

Guided Interactive Statistical Decision Tools (GiSdT): An Open Source Software Integration of Decision Analysis and Stakeholder Judgment for Sustainable Waste Management, Disposal and Remediation - 15650

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ABSTRACT

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, for decisions made under CERCLA), these efforts are usually qualitative, and hence difficult to defend. They lack technical defensibility, transparency and traceability. The purpose of GiSdT (Guided Interactive Statistical Decision Tools) is to provide a quantitative framework whereby all aspects of a decision problem, such as remediation and waste management decisions, 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 are presented with choices that have significant impacts across all three pillars of sustainability. The goal of GiSdT 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, GiSdT provides the tools needed for decision-makers and stakeholders to understand and characterize their knowledge of their current decision-making processes, and what methods and approaches they need to proactively and quantitatively address all aspects of sustainability in their decisions. GiSdT is an open source interactive framework program that provides the tools needed to address the relevant components of a sustainability-based decision problem, including describing the decision landscape, translating that landscape into goals and objectives, valuing the measureable attributes that describe each objective, identifying decision options and addressing the uncertainty in the attributes (e.g., human health risk, institutional controls) through appropriate probabilistic models. In addition to addressing these quantitative technical components, the GiSdT program is aimed at facilitating stakeholder involvement so that the perspectives, values and objectives are all relevant stakeholders are addressed explicitly in the decision making process. The technical underpinnings of our software program, called Guided Interactive Statistical Decision Tools (GiSdT), are described.

INTRODUCTION

The idea of integrating decision analysis and stakeholder judgment in sustainable waste management, disposal and remediation decisions sounds tempting. Environmental and waste management decisions are, however, often compromised by conservatism in modeling fate and transport of contaminants and human health risk assessment, and address stakeholder concerns about costs and value judgment qualitatively or not at all. Unfortunately, conservative modeling leads to decisions that are compromised, causing unnecessary costly remediation and under-utilization of the nation’s relatively few radioactive waste disposal facilities. There is nothing wrong with making conservative decisions, however, there is something wrong with making conservative decisions on the basis of conservative models. If a conservative decision is wanted, then it should be based on an understanding of expected performance, and on value judgments that properly acknowledge such conservative desires. A shift in focus has occurred somewhat in radioactive

waste disposal decisions by moving towards probabilistic models that address “reasonable realism”. However, no progress has been made towards a system that quantitatively accommodates stakeholder concerns about costs and value judgments for environmental and waste management decisions.

The conservatism in the decision making process and the lack of explication in the costs and value judgments makes it difficult to provide effective support to radioactive waste disposal decision making. Arguably, a consequence is that industries that generate nuclear waste are impacted by radioactive waste disposal decisions that are not defensible. This seems untenable. If the decision making process was open, more realistic and defensible, then these industries would be in a better position to continue operations, modify their operations, or manage closure. With the somewhat arbitrary decision making process that currently exists, such industry management decisions must be very difficult.

In conjunction with EPA, we have developed appropriate software that has been applied to complex environmental decisions concerning, for example, land re-use, watershed management, coral reef management, and regional planning. Our software is open source and interactive, and provides a forum for quantitative evaluation of stakeholder judgments. In particular, this approach has less focus on the science model, and more focus on the costs and value judgments so that effective cost-benefit decisions can be made. These computational tools facilitate pulling together comprehensive decision models under one roof, so that optimization over the decision space can be performed. This is a generic framework software program that allows stakeholders to build and specify decision models, and places probabilistic modeling in the context of the decision model. This is a paradigm shift away from supposed conservative modeling to satisfy endpoints towards more realistic modeling based upon which conservative decisions can be made if desired. This would make the decision making process more transparent and honest, and might shift the focus from environmental fate and transport modeling to the decision endpoints that are really (arguably) of interest.

