove optimal. Within the SDM structure, combinations of options are referred to as management scenarios.

What Figure 6 shows is the relationship between objectives, options and science-models as used in the SDM approach. With this type of structure it becomes clear exactly what science-based models are needed to address the decision that needs to be made.

Conceptual Site Model

The influence diagram formed at this stage essentially provides the highest level conceptual model for solving the decision problem. The conceptual model should address the options and objectives, since each different management scenario will need a different combination of models (e.g., an ET cover will require a different model than a RCRA cover). The details of each fate and transport and risk (dose) model are often developed using the features, events, and processes (FEPs) structure, although this is not absolutely necessary. The intent of the FEPs process is to support development of a CSM. GiSdT provides tools for building a CSM interactively. Of note, however, is that the model building tools available in GiSdT support development of all of the models that are needed An example is provided in Figure 7. This example focuses on a small component of the environmental model – namely cliff retreat. That is, waste disposed or contained at MDA G could be exposed in the future from erosion of the mesa into the surrounding canyons (in this case, or particular interest is erosion of Mesita del Buey near the shafts into Pajarito Canyon). Again, the Figure is meant to be illustrative of the approach.

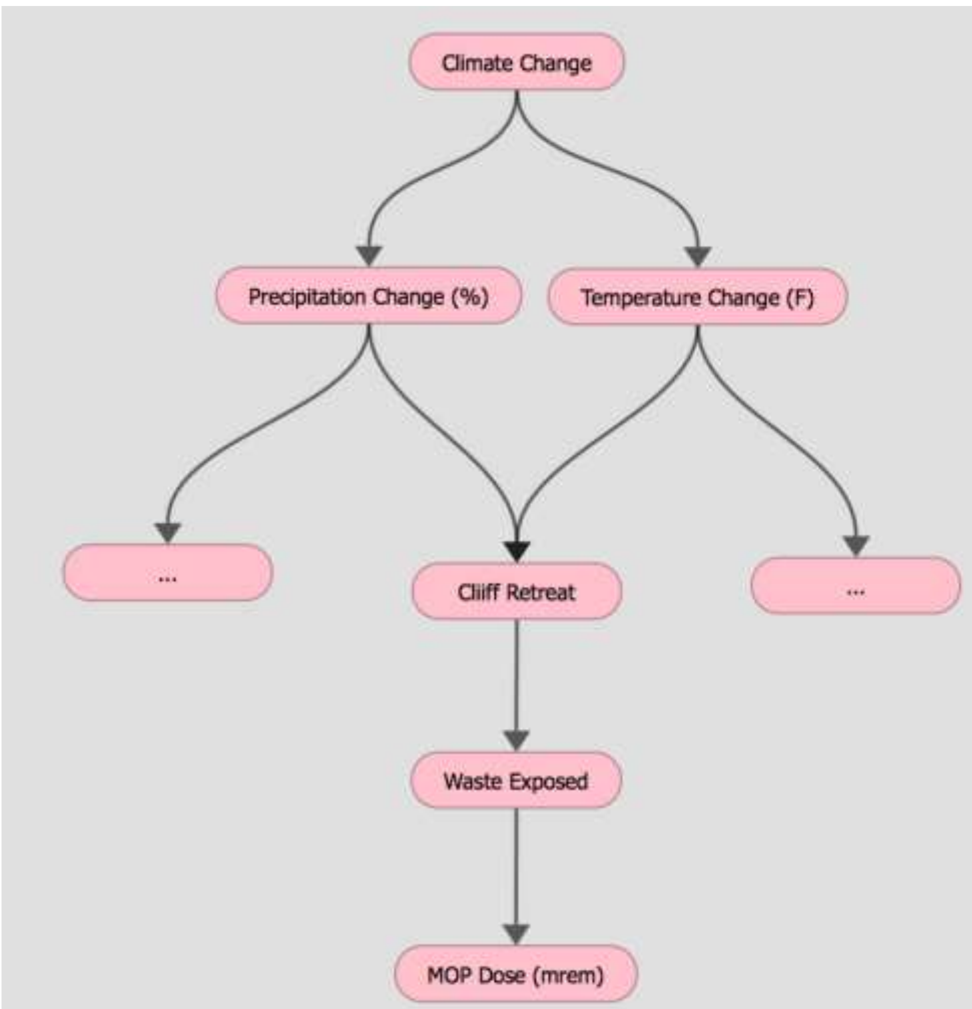


Figure 7: Partial conceptual model of cliff retreat.

