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## **Serie Research Memoranda**

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**VALUE FUNCTIONS FOR ENVIRONMENTAL POLLUTANTS:  
A TECHNIQUE FOR ENHANCING THE ASSESSMENT OF EXPERT  
JUDGEMENTS.**

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**Abstract.** This paper presents a new procedure to assess value functions for environmental pollutants. It has particularly been designed for eliciting expert-based value functions for pollutant substances. The main features of the model are the possibility to integrate direct and indirect assessment techniques, the possibility to make explicit assessment uncertainties and to avoid forcing quantitative judgements. The main aim of the procedure is to improve the reliability of the assessment but also to make the expert's task easier by using qualitative judgements more frequently. The procedure is presented on the basis of an application to soil pollution.



## 1. Introduction

Among the many available multicriteria techniques (Nijkamp and Rietveld 1986, Nijkamp *et al.* 1990, Bogetoft and Pruzan 1991) the value function approach is still one of the most common and well known methods. The value function model is used to evaluate conflicting alternatives, assigning to each alternative a total value score which summarizes its global performance. The model requires a set of evaluation criteria and, for each criterion, a value function and a weight. The criteria specify the performances of the alternatives, such as their cost, the quantity of pollutant released in the environment, etc.

The value functions attached to the criteria translate these scores into value scores representing their preference. They are necessary since the plain measure of the consequence of the alternatives can be rather uninformative from a decision perspective. For example, a quantity of pollutant released in the environment does not indicate the effects on living or non-living organisms. With the value function model a value function is attached to each criterion and translates the performance scores into values between 0 and 100. The value 100 indicates the best performance (for instance, no pollution) and the value 0 represents the worst situation considered (for example, a very high pollution). The total value of each alternative is a weighted sum of the single values corresponding to the criteria, the weights representing the relative importance of the criteria.

This model is based on a strong theoretical framework (Keeney and Raiffa 1976, French 1988); many methods to assess value functions have been used and tested. For practical reasons the additive representation of value functions is the most frequently used technique and two main assessment strategies are available: direct and indirect assessment (see Zeleny 1982).

## 2. Direct and indirect assessment techniques

Direct assessment implies stating unidimensional value functions and a combination of weights to aggregate them leading to a multidimensional value model. Unidimensional value functions are evaluated by stating the value of some criterion scores, provided numerical values for reference scores are defined. These techniques are widely known and many assessment procedures are available; the reader is referred to Fishburn (1967) and von Winterfeld and Edwards (1989) for a taxonomy of methods.

Indirect techniques reverse this approach: given a ranking among a set of alternatives and assuming an additive decision model (an underlying decision model, in general) a regression or other optimization technique calculates the set of value functions which

best represents the order according to some measure of optimum fitting. To this approach belong, among others, the so-called UTA and PREFCALC methods (Jacquet-Lagrez 1990, Jacquet Lagreze and Siskos 1982) and, with some extensions, the HOPIE technique (Weber 1985).

In this paper we concentrate on value functions and weights for pollutant substances. The value function attached to a pollutant is related to its effects and the weights represent the relative importance of the pollutants. Value functions and weights are assessed through expert interviews.

The direct and indirect assessment methods present some serious limitations in this situation. In the direct assessment a major point is the great difficulty encountered in assessing values for contaminant concentrations. The experts are usually toxicologists, biologists, chemists etc. used to the notion of dose-effect functions. These functions state a numerical relationship between a pollutant concentration and its expected effect for specific species, provided models of absorption are available (Aiking *et al.* 1989). A large number of effect data and complex models of absorption are needed to estimate dose-effect functions, which explains why they are not available for a large part of known industrial substances. Value functions, on the other hand, are often regarded as rough and imprecise tools and consequently experts feel very uncomfortable in assessing single values (see Brown *et al.* 1972 for this "psychological barrier"). This attitude can vary from an almost complete refusal to state any quantitative measure of value to an uncertain attempt to assess some basic values for well known situations (concentrations). In general, the shape of the function can be guessed in advance because of the behaviour of the pollutant but seldom does the analysis proceed with direct assessments.