Guided Interactive Statistical Decision Tools (GiSdT) implements a value-focused approach to decision making with an emphasis on stakeholder involvement. GiSdT provides a quantitative framework whereby all aspects of a decision problem, such as remediation and waste management decisions, can be addressed quantitatively, and hence, defensibly, transparently and traceably. The goal of GiSdT is to provide access to useful or usable methods and approaches for solving complex decision problems. Most decision-makers do not currently have that access when presented with choices that have significant impacts across all three pillars of sustainability. GiSdT provides an effective and user-friendly interface to decision methods and approaches that empower decision-makers to explicitly and routinely incorporate all aspects of problem solving into their decision-making. To identify and develop these methods and approaches, GiSdT provides the tools needed for decision-makers and stakeholders to understand and characterize their knowledge of their current decision-making processes, and what methods and approaches they need to proactively and quantitatively address all aspects of sustainability in their decisions. GiSdT is an open source interactive framework program that provides the tools needed to address the relevant components of a sustainability-based decision problem, including describing the decision landscape, translating that landscape into goals and objectives, valuing the measureable attributes that describe each objective, identifying decision options and addressing the uncertainty in the attributes (e.g., human health risk, institutional controls) through appropriate probabilistic models. In addition to addressing these quantitative technical components, the GiSdT program is aimed at facilitating stakeholder involvement so that the perspectives, values and objectives are all relevant stakeholders are addressed explicitly in the decision making process.

This paper is a companion to a paper titled “A Paradigm Shift: An Introduction to Structured Decision Making for Sustainable Waste Management and Remediation” (#15649), and to the panel session “A Paradigm Shift — The Key to Optimal, Defensible & Transparent Waste Management, Disposal & Remediation Decisions” (#15236).

DESCRIPTION

GiSdT provides a decision analysis framework for defensibly merging human dimensions, costs and value judgment, and technical provides this access enabling decision-makers and stakeholders to: (1) understand the underlying context of the decision, (2) define desired outcomes and measurable objectives, (3) identify options (responses) for achieving desired outcomes, (4) evaluate options using applicable data and models, or (5) take appropriate action when significant uncertainty exists. These five steps form the core of a conceptual model for environmental and waste management decisions, and hence, the core of GiSdT.

Practically, GiSdT combines the power of the internet with guidance, analysis, tools, and templates that can be used interactively to build decision models for environmental problem solving. The specific step-by-step approach to GiSdT includes:

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 and measurable attributes
 - a. Fundamental objectives
 - b. Measurable attributes
 - c. Value functions
 - d. Objectives ranking and preference weighting
3. Identify management 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. Evaluate model
 - c. Perform uncertainty analysis
 - d. Perform sensitivity analysis
5. Take action
 - a. Compare options
 - b. Value of information analysis
 - c. Choose optimal decision option or collect more data/information (including model refinement as necessary)
 - d. Iterate if necessary

Technical Specifications

GiSdT is developed using Open Source Software (OSS) based on World Wide Web Consortium (W3C) web specifications [1]. All GiSdT content has been developed using the Hyper Text Markup Language (HTML, [2]). HTML is software independent (that is, the content can be edited with any text editor) and platform independent (that is, Windows or Linux). Presentation is handled using Cascading Stylesheets (CSS, [3]). This separation allows great flexibility and variety in the choice of presentation. GiSdT is served using the open-source Apache web server. GiSdT supports any Web compatible browser that also supports Adobe FLASH technology, regardless of the platform on which the browser is running.

The GiSdT graphical user interface is programmed in JavaScript using the ExtJS open source cross-browser JavaScript library [4]. ExtJS uses AJAX (Asynchronous JavaScript and eXtensible Markup Language [XML]) technology to provide highly responsive, interactive interface widgets. Databases for GiSdT are

managed with PostgreSQL [5], a highly-scalable, Structured Query Language (SQL) compliant, open source object-relational database management system.