The diagram in Figure 7 indicates that cliff retreat depends on precipitation and temperature, both of which could be impacted by climate change. Cliff retreat leads to exposing waste directly to the environment, and hence a dose to a receptor who is exposed to the waste. These types of relationships are often inherent in modeling software, but they are obscured in such platforms. Here the conceptual model can be depicted in full, and can be placed in the context of the decision problem. A further advantage is that this influence diagram structure for a decision model can be translated into a Bayesian belief network (BBN), which presents the possibility of screening inputs for their likely impact on models. Figure 8 presents the cliff retreat model as a BBN.

The BBN can be set up for every relationship in the decision model. In terms of screening, the approach is simply to provide probabilities of the likely effect at each connection. This is not meant to be precise, but is meant to provide an indication of whether some inputs are important. The factors are discretized as appropriate, and an indication is provided of the strength of relationship by specifying probabilities. For example, the probability of "climate change" is specified as 0.95 (note that the time frame and type of climate change (e.g., natural or human-induced) should be specified so that the term is not ambiguous). Figure 8 shows some of the conditional probabilities that are used as inputs. For example, the probability of a decrease in precipitation of greater than 5 inches per year given climate change is 0.75. When the BBN is run (results are in Figure 7), then the probability of a significant reduction in precipitation is 0.68.

Note that the probability that the MOP dose for this pathway is < 1 mrem/yr is quite high (0.83), and hence the probability that this pathway would contribute > 1 mrem/yr to dose is 0.17. However, there is precedent for using a much smaller probability of potential effect before screening out a pathway, in which case this analysis would suggest including cliff retreat in the model.

The probability values can be changed easily, but the intent is to evaluate the full model to see which components are important and which are less important. Although some effort is involved in specifying the BBN, this approach to screening could prove valuable in reducing resources needed for model building. Again, the intent is to support effective modeling, and to focus on factors that actually matter to the final decision.

CONCLUSIONS

The SDM approach is being taken to address long-term disposition of the LANL remote handled TRU waste. The project is in its early stages, in which case the examples figures show progress without the final products. The final products could involve many variables, objectives and options, and could appear quite complicated. However, that is why this type of approach is helpful. It allows complex decision models to be evaluated effectively. It provides technical defensibility, transparency and traceability for the decisions that need to be made.