With indirect assessment techniques the basic information needed is a ranking among a set of real or artificial alternatives. If the model is based on  $n$  evaluation criteria the experts need to compare  $n$ -dimensional alternatives. For example, in the case of soil pollution, we can imagine a number of sites polluted with  $n$  contaminants in various combinations of concentrations. A rank based on remediation urgency, for instance, provides the necessary information for an indirect assessment. If the number of substances is high, the experts face the problem of comparing multidimensional alternatives: the higher the number of criteria (pollutants), the more difficult the task. As a result, the experts feel that such approaches are providing very crude and unreliable responses which are also far away from their own expertise. It is clear that the lower the dimension of alternatives, the easier and reliable the responses. For practical reasons, therefore, it is advisable to avoid comparisons among complex multidimensional alternatives and to stick to simple cases, for example bi-criteria alternatives, to make the ordering task sound in the expert's view.

Finally, the direct and indirect assessment are often seen as alternative ways of stating someone's preferences, although an integrated procedure should take advantage of both methods and lead to a more reliable assessment. On a practical basis this is clearly highlighted: firstly, there is a need to connect the assessment phase with the decision phase to make experts aware of the possible selections based on the functions they provide. Secondly, there is the need to maximise the expert's contribution by widening the assessment boundary including indirect assessments, so as to lead to more reliable outcomes.

Related to the first point is the fact that the experts are not the decision makers; they just provide information which is not otherwise available. Although they may feel concerned with the outcomes of a decision based on the information they provide, they do not have a precise idea on the decision that could be made according to their assessments. Even assuming that they are accustomed to multicriteria value functions, by using direct assessment techniques they do not have the opportunity to link future decisions to current elicitations. As concerns the second point, it can be observed that experts tend to stick to a particular definition of value by considering it in a strictly toxicological or biological sense; in indirect assessments they partly have to abandon this requirement since trading off among alternatives means considering them in a composite fashion and not only according to a very specific point of view.

All these remarks make clear the need to support the assessment of expert-based value functions with some specific tools. The assessment procedure should take into account the difficulties in assessing direct values by avoiding forcing expert responses; it should be based on an integrated direct-indirect assessment procedure while the indirect phase should be based on rankings of simple alternatives. Moreover, the elicitation process should have an interactive character by providing the analysis with indications of which kind of elicitations need to be checked or refined.

### 3. A new procedure to assess value functions for environmental pollutants

Let  $X_1, \dots, X_n$  be the evaluation criteria (e.g., concentrations of pollutants) and  $R_i = [x_i^*, x_i^*]$ ,  $i=1, \dots, n$ , the criterion ranges such that  $x_i \in R_i$ ,  $i=1, \dots, n$ . Let also  $v_i: [x_i^*, x_i^*] \rightarrow [100, 0]$ ,  $i=1, \dots, n$  be the monotonically decreasing unidimensional value functions attached to the criteria and  $w_i$ ,  $i=1, \dots, n$ , the weight of the  $i$ -th criterion such that  $w_1 + \dots + w_n = 1$ . An alternative is a combination of  $n$  criterion scores  $(x_1, \dots, x_n)$ ,  $x_i \in R_i$ , while the overall value is the weighted sum of the unidimensional values (1).

$$v(x_1, \dots, x_n) = \sum_{i=1}^n w_i \cdot v_i(x_i) \quad (1)$$

The assessment procedure guides the experts in defining the set of  $v_i(.)$  and  $w_i$ ,  $i=1,...,n$ . The structure of the procedure is shown in Figure 1, where each block corresponds to one step of the method. Some of these are based on question-answer sessions between analyst and expert while others are computational steps. Apart from block A, which aims to provide the necessary information before the assessment, the procedure starts eliciting three kinds of information: value functions (Block B1), weights (Block B2) and rankings on sets of alternatives (Block B3), which represent the indirect assessment. A optimization procedure calculates the most consistent set of functions and weights with all information collected (Block C). The results are confronted with initial elicitations (Block D) and if considered as satisfactory the procedure ends. If refinements are necessary, the procedure starts again on a more precise data base (Block E). The next sections explain the modules in greater detail.