Code that executes on the web server is written in PHP and R [6]. PHP is an open source general-purpose scripting language that is especially suited to server-side web development. PHP is primarily be used to query the PostgreSQL database and pass the returned data back to the JavaScript code running in the user's web browser. PL/R, a procedural language for PostgreSQL, which provides an interface to the R statistical programming language, allows code written in R to be accessed via database queries. All statistical computations and generation of dynamic plots and modeling diagrams is coded in R and called from PL/R functions accessed via PostgreSQL database queries.

GiSdT Framework Program

GiSdT is organized along the five steps of the structured decision making concept:

1. Understand context
2. Define objectives
3. Develop options
4. Evaluate options
5. Take Action

At the top level, GiSdT consists of a set of guidance and software tools designed both to educate decision-makers in using this conceptual model and to allow them to create their own decision-specific model using interactive tools that allow them to input data and generate graphs, charts, and statistical analyses. Using these tools, different decision options can be quantified and evaluated in the larger context of the conceptual model. In addition, GiSdT houses case studies, which demonstrate how the tools and guidance can be applied to specific real-world decision contexts. The case studies will be used as the building blocks for the upper levels of GiSdT.

In terms of site navigation, the above structure is implemented as a series of tabs. The first tab is called “GiSdT steps” and will house the guidance and interactive tools referred to in the previous paragraph. Subsequent tabs will house case studies demonstrating how the tools and guidance have been applied to real-world decision contexts.

Each of these top-level tabs contains five sub-tabs, one for each step of the conceptual model. The “GiSdT steps” also contain an overview tab that provides an introduction to the individual steps. Each of these sub-tabs may in turn contain its own sub-tabs, housing guidance or tools. Requirements for each tab depend on whether the tab contains guidance or houses a software tool, or both.

The web site is organized such that different areas of the site are easy to find and access (with minimal clicks). Different site sections display promptly in response to mouse clicks. Users should easily understand “where they are” on the site at all times, and the organization of the site reflects the five steps of structured decision-making. Online guidance is presented in the context of structured decision making. Online guidance on using the embedded software tools addresses all the functionality of the tool in question in language that is understandable by a layman without special scientific or technical knowledge.

The interfaces are dynamic, responsive, and intuitive. Interacting with a tool should not lead to page reloads or require the user to go to a different page on the site or open a new browser window.

Users are able to input data relevant to their decision process and have that data stored in a persistent database. They are also able to modify or delete data after it has been entered. Data input interfaces are responsive and intuitive.

GiSdT performs technical analysis of user-entered data. Presentation of the user-specified information includes statistical analysis of the data using Bayesian methodology and visualization using plots, charts, and graphs of the data. Images generated by analysis tools are displayed promptly and without requiring the user to go to a different page on the site or open a new browser window.

Because GiSdT is a web-based application, user hardware and operating system requirements are minimal. GiSdT supports any Web 2.0 compliant web browser that also supports Adobe FLASH technology. However, GiSdT has only been tested comprehensively with Internet Explorer versions 7 and higher running on Windows and Firefox version 3.5 and later running on Windows and Mac OS 10.6. GiSdT is served from computers running the Linux operating system, with a minimum of 2 Gigabytes of RAM and 300 Gigabytes available hard disk space.

System Design

Figure 1 depicts the overall client-server System Design for GiSdT. The major components are depicted in Figure 1 and outlined in the following sections.

The GiSdT graphical user interface (UI) is programmed in JavaScript (officially known as ECMAScript [7]) using the ExtJS open source cross-browser JavaScript library. ExtJS uses AJAX (Asynchronous JavaScript and eXtensible Markup Language, XML) technology to provide highly responsive, interactive interface widgets. The ability of individual UI components to interact asynchronously with the server allows page content to be dynamically updated without reloading the page, providing a level of responsiveness more commonly associated with “desktop” applications running on the user's computer than with traditional web applications. Site navigation will be implemented via a tab-based layout which allows users to drill down to more and more specific layers of content while still being able to visualize the overall structure of the site.