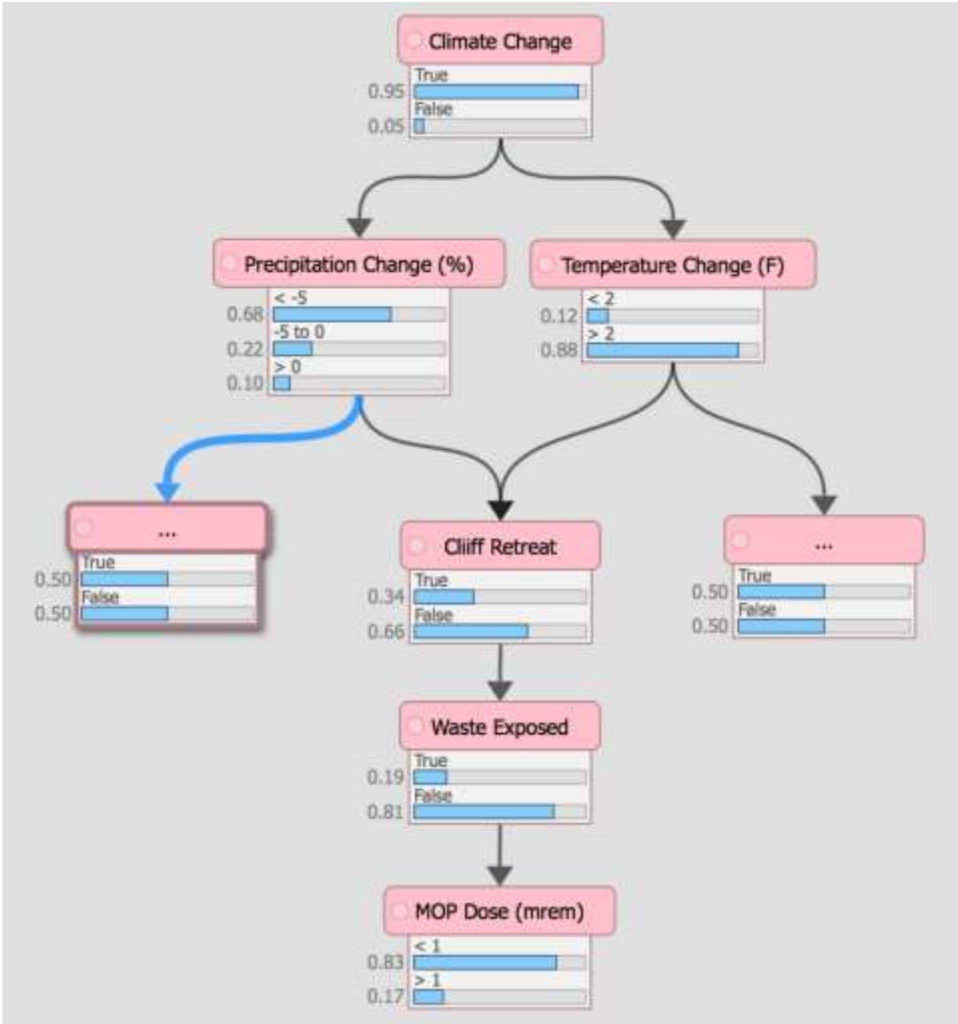
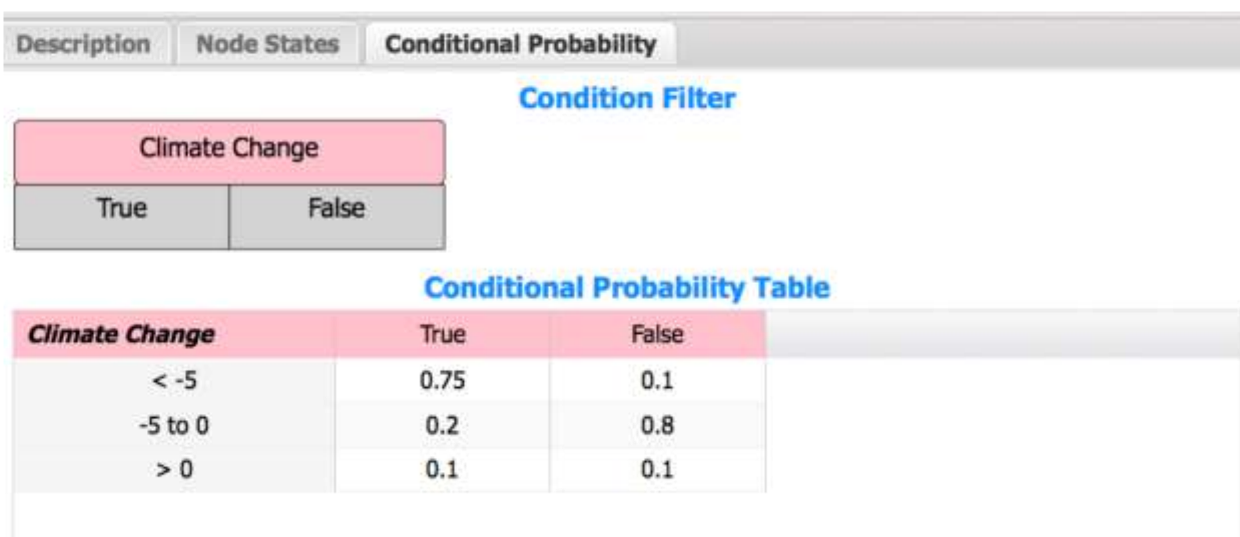


Figure 7: Bayesian belief network for the model of cliff retreat.