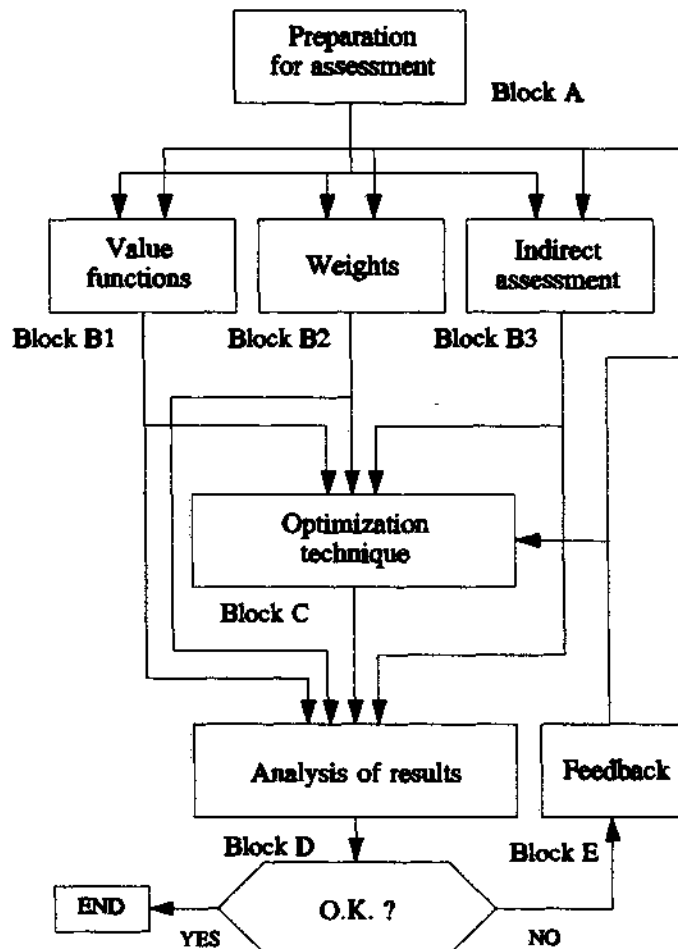


Figure 1. Flow chart of the assessment procedure.

#### 4. Value function assessment

As stated before, experts find it difficult to assess single values with direct assessment techniques. Better results can be obtained by making uncertainty explicit and avoiding forced responses. Instead of assessing single values, experts are asked to state in which value interval the real value is likely to be included. Basing the analysis on some reference scores<sup>1</sup>, they are asked to assess ranges of reliable values. This leads to a definition of "region of values". The value region can be seen as the effect of assessment uncertainty but also as an attempt to consider simultaneously various curves for various species and effects. The value regions can be rather broad but they seem to be more reliable and easier to assess than single curves. For each value region we can assume that the real curve falls within the extreme curves  $v_{i*}$  and  $v_i^*$ . (Figure 2).

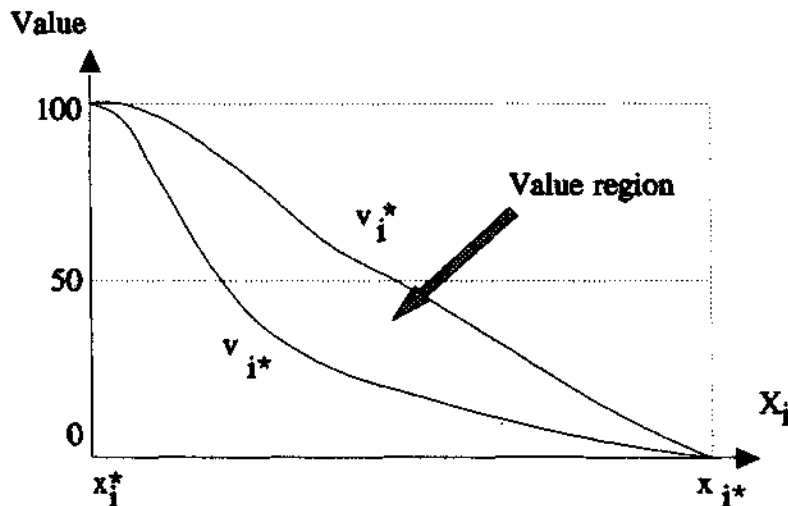


Figure 2. Example of value region and extreme curves.