The content portion of the web interface is created in the open-source word processing program Open Office and exported to HTML, while the JavaScript code resides in separate source files with a .js file extension. Presentation and styling is controlled using Cascading Style Sheets (CSS); CSS source code will also be stored in separate .css files. All three kinds of files are served using the Apache web server in response to requests from the user's web browser. The JavaScript is then executed in the browser. The server also displays dynamically generated images of plots and graphs created by the R module.

PHP is an open source server-side scripting language that runs as a plug-in module to the open source Apache web server. The PHP module implements the model and controller components (the view is implemented in the user interface) of a model/view/controller (MVC) architecture that allows users to interact directly with tables in the PostgreSQL database. Supported operations include displaying table data and creating, deleting, and editing rows in the table. The PHP module also implements an interface that allows the web interface to directly call stored procedures in the database. These stored procedures are written in PL/R (see Section 2). PL/R is a PostgreSQL Procedural Language for R that allows R functions to be stored and run in the PostgreSQL database using SQL.

Databases for GiSdT are managed in PostgreSQL, a highly-scalable, Structured Query Language (SQL) compliant, open source object-relational database management system. Data are organized using schemas. Schemas provide namespacing, which allows multiple tables with the same name to exist as long as they are in separate schemas. This provides great flexibility in database design. For example, multiple users can each have a set of tables which are identical in structure but which contain user-specific data. Schemas can also be used on a per-project (rather than a per-user) basis – this is how data for separate case studies will be managed.

Technical analysis of the data is implemented in stored procedures written in PL/R, a procedural language for PostgreSQL which provides an interface to the R statistical programming language.

