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Technology Assessment Tool – An Application of Systems Engineering to USDOE Technology Proposals

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Technology Assessment Tool

(A Systems Engineering Approach to Assessing U.S. Department of Energy Technology Proposals)

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Abstract. This paper discusses the system design of a Technology Assessment (TA) tool that can be used to quantitatively evaluate new and advanced technologies, products, or processes. Key features of the tool include organization of information in an indentured hierarchy; questions and categories derived from the decomposition of technology performance; segregation of life-cycle issues into six assessment categories; and scoring, relative impact, and sensitivity analysis capability.

An advantage of the tool's use is its ability to provide decision analysis data, based on incomplete or complete data.

PURPOSE AND OBJECTIVE

The objective of TA work is to deliver a technology analysis/assessment methodology that can be used to quantitatively evaluate new and advanced technologies, products, or processes. By using the TA tool, decision-makers will be able to trace the data influencing the decision, defend decisions based on quantifiable data, and determine characteristics that dominate the data (sensitivity).

This paper documents the system design of the TA tool. The intent of the author is to build confidence in the tool's ability to evaluate a proposed technology's impact by understanding the system approach taken in developing the evaluation tool. By understanding the development methodology, hopefully the link to understanding how the tool considers a technology's total impact can be inferred.

Purpose. Selection of a new or modified technology or technology process may impact one or more components in the design, manufacturing, deployment, operations, or decontamination and decommissioning of a complete system. It may harm the environment, enhance safety and health, require construction, or impact personnel. Many times other areas are not considered until the impact surfaces as a problem; a problem that reflects itself in decreased technical performance or cost and schedule increases. Ultimately there are hundreds of elements to consider with various system impacts. The TA tool is being developed to assist in assessing the appropriate technologies and to identify potential problems.

A benefit of using the tool is the acceleration of technology decisions, done wisely (i.e., avoid making costly mistakes by choosing inappropriate technologies that fail to consider all of the potential problems or impacts on other systems).

ELEMENTS OF SYSTEM DESIGN

The focus of TA is a total system approach that establishes a formal and quantitative performance criteria process as the basis of technology decisions. This approach is a fundamental paradigm shift away from ad hoc prioritization of technologies, needs, and funded programs. It is consistent with the National Research Council, April 1996, and the U.S. House of Representatives Committee of Commerce, 1996, recommendations to the U.S. Department of Energy (DOE).

System design consists of (1) the requirements—"what" must be done, and (2) "how to" satisfy the requirements. Defining the structural architecture, implementing the design, and verifying that the design satisfies the requirements are all phases included in the system design.

Computer-Aided Solutions. A computer aid is used to keep track of the categories to consider, the scores associated with the categories, the data contributing to each score and the importance (weight) of the category considered. How many separate categories can a decision-maker comprehend when making a decision? A consensus among the project team members suggests that ten categories are the maximum that a decision-maker can use. It was discovered that most elements to consider in the decision-making process were related to six separate categories (well within the requirement of less than ten categories). The six decision categories that form the boundary condition for the project requirements are the following:

1. Environment, Safety, and Health (ES&H)
2. Risk
3. Improvement (benefits)
4. Schedule
5. Cost
6. Savings to Investment Ratio.

Assessment Categories. Clever manipulation of these few assessments enhances timely and effective decisions. Three category scores (ES&H, Risk, and Improvement are calculated from the input data. The three remaining category scores (Schedule, Cost, and Savings to Investment Ratio) are derived from the input data of the calculated categories.

Environment, Safety, and Health (ES&H). The decision category ES&H provides an assessment of a technology proposal on ES&H. A technology proposal may be beneficial to or may harm the environment; it may increase or decrease safety of personnel and/or of equipment; and it may improve or degrade the health of the workers and/or the public. The TA tool is looking for the impact of the change. Typically the impact to the environment is caused by adding or deleting materials either in the product or in the processing of the materials. For example; adding a toxic, hazardous, radioactive, or explosive material to the product would be a negative impact on ES&H. On the other hand, deleting such materials has a positive impact on ES&H. These examples are representative of the concerns a decision-maker may have, relative to the impact on ES&H. Such concerns are captured in the design of the TA tool.