Figure 3 shows an example of value region for lead soil pollution. The extreme curves are obtained interpolating the value intervals for three reference concentrations. The first version of a value region is a preliminary result which can be refined. At the very beginning experts tend to provide safe elicitations which determine very large value regions. By checking some values it is often possible to reduce the region of values to narrower limits (Beinat 1992).

<sup>1</sup> In the case of soil pollution, for example, legal standards are available. Dutch Legislation [Soil Clean-up Guideline (1983)] provides a list of common pollutants and for each substance three reference concentrations to evaluate the state of polluted sites. The effects of these standards are rather well known and they can be used as reference points for the assessment.

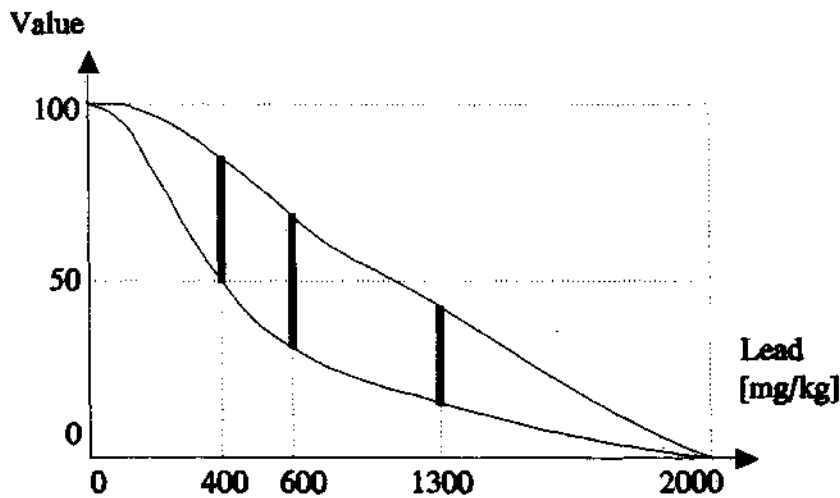


Figure 3. Value region for lead soil pollution. The extreme curves are obtained interpolating three value intervals for three selected concentrations.

The aim of block B1 is that of assessing  $n$  value regions. They provide little information on the real value functions but fix some robust boundaries for the final curves. Accepting such an incomplete information from the experts clearly makes the assessment easier. Sometimes this is the only way to obtain judgements and, in general, the elicitation is regarded as a more reasonable task compared to single value assessments.

### 5. Weight assessment

Among the various techniques to assess weights (see von Winterfeld and Edwards 1986 and Janssen 1992), the swing technique proves useful and easy to understand (name according to von Winterfeld and Edwards 1986). Figure 4 illustrates the assessment for a case of soil pollution with four pollutants. The first diagram (a) illustrates the initial situation in which all criteria take on the highest level ( $x_{i*}$ ). This is the poorest condition since all substances are detected at the highest possible level. By swinging one criterion at a time from the poorest ( $x_{i*}$ ) to the best level ( $x_i^*$ ) we design four extreme alternatives. Ranking these alternatives implicitly means to assess a weight order. Starting from the initial situation, we imagine that it is possible to clean one substance at the time, so as to reduce its level from  $x_{i*}$  to  $x_i^*$ ,  $i \in [1, \dots, n]$ . The first to be cleaned is the substance which provides the highest improvement in the soil quality, i.e. that with the highest weight. In Figure 4 (b) we see that benzene is cleaned first. Benzene, therefore, has the highest weight. It is now possible to clean another substance, which will be given a lower weight and so on and so forth. The weight order depends on the intrinsic characteristics of the pollutants but also on the range of concentrations considered, which is important to build

a model which respects the value function theory (see Keeney and Raiffa, 1976). Although numerical estimations of weights are also possible, they seem difficult and of little reliability in experts' view. The procedure is therefore used only to assess a weight order.