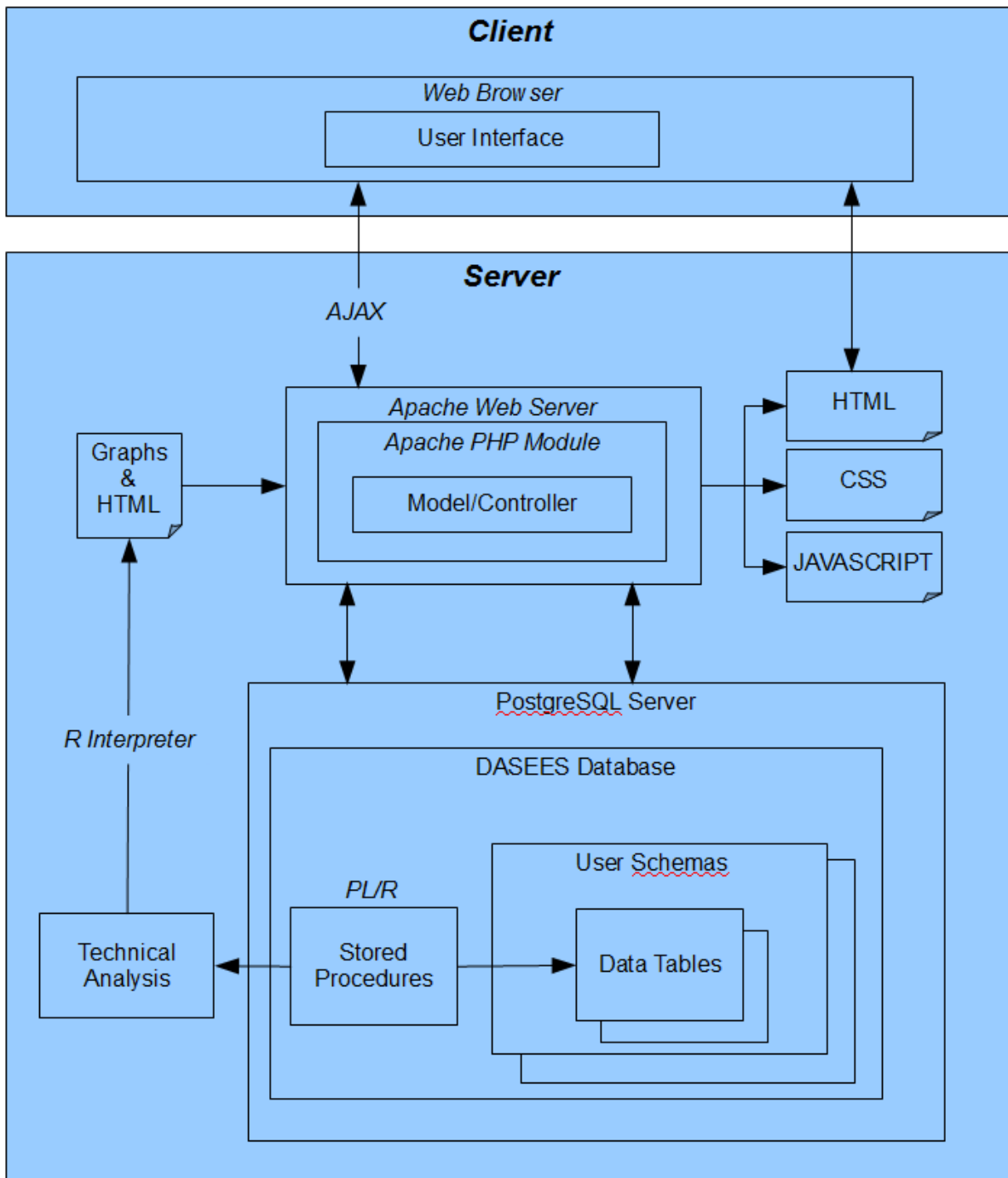


Figure 1. GiSdT System Design Diagram

Technical analysis, computations, and algorithms are programmed in R, a statistical computing, programming, and graphics language environment (www.r-project.org). R code is accessed from PL/R functions written as stored procedures in the PostgreSQL database. The Technical Analysis module performs statistical analysis on user data and return results to the user interface. In some cases, it also generates charts, graphs, or plots, which are saved as images in a server-side storage location. The location of the image is also returned to the user interface so that it can be displayed in the browser.

There are several obvious advantages of designing GiSdT using Open Source Software (OSS) standards, some of which are described below. Use of OSS is not only advantageous in terms of software licensing and cost, but also in terms of the philosophy that underlies the Open Source community. The Open Source philosophy is aimed at sharing information at all levels, gathering and responding to feedback for continuous improvement, and encouraging users to supply functionality and content. For GiSdT, this consists of sharing content and all resources (including code), operating a continuous feedback option, and encouraging users to submit case studies that can be shared with the GiSdT community of users.

The benefits of following the Open Source approach to the development of GiSdT include:

- By building GiSdT using only Open Source web-based tools, potential users are not encumbered with difficult software licensing issues.
- GiSdT allows users to engage at various levels of complexity depending on their interest. Different levels of complexity might include, for each component: an overview, access to supporting information, details of mathematical methods (for example, environmental modeling, risk assessment, statistics, economic modeling, and decision analysis), computer code (for example, HTML, JavaScript, PHP, R), and case study examples.
- The holistic approach facilitates defensibility, traceability and transparency for each application.
- The approach promotes QA through internal testing and through user-supplied feedback. The open nature of the JavaScript, PHP, and R code allows every aspect of GiSdT to be thoroughly reviewed.
- As a web-based system, GiSdT can be easily updated as new tools, technologies, and approaches become available without requiring users to install any new software.

Software Development and Implementation

GiSdT developers created an initial navigational, scripting, database, and technical analysis structure that reflects the system design as described in Figure 1. The user interface skeleton was developed in HTML and JavaScript; the Model/Controller skeleton was developed in PHP, the Database skeleton was developed using SQL and PL/R, and the Technical Analysis skeleton was developed in R. These skeleton components provide containers for implementing specific functionality required by individual tools.

Once skeleton modules had been created, interfaces were developed to allow communication between modules. The User Interface communicates with the Model/Controller via AJAX requests; the Model/Controller communicates with the Database via direct SQL queries and calls to PL/R stored procedures; the Database communicates with the Technical Analysis module via R code embedded in PL/R stored procedures.

