DECISION SUPPORT TOOLS FOR EVALUATION AND SELECTION OF TECHNOLOGIES FOR SOIL REMEDIATION AND DISPOSAL OF HALOGENATED WASTE

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Introduction

One of the most justified demands in abating the pollution created by polychlorinated substances is the remediation of contaminated sites, mainly soil remediation, which is also the most complex technical task in removing pollution because of the necessity to process huge quantities of matrix and to account for numerous side factors. The commercial technologies are usually based on rather direct and simplified but also secure processes, which often approach remediation in a general way, where different types of pollutants can be decontaminated at the same time by each technology. A number of different soil remediation technologies are nowadays available and the continuous competition among environmental service companies and technology developers generates a further increase in the clean-up options [1-2].

The situation around the problem of disposal of stockpiles of polyhalogenated substances, for example, persistent organic pollutants (POP), such as pesticides and PCBs, seems to be technically more feasible, though usually not sustainable or even dangerous technologies are employed (simple combustion). Over the last 10-15 years, a number of non-combustion technologies have been demonstrated to effectively treat POPs wastes [3] in some developed countries. The same as in the case of remediation, a number of options are available for disposal of polychlorinated pollutants, which are often more or less favorable for one or another pollutant, and where the interplay of other competitive criteria hampers the process of decision making.

The demand for decision support tools that could help decision makers in selecting the most appropriate technology for the specific contaminated site has consequently increased. These decision support tools (DST) are designed to help decision makers (site owners, local community representatives, environmentalists, regulators, etc.) to assess available technologies and preliminarily select the preferred remedial options. The analysis for the identification of the most suitable options in the DST is based on technical, economic, environmental, and social criteria. These criteria are ranked by all parties involved in the decision process to determine their relative importance for a particular remediation project. The aim of the present paper id to present the new approach for building decision support tool to evaluate different technologies for remediation and disposal of halogenated waste.

Methods and Materials

A new Decision Aid for Remediation Technology Selection (DARTS) has been developed and implemented over proposed multricriteria analysis system and utilized as reference database. The multicriteria analysis performed with DARTS is the process during which the relative merits of the remediation alternatives are compared to each other and the most appropriate is selected from among them for site clean-up implementation.

There are a number of fundamental problems when there are multiple objectives. For instance, consider the case where there are a number of decision makers, each with a preference ordering over a number of alternatives. The goal is to choose the "fair" alternative that aggregates the preferences of the decision makers. This is an example of multiple criteria decision making (each decision-maker represents one criterion), and those objectives need to balance in a fair way. The situation is even more complicated when there are also multiple and even conflicting criteria like in the DARTS (where for instance, minimizing cost and clean-up time could be conflicting requirements). The decision-maker is asked to specify goals and relative weightings for the different criteria. The weighting can be changed to assess sensitivity of the solution or to reflect different opinions.

The explicit consideration of multiple, even conflicting objectives in a decision model has made the area of multiple criteria decision-making (MCDM) very popular among researchers during the last two decades [4, 5]. Interactive methods and outranking methods were adopted to solve multicriteria problems in DARTS. A special outranking method, based on extensions of the notion of criterion [8] (PROMETHEE I, providing a partial preorder, and PROMETHEE II, providing a total preorder on the set of possible decisions).

These extended criteria can be easily defined by the decision maker, because they represent the natural notion of intensity of preference, and the parameters to be fixed (maximum 2) have a real world meaning. The extension is based on the introduction of a preference function, giving the preference of the decision maker for an action *a* with regard to *b*. This function is defined separately for each criterion, where its value is between 0 and 1 (meaning a range between 0 and 100%), within the same defined criterion. The smaller the function is, the greater is the indifference of the decision maker; the closer to one, the greater his preference. In case of strict preference, the preference function is 1.

A preference function, $P_h(a, b)$, is usually presented by a function $p(x)$:

$$p(x): x \rightarrow [0, 1] \text{ and } x = f(a) - f(b),$$

where $f(a)$ and $f(b)$ represent the values of a particular criterion, *h*, for actions *a* and *b* respectively.