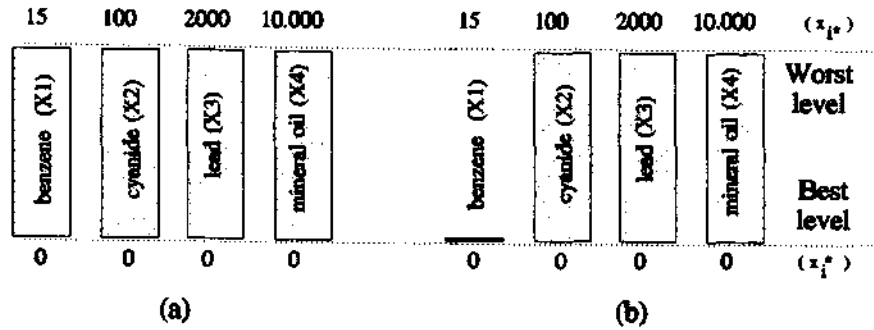


Figure 4. Swing technique for weight assessment. In the initial situation (a) all substances are held at the highest level of concentrations.

The weight order can be a simple rank order or a more complex order with indifference, incomparability or strength of preference information. In general, given  $n$  criteria, they can be grouped into  $p$  weight classes,  $C_1, C_2, \dots, C_p$ , where every class can be an indifference or incomparability<sup>2</sup> class and between every class a preference relation can be established. In the case of Figure 4 the order assessed was  $w_1 > w_2 = w_3 > w_4$  which corresponds to three classes  $C_1 = \{w_1\}$ ,  $C_2 = \{w_2, w_3\}$  and  $C_3 = \{w_4\}$ , where  $C_1 > C_2 > C_3$ . Due to the simplicity of the approach and due to the strict connection between weights and ranges this step of the assessment does not present particular difficulties and the results are usually rather reliable.

## 6. Indirect assessment

The indirect assessment is based on the information given by a subjective ranking on a set of alternatives (real or artificial). The alternatives used in this procedure are simple bi-criteria artificial alternatives (2c-alternatives): a 2c-alternative on  $X_i$  and  $X_j$  is defined as:

$$(x_i, x_j)_{2c} = (x_1^*, \dots, x_{i-1}^*, x_i, x_{i+1}^*, \dots, x_{j-1}^*, x_j, x_{j+1}^*, \dots, x_n^*); x_i \in R_i, x_j \in R_j \quad (2)$$

<sup>2</sup> Incomparability means that the expert is not able to assess reliable weight differences and prefers to defer the judgement.

This is an  $n$ -dimensional vector in which all scores but two take on the best level. Given a set of two criteria alternatives, the experts are asked to provide a rank order among these simple alternatives. A set of 2c-alternatives is shown in Figure 5 for the criteria  $X_i$  and  $X_j$ . As will be shown in the next section, the optimization procedure is based on rank orders of these simple alternatives and the outcomes are the value estimations of the points composing 2c-alternatives. In Figure 5 they are the values  $v_i(x_{i,k})$  and  $v_j(x_{j,k})$ ,  $k=1,2,3$ .

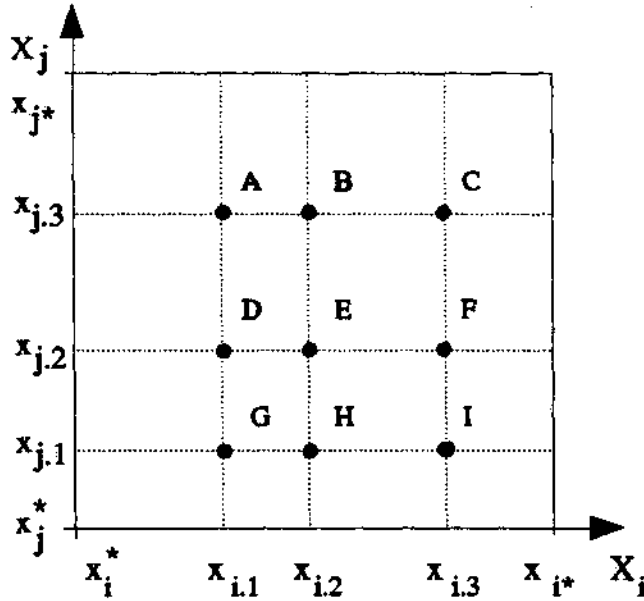


Figure 5. Set of 2c-alternatives for criteria  $X_i$  and  $X_j$ .