Once the skeleton infrastructure had been implemented, tool development began. Each tool had a specification for its user interface and functionality. Each time a new tool is integrated into the overall framework; all existing tool test plans are run to assure that new code introduced to support the new tool does not compromise existing functionality.

The GiSdT system undergoes a three-phase deployment process: development, beta-testing, and deployment. In the development phase, the running system undergoes continual testing on individual development machines as the upcoming release of GiSdT is being developed. That is, each of the new functions and components are continuously tested as outlined in Section 5.0. At the end of the development phase, the new functions and components are deployed on a test server. In the beta-testing phase, an internal review of the content and function of the new GiSdT functions and components is conducted.

GiSdT is managed under Subversion [8]. Subversion (subversion.tigris.org) is an open-source version control system that keeps track of changes to files and folders in a project repository. It acts as a central repository of the most up-to-date project files and allows users, contributors, and developers to share them conveniently. All major releases of the GiSdT system, source code, and documentation are tagged and archived in Subversion. In addition, the entire Subversion system will be backed up on a daily basis and an off-site backup is performed weekly.

Documentation, Maintenance and User Support

GiSdT electronic documentation provides information on:

- How to use GiSdT
- The technical components and methods GiSdT employs
- General guidance
- The Quality Assurance Project Plan (QAPP)

The documentation will be updated regularly to reflect functional changes in GiSdT. In addition, since GiSdT is Open Source Software the underlying software code will be available for download under the terms of the associated Open Source license.

As a web-based application, GiSdT has the advantage of centralized maintenance. If defects in the software are discovered, fixes can be applied directly on the public site without the need to distribute software patches to users. If a defect is identified by the GiSdT team, or by reviewers or users, the procedure described in Figure 2 is followed to identify the problem, implement a fix, and eventually deploy it on the public site.

The servers used for GiSdT development, beta-testing and deployment and the server which hosts the Subversion source control system are Linux servers running the Fedora operating system. Linux was chosen as the preferred operating system for deployment and testing because it offers superior performance to Windows and is inherently more secure because the majority of viruses and malicious software is written specifically targeting Windows. Linux is immune to these threats. Updates on Linux are automatically downloaded and installed nightly. The servers also implement a RAID-5 configuration to protect from hard drive failure and use Uninterrupted Power Supplies.