Using a preference index, $\pi(a,\ b)$, we can determine the preference for *a* with regard to *b* over all criteria:

$$\pi(a,\ b) = \frac{1}{\sum_{h=1}^{k} W_h} \sum_{h=1}^{k} W_h P_h(a,\ b)$$

where *k* represents the number of criteria, W_h is a weight for the criterion *h*, and P_h *(a, b)* is the preference function for the criterion *h*. A *valued outranking graph* consists of nodes represented by actions and arcs, where each arc *(a, b)* has a value *π(a, b)*. When obtained, the *valued outranking graph* offers a decision-maker means for determining a partial preorder (PROMETHEE I), or a total preorder (PROMETHEE II).

In order to rank the actions by a partial preorder, we must evaluate the outgoing flow:

$$\phi^{+}(a) = \sum_{x \in K} \pi(a,\ x),$$

where *K* is the set of all actions, and the incoming flow:

$$\phi^{-}(a) = \sum_{x \in K} \pi(x,\ a).$$

The outgoing flow $\phi^{+}(a)$ describes the degree to which *a* dominates the other actions in K, while the incoming flow $\phi^{-}(a)$ represents the degree to which *a* is dominated. Using the outgoing and incoming flows, the two total preorders (P^{+}, I^{+}), and (P^{-}, I^{-}) can be defined, such that:

$$a\,P^{+}\,b \quad \text{if} \quad \phi^{+}(a) > \phi^{+}(b), \qquad a\,P^{-}\,b \quad \text{if} \quad \phi^{-}(a) > \phi^{-}(b);$$
$$a\,I^{+}\,b \quad \text{if} \quad \phi^{+}(a) = \phi^{+}(b), \qquad a\,I^{-}\,b \quad \text{if} \quad \phi^{-}(a) = \phi^{-}(b).$$

Then the partial preorder ($P^{(1)}$, $I^{(1)}$, *R*) can be determined by considering their intersections:

$$\begin{cases} a \text{ outranks } b\ (a\,P^{(1)}\,b) & \text{if } \begin{cases} a\,P^{+}b \text{ and } a\,P^{-}\,b, \\ a\,P^{+}b \text{ and } a\,I^{-}\,b, \\ a\,I^{+}b \text{ and } a\,P^{-}\,b, \end{cases} \\ a \text{ is indifferent to } b\ (a\,I^{(1)}\,b) & \text{if } a\,I^{+}b \text{ and } a\,I^{-}\,b, \\ a \text{ and } b \text{ are incomparable } (a\,R\,b) & \text{otherwise.} \end{cases}$$

The net-flow: $\phi(a) = \phi^{+}(a) - \phi^{-}(a)$ is used to rank the alternatives by a total preorder ($P^{(2)}$, $I^{(2)}$): $\begin{cases} a \text{ outranks } b\ (a\,P^{(2)}\,b) & \text{if } \phi(a) > \phi(b), \\ a \text{ is indifferent to } b\ (a\,I^{(2)}\,b) & \text{if } \phi(a) = \phi(b). \end{cases}$

The laboratory prototype of DARTS has been developed as JAVA application, using Symantec Visual Café dbDE development environment [6].

Results and Discussion

The general software platform employed in DST is designed and implemented over a Multi Criteria Analysis system and utilizes a reference data-base in which the technologies are grouped in classes and categories according to their type of application (in case of remediation, in-situ and ex-situ types are applicable) and to the main mechanism involved in the process (physical, chemical, biological, thermal). The contaminants are also distributed in categories, by type (e.g. nonhalogenated VOCs, halogenated VOCs, nonhalogenated semi-VOCs, halogenated semi-VOCs, fuels, heavy metals, etc. in DARTS) or exact formula / class of compounds (e.g. drins, PCBs, lindane, DDT, and so on for disposal of waste).

The DST user, after inputting data relevant to the project and the general site/stockpile characteristics defines the contaminant (or a group of contaminants), selects a subset of technologies in which there is interest, or uses a full set of technologies and ranked criteria [7]; selects the criteria, preference functions (or use default functions chosen by the DARTS developers) and corresponding weighting factors and then performs a multicriteria analysis.