The indirect assessment requires the selection of which pairs of criteria to use and the points which generate the 2c-alternatives. As concerns the pairs of criteria, we note that the frame in Figure 5 contains information only on  $X_i$  and  $X_j$ . The optimization procedure which follows, (see Figure 1) estimates a value function and a weight for  $X_i$  and  $X_j$ . Clearly this is not possible for the remaining criteria since the set of 2c-alternatives does not provide the necessary information. With  $n$  criteria we would need at least  $n-1$  sets of 2c-alternatives, each set based on a different pair of criteria. In order to assess the same amount of information for each criterion, the actual number of sets is equal to  $n$ . Figure 6 shows the situation. The criteria are linked in pairs and for each pair we can define a set of 2c-alternatives for the indirect assessment. The set of pairs of criteria is defined as a Pairwise Group (PWG). In Figure 6 it is:

$$\text{PWG} = \{(X_1, X_2), (X_2, X_3), (X_3, X_4), \dots, (X_{n-1}, X_n), (X_n, X_1)\} \quad (3)$$

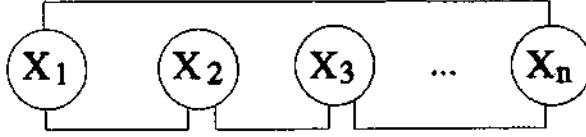


Figure 6. To each pair of criteria linked with a line corresponds a set of 2c-alternatives.

With  $n$  criteria ( $n > 2$ ) many different pairwise groups are possible. For reasons of symmetry every possible PWG consists of  $n$  pairs of criteria and every criterion is used twice with two different partner criteria. In principle every PWG is equally useful and the choice of the PWG for the assessment is essentially a matter of practical convenience (see Beinat 1992).

Besides that, it is necessary to select the coordinates for the 2c-alternatives. In Figure 5 three points have been selected for each criterion ( $x_{i,k}$ ,  $x_{j,k}$ ,  $k=1,2,3$ ), which determine nine alternatives. A different number of points could have been selected although the choice of three points seems a reasonable compromise between the advantage of having a many alternatives and the length and difficulty of assessing their rank order.

The selection of which points is then based on the need to distribute the value estimations on both the value and score axis, so as to set sets a good base for the interpolation of the results (see Beinat 1992 for details and examples). In the following exposition we assume that for each criterion three points have been selected as 2c-alternative coordinates; in general,  $n_i$  points can be selected for the criterion  $X_i$ . They define  $n$  sets marked with  $SP_i$ :  $SP_i = \{x_{i,1}, x_{i,2}, \dots, x_{i,n_i}\}$ ,  $i=1, \dots, n$ . For every  $(X_i, X_j) \in \text{PWG}$  a set of 2c-alternatives,  $SA_{ij}$ , is defined as  $SA_{ij} = \{\forall x_i \in SP_i, \forall x_j \in SP_j: (x_i, x_j)_{2c}\}$  and the output of Block B3 is a rank order of these alternatives.

## 7. Optimization procedure

The set of data available at this stage consists of  $n$  value regions, a weight order and  $n$  rank orders of 2c-alternatives. The aim of the optimization procedure, a linear programming module (LP), is to calculate the set of weights and the set of value functions (point estimations) which are to the largest possible extent consistent with all data collected. The objective function of the LP model is the sum of three kinds of errors to be minimized: the deviation of value functions from value regions ( $er$ ), the departure

of weights from the weight order (ew) and the departure of computed orders from assessed orders<sup>3</sup> (eo). The basic formulation of the linear optimization model<sup>4</sup> is shown in Equation 4. The constants  $\delta_w$  and  $\delta_o$  are threshold variables which can be used to highlight a minimum difference between weights or qualitative orders. This model can be further extended to take into consideration more detailed information such as indifference among weights, indifference among 2c-alternatives, strength of preference in weight order, and strength of preference for 2c-alternatives orders (Beinat 1992).