Risk. Risks must be assessed for their impact on the total system. A technology proposal that implies additional risk is scored negative. On the other hand, actions to mitigate already existing risks or new risks are scored positive. Examples of risks to be considered include the following:

- *Technical Design*—proposal may impact other components of the system.
- *Production*—proposal may impact the mean-time-between-failure for the system.
- *Deployment*—proposal may impact the ease or difficulty of system setup and delivery.
- *Decontamination and Decommissioning*—proposal may introduce a new material that has no disposal criteria.
- *Cost and Schedule*—all technology proposals have some cost and schedule impact.
- *Management*—proposal may enable more positive control of security or may make controlling security more difficult.
- *Politics*—A congressman may determine that implementation of the proposal has a negative impact on his reelection. Political risks are often the hardest to assess but may have the most impact on acceptance or rejection of a technology proposal.

Improvement (Benefit). A proposal may improve technology and technology processes. The TA tool quantifies the benefits of a technology proposal through elements consisting of the company, controls, manufacturing, maintenance, and operations. The Improvement section is the most extensive section in the tool design, "a catch all section." Examples of improvements include the following:

- *Company*—proposal has a social or economic impact on the community.
- *Controls*—proposal changes controls that impact the production output.
- *Manufacturing*—process impacts the number of machine interfaces.
- *Maintenance*—proposal impacts the difficulty of maintenance by changing access to maintenance panels on the product.
- *Operations*—proposal changes the personnel skill mix required to operate the manufacturing machines.

SCOPE

TA will provide data used to make decisions concerning new technology, new product infusion, new process infusion, or life-extension production technology. New technology research and development is out of scope due to its dependence on policy decisions.

TA Uses. Possible uses of the TA tool include the following:

- Used to identify the data required in response to proposal solicitation.
- Used by field organizations to quantitatively assess technology proposals and trace the elements that influence the decision.
- Used by field organizations to ensure that impacts to all areas are considered.
- Used by field organizations to compare technologies, products, and processes to optimize the decision process.
- Used to screen technologies, products, and processes.
- Used to determine potential impacts to the system prior to implementation (i.e., where and when to look for absolute impacts or more specific data on the system).
- Used by high-level managers for major level decisions where decisions must be made on incomplete data and to provide supporting data for defending the decision.

The current design of the tool focuses on use by field organizations, since it is the field organization that will help to develop and evaluate the tool.

TOOL OVERVIEW

The TA tool is a decision aid whose purpose is to organize evaluator input and provide pre-defined and calculated outputs. Multiple choice questions, weights, and summing categories provide the means to quantify and roll-up question answers and score impacts. Organization of questions and categories is presented in a hierarchical structure. Changes to questions, weights, and categories are allowed but are governed by rules. Evaluations can be performed by summarizing scores, presenting sensitivities, and assessing uncertainties. Outputs can be textual and graphical reports or data files.

FEATURES

Hierarchy. TA is intended to evaluate relative technology performance. Organization of the information in the TA tool reflects a decomposition of performance categories.

Questions and Values. Input reflecting relative technology performance or effects on the life-cycle process is solicited through questions arranged in the hierarchy.

Question Scores and Weights. Weights are associated with active questions. Under a node, the sum of weights is always 1.0. Question weights are assigned by the TA tool and can be changed by the evaluator.

Objectives. A statement of the objective of each node is available to the evaluator through the screen display. The objective explains what information is desired and may explain the context.

Categories. Categories provide a pathway to relate question values to rolled up scores. The hierarchy defines placement and relationships among categories. There is one parent category for each question.

Assignment of Weights. Weights are assigned to categories and questions. Initially, default weights will be assigned to all categories (except the top-level category, as discussed earlier) and questions in the hierarchy. These will be assigned during the TA tool design process. The evaluator for specific evaluations can change weights associated with questions and categories.

Sensitivity. Sensitivity relates changes in answers to changes in node scores and can be used to investigate the effects that questions or groups of questions have on scoring.

Uncertainty. The TA tool provides the evaluator a measure of uncertainty for any category in the hierarchy. Uncertainty is solely due to questions with “unknown” answers.

Storing and Working with Evaluations. The TA tool can be used to perform evaluations of existing data and to perform certain assessments. An evaluation is defined as a unique combination of question answers, weights, and active categories leading to an overall score.