Climate Change	True	False
< -5	0.75	0.1
-5 to 0	0.2	0.8
> 0	0.1	0.1

Figure 8: Conditional probability table.

Advances in technology have been applied to the science side of DOE environmental and waste management decision problems, such that complex computer programs have been developed and improved, and continue to be improved, to address fate and transport modeling and risk/dose assessment. Unaddressed is a formal approach for incorporating the costs and value judgments that are implicit in concepts such as ALARA (as low as reasonably achievable), and are required to complete a decision analysis. And yet, arguably, the greatest uncertainties in the decision making process are associated with the costs and values. It is curious that more technical effort is put towards fate and transport modeling, which is reasonably well developed, than in understanding the costs and stakeholder values associated with these complex decisions, for which models are not yet well developed.

That is not to say that costs and value judgments are not currently considered at all in the decision making process. However, they are not considered using formal quantitative methods. They are usually considered in an *ad hoc* fashion, which unfortunately inadequately addresses desirable attributes such as technical defensibility, transparency and traceability. The technology exists to continue to evolve risk-based decision making by acknowledging and incorporating formal decision analysis methods. This approach also provides an opportunity to change the way in which stakeholders are engaged in the decision-making process. Through use of decision analysis tools, stakeholders can be engaged in establishing the decision space, and participating in the subsequent identification of optimal solutions to environmental and waste management decisions.

Combining the two basic tenets of decision analysis (science-based modeling and costs/values modeling) allows for the formulation of better risk-based cost-benefit decisions in collaboration with the stakeholders. This process is not a short cut, but a thorough vetting of the issues, risks, and costs that go into determining best resolution of nuclear waste storage and cleanup decisions. The anticipated outcome of this process is a greater understanding and acceptance of the risks and associated costs that different levels of residual risk lead to in these decisions.

The focus of this paper and associated panel session is on the costs and value judgments component of a stakeholder engaged structured decision analysis as it might be applied to DOE environmental and waste management problems. The focus is decision risk, and making decisions that balance stakeholder preferences and desires with the likelihood or probability of human health risk or dose. This paper and panel session follows the paradigm shift of focusing first on the decision risk, and using tools such as fate and transport models to support those decisions, as appropriate.

Key components of structured decision analysis are the identification of objectives and management options that provide decision makers with multiple approaches for addressing an issue. Relevant stakeholders and decision makers can then weigh these different objectives and ascribe value to various possible levels of achieving each objective. In order to select an approach that best meets the objectives of the policy or program for the community, each management option (or set of management options) is evaluated against how well it would achieve the stated objectives. This prioritization of multiple alternatives according to agreed-upon objectives allows for a rational decision making process when dealing with complex decisions in uncertain environments. Although the LANL RH TRU options analysis is in its early stages, an initial decision model structure has been developed. Continued refinement will lead to specification of the model within the next year, and subsequent technical support for the options analysis that is needed. Using SDM and GiSdT to drive the modeling and analysis means that the decision choices are fully supported technically, are fully traceable to the source information, and are fully transparent. This level of technical support is not available otherwise. Although many of the factors considered here are often considered to support complex environment decisions, including when using the CERCLA nine criteria, this is not usually done with the technical rigor, traceability and transparency that is possible with the GiSdT implementation of SDM.

The paradigm shift is that of turning the focus …

- From a conservative to a "realistic" analysis
- From starting with the decision-science before the natural science
    - (that is, from starting with the "Why?" before the "What?")
- From an alternatives-focus to a values-focus

The paradigm shift results in solutions that …

- Are optimal, thus save DOE money
- Are safe and compliant
- Are defensible and transparent

It is too early to draw any conclusions about the long-term disposition of the RH TRU waste. However, the stage is being set following this SDM process.

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