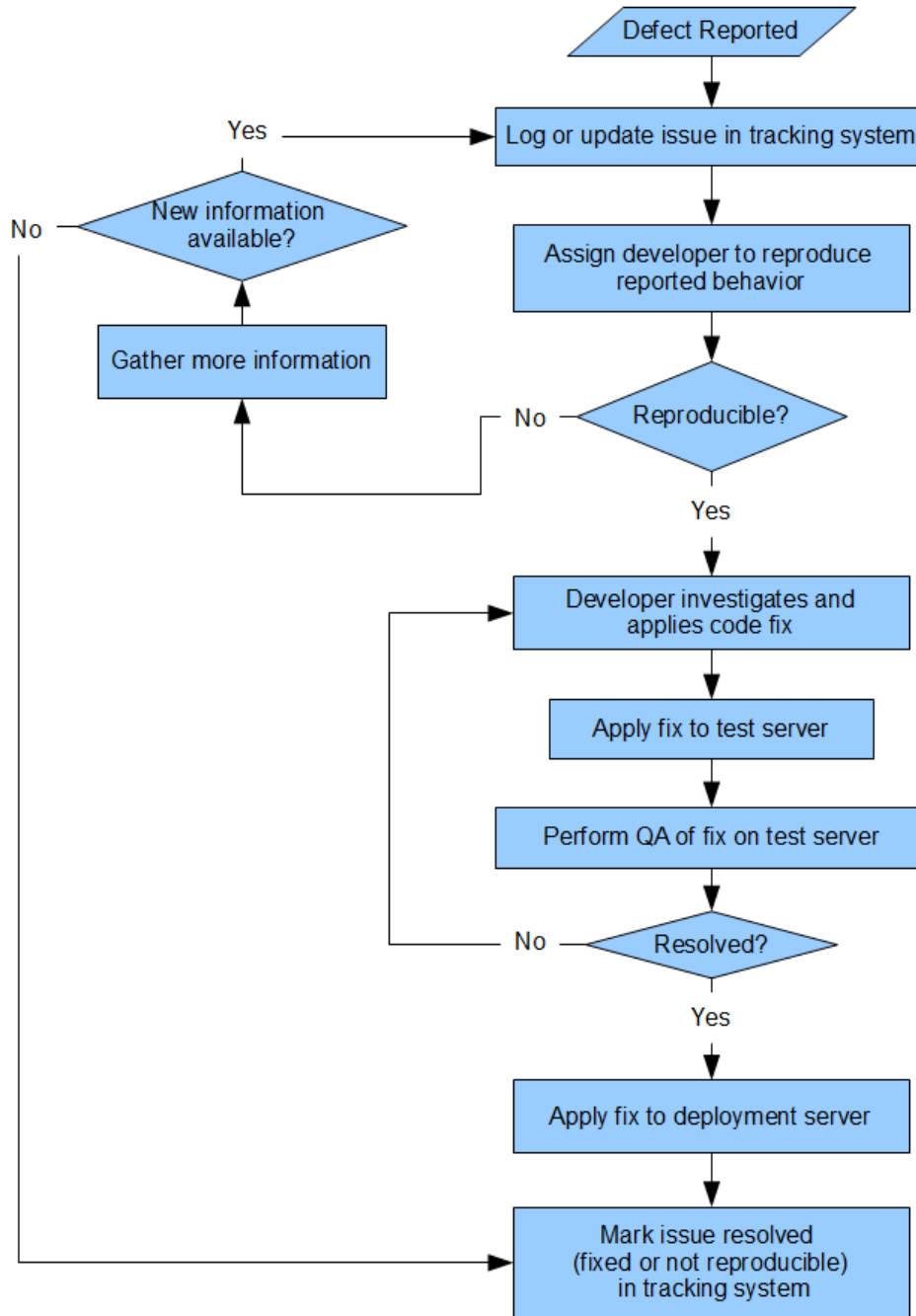


Figure 2. Maintenance and User Support Workflow.

DISCUSSION

GiSdT provides a computer interface that facilitates development of decision analysis modeling for complex problems. It addresses the fundamental components of true decision analysis, merging costs and value judgments with science-based modeling so that the final decision is based preferences (values and costs) balanced by probability. This is the way real decision making works. Some environmental

regulations have effectively curtailed the full decision making process by creating a set of metrics that supplant the costs and values side of the decision making process, usually by inserting conservatism in the regulatory process. This is not necessarily unreasonable. However, when coupled with conservative modeling conservatism in both costs/values and in the science-based modeling is not reasonable. It is acceptable to make conservative decisions, but not to make conservative decisions based on attempts at conservative science-based modeling. The conservatism should enter through the value judgments that are made. This is evident in the way some important waste management decisions have been made already. For example Yucca Mountain was shut down based on value judgments of its local community, and WIPP was opened based on value judgments of its local community. GiSdT provides a tool for properly acknowledging costs and value judgments in the decision making process. In doing so, the sums of money that have been spent unsuccessfully trying to achieve specific results, will be avoided. GiSdT instead opens the door to making decisions in defensible, transparent and traceable ways, removing conservatism from the process, and engaging stakeholders in a new and innovative way that encourages stakeholder ownership. Note that “stakeholders” does not mean the public. It means anyone who has a stake in the decision, which might include the public.