Evaluator Interface. The evaluator interface of the TA tool must satisfy three major tasks:

1. Input data required to perform an assessment of a technology proposal

2. Display results of an assessment

3. Perform routine administrative tasks.

Although some of the interface screens may be used in the performance of multiple tasks, the interface description will be divided into sections according to these major tasks. The interface could be implemented on a desktop using an interface builder, such as Microsoft® Visual Basic© or as a Web browser interface using Java©.

DATA INPUT

This section describes what the interface must do and the capabilities required by the interface. Sample screens illustrate the capabilities required by the evaluator interface. These screens have been taken from the rapid prototype developed to aid in requirements definition. There will be no discussion of the specific software implementation of the interface in this section.

Password Screen. In all cases, the initial screen in the TA tool is a *Password Input Screen* (see Figure 1). The evaluator will select the database containing the TA tool data and enter a password to access the data. The password will be database specific to ensure only authorized evaluators can access specific databases.

Figure 1. The Password Input Screen

Data. Once a database is open, the TA tool will display a list of the existing evaluations contained in the database (see Figure 2). The evaluator will then either select an existing evaluation to enter new data or review existing results, or create a new evaluation. The capability to create a new evaluation will be provided in the administrative actions window that is accessed by the "Administration" button in Figure 2.

Each evaluation consists of six hierarchies or trees used to determine evaluation results. After the selection of an evaluation, a top-level evaluation status screen will appear showing the current values or scores for each of the six trees. The evaluator will then be able to select one of the six trees to input new data or display results. This top-level evaluation display window is shown in Figure 3.

Figure 2. The Choose Evaluation Screen

The Improvement, Risk, and ES&H hierarchies contain the questions that are the basis of evaluator input for TA. The remaining hierarchies display the impact of evaluator input on cost and schedule derived from the answers to the questions in the previous hierarchies. If available, the evaluator may also enter absolute cost data if the cost hierarchy is selected.

Figure 3. The Evaluation Status Screen

After selection of a question hierarchy for data input (i.e., Improvement, Risk, or ES&H), a tree display is opened. The evaluator will be able to expand and shrink the tree to show branches of the tree as needed. The example shown in Figure 4 is a portion of the Improvement hierarchy. Selecting "+" or "–" will expand or collapse the branch of the hierarchy. The weight assigned to each node and the current score associated with each branch are displayed.

Selecting a node in the *Question Interface Screen* (the left half of Figure 4) will display the details associated with the node. If the node children are questions, a *Question Display Screen* (right half of Figure 4) will be displayed allowing the evaluator to change the weights associated with the children of the selected node. The weight change will affect the current evaluation only and will not impact the default weights initially assigned to the questions. In a similar fashion, if the weight of a single node is changed, the weights of the remaining categories will be automatically modified so the sum of the weights is 1.0. The TA tool also has the capability to change the weights of all categories simultaneously, which can be achieved by selecting the "Modify All Weights" button. The default weights can be recovered by selecting "Restore Defaults."

Derived Scores. As alluded to earlier, cost and schedules scores are derived for the inputs given in the three main topics—Risk, Improvement, and ES&H. The question then arises, what do we do with an actual known time or dollar value? This known value is a quantitative value that needs to be compared to a qualitative measurement of impact.

In order to explain how we compare a qualitative and quantitative values, use a thermodynamic steam property analogy. In determining the steam quality, state properties of the steam are given (temperature and pressure). From the defining state conditions, a quality factor can be determined based on knowing the saturated vapor point and saturated liquid point. Once these upper and lower bounding limits are known, the quality is determined as a point between these boundaries. Essentially in determining a qualitative value for a known quantitative value, the TA tool determines a "quality factor" for a known quantitative value. To find the value, the user of the system is asked to provide the state conditions (i.e., known dollar or time value). The user is then asked to supply the bounding conditions. The "quality factor" of the known