The L constants included in the objective function have a twofold function: firstly, they are used to rescale errors on weights (measured in a 0-1 range) and errors on values (measured in a 0-100 range). Secondly, they serve to modulate results according to the reliability of elicitations. The pieces of information collected in blocks B1, B2 and B3 may have a different reliability; usually the experts feel more confident in some part of the elicitations and less in others. By increasing one particular  $L_i$  the LP model tends to reduce the corresponding errors with higher priority and this feature can be used to modulate the LP solution according to data reliability. The number of constraints of the LP model can be considerable<sup>5</sup> and for practical applications large LP models are rather common; this is not a severe problem since current standard LP software can easily handle several hundred constraints and variables, which covers almost all practical needs.

To summarize, the outcomes of the LP module are the point estimations of value functions ( $\forall x_i \in SP_i, \forall i=1, \dots, n: v_i(x_i)$ ), a set of weights and a set of errors on weights, value regions and orders; the complete value functions can be obtained via interpolation of point estimations.

The errors can be very useful if interpreted as a measure of consistency of elicitations. If they are zero, the LP solution is consistent with all kind of elicitations, whereas some positive errors indicate some inconsistency in the assessment. The amount and distribution of errors can be used in evaluating and refining the results.

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<sup>3</sup> The assessed orders are those assessed by the expert, the computed orders are those calculated with value functions and weights.

<sup>4</sup> For the sake of the notational care the set of order constraints is presented as non-linear; to make the model linear a set of normalized variables is introduced. They are defined as  $z_i(.) = w_i \cdot v_i(.)$ ,  $i=1, \dots, n$ .

<sup>5</sup> Due to the monotonicity assumption, some of the order constraints for 2c-alternatives can be dropped as they are automatically satisfied. The number of constraints in the LP, therefore, depends on the particular rank order assessed; empirical tests show that the total number of constraints of the LP model is about 20 to 25 times the number of criteria.

(4)

$$\text{Min } ( L_1 \cdot \sum_{\forall (X_i, X_j) \in \text{PWG}} eo_{ij} + L_2 \cdot \sum_{\substack{w_i \in C_k \\ w_j \in C_r \\ r > k}} ew_{ij} + L_3 \cdot \sum_{i=1}^n er_i )$$

Subject to:

(value functions and weights respect the order of alternatives)

$$\forall (X_i, X_j) \in \text{PWG}, \forall (x_k, x_h)_{2c}, (x_i, x_j)_{2c} \in SA_{ij} \text{ such that } (x_k, x_h)_{2c} > (x_i, x_j)_{2c} : \\ [w_i \cdot v_i(x_k) + w_j \cdot v_j(x_h)] - [w_i \cdot v_i(x_i) + w_j \cdot v_j(x_j)] > \delta_o - eo_{ij}$$

(weights respect weight order)

$$\forall w_i \in C_k, \forall w_j \in C_r \text{ such that } w_i > w_j: w_i - w_j > \delta_w - ew_{ij}$$

(point estimations of value functions fall within value regions)

$$\forall i=1, \dots, n, \forall x_t \in SP_i : v_i^*(x_t) - er_i < v_i(x_t) < v_i^*(x_t) + er_i$$

(monotonicity of value functions)

$$\forall i=1, \dots, n; \forall x_t, x_{t+1} \in SP_i \text{ such that } x_t > x_{t+1}: v_i(x_t) < v_i(x_{t+1})$$

(scaling constraints for weights)

$$w_1 + w_2 + \dots + w_n = 1$$

## 8. Analysis of results and feedback

The complete set of results is submitted to the experts for the final evaluation. If the results are not accepted, the original elicitations are updated and a new LP model is defined. This second round provides a new set of results and the same steps are repeated until a satisfactory set of value functions and weights is obtained.

The analysis of results consists in comparing the LP outcomes with the original elicitations. For the value functions the analysis does not usually concern single values but rather the whole curve or some representative parts. The refinements, when needed, concern value regions rather than value functions and this phase may lead to a more refined set of value regions or to some new regions of values.

Similar conclusions can be drawn for 2c-alternative orders. The original orders are compared against the orders defined by value functions and weights and the refinements concern the orders rather than the overall numerical value of alternatives.

Some more precise results seem to be possible for weight evaluation. Since the numerical estimation of weights can be closely related to danger of substances and criterion ranges, it is often possible to make some more precise statements on their numerical estimations. The refinements can lead to a more reliable weight order but also to a new numerical estimation of weights. This is not always easy and feasible but, while the interpretation of numerical results seems to be extremely difficult for value functions and orders, it seems to be comparatively simple for weights.