For the technology evaluation, some key parameters (criteria) are selected and a specific rating system is applied. Each technology is rated according to its performance under each criterion. For example the criteria included in the current DARTS prototype are as follows: 1) applicability, 2) overall cost, 3) minimum achievable concentration, 4) clean-up time required, 5) reliability and maintenance, 6) data needs, 7) safety, 8) public acceptability, 9) development status, 10) stand alone character, and 11) residuals produced.

Multicriteria analysis of all the factors involved in the decision process determines whether a remediation/disposal strategy is a feasible, effective and efficient solution and whether it satisfies all criteria and constraints defined by the user. Depending on the context in which technology assessment and selection is performed, the users can tailor decision strategy balancing out various effectiveness and efficiency parameters, other criteria and constraints. From the user's point of view, the general algorithm of DST is represented by the following sequence:

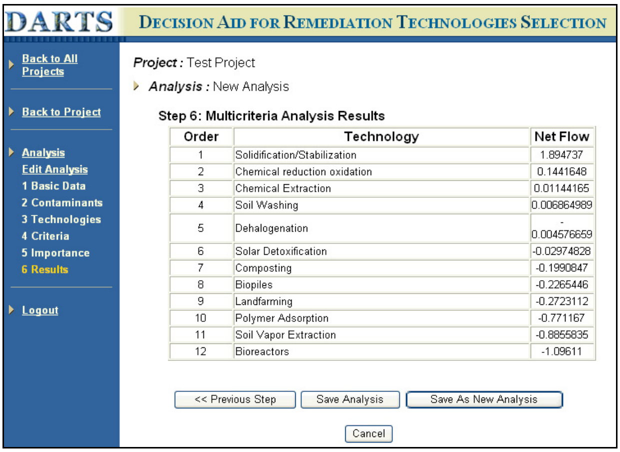
Step1. The user inputs basic project description
Step2. The user indicates one or more target pollutants/waste
Step3. The program displays the available technologies for the specific contaminants to select
Step4. The user then indicates the criteria according to contaminant type and parameter rating
Step5. The user sets criteria importance (weight ranges between 0 and 100%)
Step6. Multicriteria analysis is performed and recommended technologies are shown and sorted
Step7. Want to iterate again? → "Yes"– go to step 3, "No" – go to step 8
Step8. The user selects the best ranked technology

A dialogue box of DARTS prototype, requesting the user to select technologies to be simultaneously evaluated and compared with one another, and the *Multicriteria Analysis Results* window, displaying the results of the multicriteria analysis process are presented in Fig. 1. As from the example in Fig. 1, the solidification/stabilization technology of remediation is recommended as the best choice for a random selection of input parameters. This result, however, has to be exclusively intended as output from a test-phase of the system and not representing a real case of application.

The DST for technologies of polychlorinated waste disposal is under development according to the same scheme and software algorithm. The basic technologies to be included in the package are the following:

1. Base Catalyzed Decomposition (BCD),
2. CerOx ™ (Mediated Electrochemical Oxidation),

A)



B)

Figure 1. A) Technologies to be selected during analysis, B) Multi-Criteria analysis results

3. GeoMelt ™ (Mediated Electrochemical Oxidation),
4. SILVER II ™ (Mediated Electrochemical Oxidation),

5. Gas-Phase Chemical Reduction Process (GPCR),
6. In-Situ Thermal Destruction,
7. Mechanochemical Dehalogenation (Ball Milling),
8. Self-Propagating High-Temperature Dehalogenation,
9. Solvated Electron Technology (SET ™),
10. Supercritical water oxidation (SCWO),
11. TDT-3R ™ (Low temperature thermal desorption treatment),
12. Sodium Reduction,
13. Molten Salt Oxidation,
14. TiO_2 based V_2O_5/WO_3 catalysis,
15. Molten Metal,
16. Photochemically enhanced microbial degradation, etc.

The above listed technologies include the already commercialized ones or the ones in the phase of commercialization, i.e. those for which the realistic estimate of cost/efficiency/applicability can be made. Several previous studies on their assessment and classification [2, 3, 8], including the application results build the basis for the technology database structure and the system of criteria.

Further work on the integration of a risk assessment tool with DARTS is being conducted. A new decision support tool on POP disposal technologies (DAPTS) is currently underway (available as preliminary guidelines [8]) at ICS-UNIDO. Similar criteria are applied for the POP disposal technologies.

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