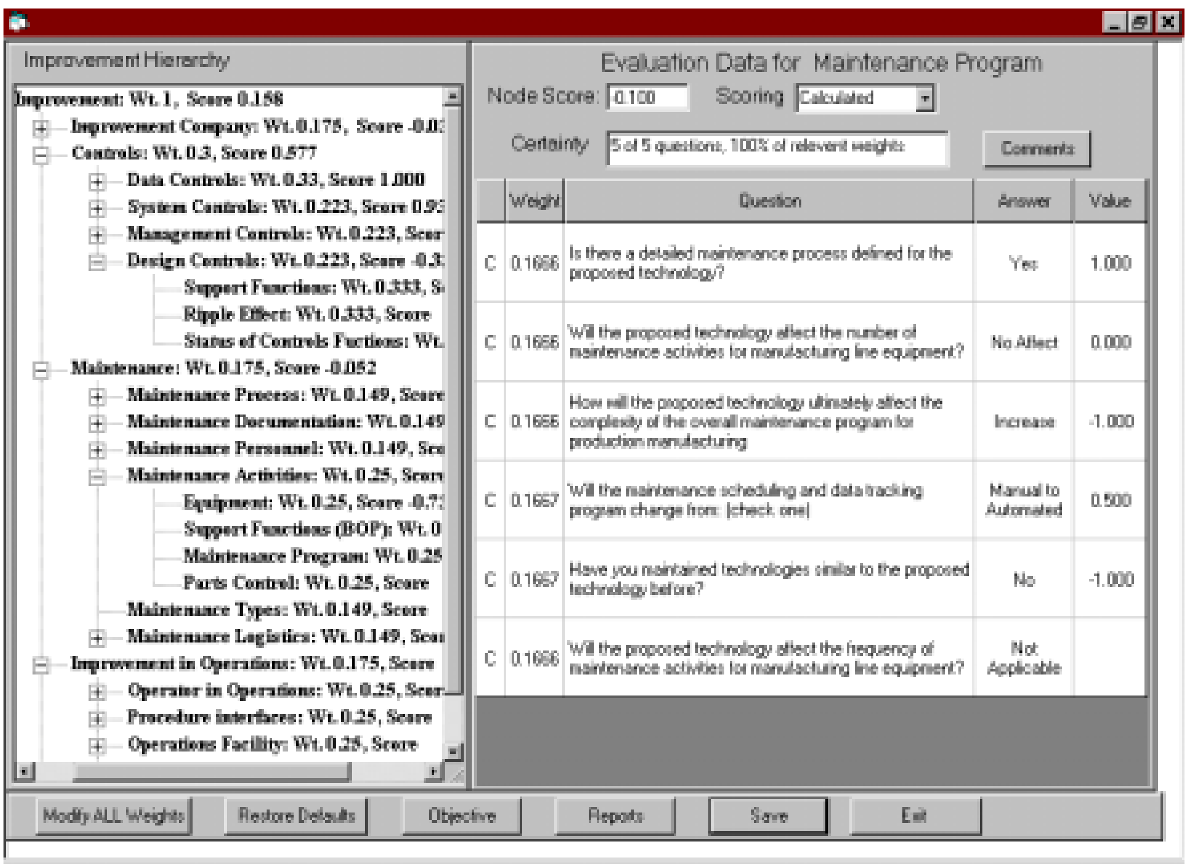

Figure 4. Question Interface Screen

value between the bounding points is calculated and used in the tool as the qualitative measure.

Evaluation Results. The results of an evaluation can be reported in various formats. A graphical representation of the results is presented in Figure 5.

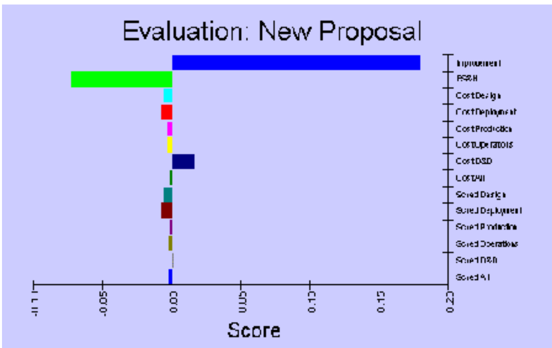

Figure 5. Graphical Results Report

A summary reporting of the scores will also show up in an update of Figure 3, see Figure 6 *Evaluation Status Scores* below.

CLOSING SUMMARY

TA is a requirements-based approach to establishing a formal and quantitative performance criteria process as the basis for evaluating new and advanced technologies, products, and/or processes. Using the TA tool, the technology evaluator will be able to trace the data influencing the decision, defend decisions based upon quantifiable data, and determine characteristics that dominate the data (sensitivity). The technology evaluator may be a low-level manager, a subject matter expert, a proposer of technologies, or a higher level manager who wishes to judge a technology.