In this paper an overview of the technical details of GiSdT is provided. GiSdT has been built using open source software in an interactive web-based setting. The flexibility that can be provided by GiSdT is enormous because of access to the internet, and because of the tools used that allow users to enter decision analysis related input and any text/content desired that helps to explain the problem. This is a unique approach to supporting solving decision analysis problems. This technology has been used already by several government agencies – EPA, FDA, DoD – to help solve some complex problems. The results have been very positive and continued development of GiSdT is guaranteed. There is an opportunity now to bring this same technology into DOE waste management and environmental management decisions, which can help turn the corner away from the challenges of increasing budgets and schedules for completion. This will result in using fewer resources to achieve DOE’s waste management and environmental management objectives, by providing the tools needed for an effective stakeholder engaged structured decision making approach to problems solving.

CONCLUSIONS

GiSdT is open source interactive web-based software that can be used to facilitate solving decision problems. Of course, all real problems are decision problems. GiSdT provides a different environment for supporting decision making than has been seen before. Other decision analysis tools exist, but they need to be used primarily by decision analysis professionals because the technical details are hidden and not easy to understand. GiSdT is very different in this regard, and opens the door for more widespread use of decision analysis to solve decision problems.

In particular, GiSdT can be brought into the DOE realm of waste management and environmental management decision making. The primary goals of GiSdT, to engage stakeholders in structured decision making that is technically defensible, transparent and traceable, are exactly what is needed to effect a paradigm shift away from the current practice of conservative science based models with essentially ineffective stakeholder involvement, towards “realistic” probabilistic science-based models coupled with specification of costs and value judgments, the latter of which is used to address stakeholder concerns directly (which might include a desire to make conservative decisions).

GiSdT takes the user through a set of steps that implement structured decision making. These steps start with addressing the problem statement, defining objectives and preferences of the stakeholders, identifying management options for solving the problem. In this way the stakeholders’ concerns are addressed up front. The decision path becomes clearer, and the need for science-based modeling becomes focused. At this point, the science-based models are developed and enter the decision analysis (GiSdT) system. Final decisions are made from merging costs and value judgments with the science-based models. Uncertainty and sensitivity analysis are then performed, and the best decision is chosen, which might include collection

of additional information/data, depending on the results of the uncertainty analysis and the sensitivity analysis.

GiSdT can interact with any science-based modeling tools. Science-based models can be developed directly in GiSdT, which has underlying native programming code, R (www.r-project.org [6]), which can be used to develop any form of model. However, GiSdT can also interact with other codes (e.g., GoldSim, ASCEM, MODFLOW), by direct inclusion of those codes, by abstraction of model results, or by full integration of GiSdT with any of these codes. Native programming in GiSdT is sufficient for relatively simple problems, and although it is possible to program more complex models directly in R, it is not the appropriate tool for doing so. Other tools, such as those mentioned, are designed specifically to develop complex models. Direct inclusion of these codes in GiSdT would be cumbersome (e.g., as DLLs), but it is reasonable to abstract results from science-based models into GiSdT. This can be done probabilistically or through experimental design, which would involve developing a simpler model for inclusion in GiSdT. Or, an option is to bring the simulated input and output directly into GiSdT. This latter option might be best, since it preserves the information needed for a full sensitivity analysis. Finally, full integration of GiSdT with one or more science-based codes is probably the most reliable long-term solution, but this will require allocation of resources to achieve this goal.

GiSdT can be the tool that changes the paradigm on how complex decisions can be supported. This seems critical at this juncture for DOE, when complex waste management and environmental management are currently looking at increasing costs and schedules while budgets continue to decrease. This paradigm shift has been shown to work on complex problems for other agencies, and can be used to good effect for DOE as well. It is time for DOE to take advantage of 30 years of experience with complex environmental problems, coupled with the massive advances in computer technology in that time frame, so that a better path to effective decision making is realized for the future of waste management and environmental management decisions.

This paper and presentation is a companion to two other papers and one panel session given at WM2015. These other papers are 15649 (Modern Sensitivity Analysis, Black et al.), 16561 (A Paradigm Shift: AN Introduction to Structured Decision Making for Sustainable Waste Management and Remediation, Black et al.). The panel session is 15236 (A Paradigm Shift: The Key to Optimal, Defensible & Transparent Waste Management, Disposal & Remediation Decisions, Dixon et al.).

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