The development strategy uses a hierarchical structure bounded by six categories that have supporting categories (elements). As such, the decision-maker has to review only six numbers to make a decision. If more detailed information on any of the categories is needed, it is available. The six categories are as follows:

1. Improvement
2. Cost
3. Schedule
4. Risk
5. Environment, Safety, and Health (ES&H)

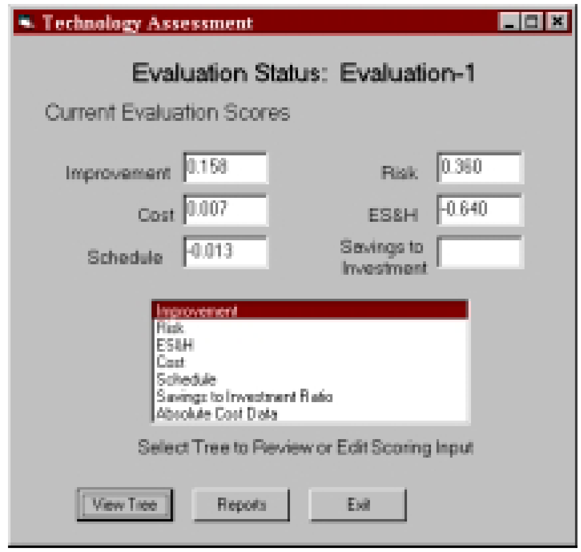

Figure 6. Evaluation Status Scores

6. Savings to Investment.

ES&H, Risk, and Improvement are scored based on input data from an electronic questionnaire consisting of about 400 plus questions that support the elements of the six categories. Questions are all multiple choice, such as “Yes or No,” “Increase or Decrease,” or “Chose one or more of the following answers.” Not all questions must be answered; that is, selecting “not applicable” eliminates all the questions under an element. All questions have an assigned value based on the answer selected. Weights are assigned to designate the level of importance. A score is generated by multiplying the question value by the weight. Cost and schedule scoring uses an algorithm to derive relative scores from inputs to ES&H, Risk, and Improvement. However, if specific costs are known, they are used and relative cost scores are not computed.

This computerized decision aid was developed for subject matter experts to evaluate questions, assign weights, and evaluate computer screens. The structure of the decision aid is the structure for the system and includes uncertainty analysis, sensitivity analysis (those functions that dominate the scoring), and reports. Reports can be textual, graphic, or data files. Reports can be selected to present data relative to the categories or to design, production, deployment, operations, or decontamination and decommissioning phases.

This tool will support organizations that strive to use a structured decision-making process. Such processes have the obvious advantage of forcing the decision-makers to systematically consider all the issues, while allowing them to publish their criteria and weighting factors for the decision. This feature will allow others to specifically challenge both the issues and their relative weights, which will potentially lead to a better defendable decision.

REFERENCES

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BIOGRAPHY

Michael Ardel Rynearson is a systems engineer with Lockheed Martin Idaho Technologies Company at the Idaho National Engineering and Environmental Laboratory. His current duties with the systems engineering directorate include performing life-cycle cost analysis and integration of large and small projects for the Department of Energy. He has supported projects in all phases of development: concept, full scale, and production. Michael has a Masters of Engineering degree in Engineering Systems; Energy Systems Speciality from the Colorado School of Mines.

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Donald E. Sebo is an advisory engineer at the Idaho National Engineering and Environmental Laboratory. Donald contributed in the are of support systems, data modeling and representation.

W. Brooks Cooper is a systems engineer for Lockheed Martin Idaho Technologies Company at the Idaho National Engineering and Environmental Laboratory (INEEL). Brooks provided systems engineering support for the conceptual design of a decision analysis software tool and the integration of programs at the INEEL.

John G. Richardson, systems engineer with Lockheed Martin Idaho Technologies Company, provided engineering support for the conceptual design of a decision analysis software tool and the integration of programs at the INEEL.

Rudy J. Theriault, project manager for Lockheed Martin Idaho Technologies Company, provided management support for the development of the software tool.