In the refinement phase an important guide is offered by the optimization errors. They are a measure of concordance between LP results and original elicitations and suggest which piece of information needs to be checked with higher priority, as this likely needs refinements. The refinement phase ends with a new set of assessments. On this basis a new formulation of the LP problem is defined and the new optimization procedure provides a new set of results. In general terms, the results are refined step by step and every new optimization phase is more and more constrained around the final results.

### 9. An Assessment example for soil pollutants

This example concerns the assessment of value functions for four common soil contaminants: benzene ( $X_1$ ), cyanide ( $X_2$ ), lead ( $X_3$ ) and mineral Oil ( $X_4$ ), all measured in mg[contaminant] per kg[dry soil weight]. The test took place with an expert of soil contamination of the Dutch National Institute of Environmental Management (RIVM).

This assessment took two rounds: after the first, the results were considered almost satisfactory but some marginal refinements were required. This led next to a new set of elicitations and a new LP model which provided the final results. After an introductory phase and the range assessment for each criterion, the session started by assessing the value region for each substance. Figure 7 shows the value region for cyanide.

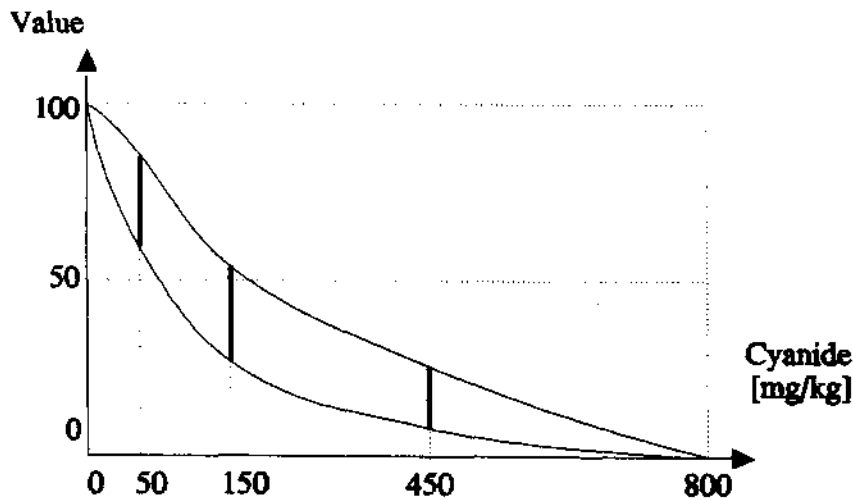


Figure 7. Cyanide value region (concentrations in mg of pollutant per kg of dry soil).

Afterwards a weight ranking was assessed by using the swing technique. Figure 4 was used as a graphical aid and the swing order led to the following weight order:  $w_1 > w_2 = w_3 > w_4$ , where the equal sign is interpreted as an approximate equivalence.

The third set of elicitations concerned the rank orders for 2c-alternatives. The pairs of criteria selected were:  $PWG = \{(X_1, X_2), (X_1, X_3), (X_3, X_4), (X_4, X_2)\}$ . Figure 8 shows the frame for  $X_1$ - $X_2$ . The expert was asked to consider these alternatives as polluted soils to be cleaned and to provide a rank order based on cleaning-up priority. The numbers shown in Figure 8 represent the order: number 1 is the first to be cleaned, number 2 the second and so on and so forth. Three other similar sets of 2c-alternatives were used in the assessment and a total of 36 alternatives was analysed.

On this basis the LP model was built and the first set of results was available. The expert considered the outcomes as almost satisfactory and only marginal refinements were necessary. They concerned those 2c-alternatives which were initially ranked different but after the first round obtained an equal overall value. The expert asked to emphasize a difference in value, which was obtained by imposing a  $\delta_0 = 0.5$  in the order constraints of the LP model. The results of the second round are shown in Figure 9, 10 and 11 in comparison with those of the first round. As it can be seen, the second round led to very marginal changes. The expert accepted these results which were considered as a good representation of his judgements.

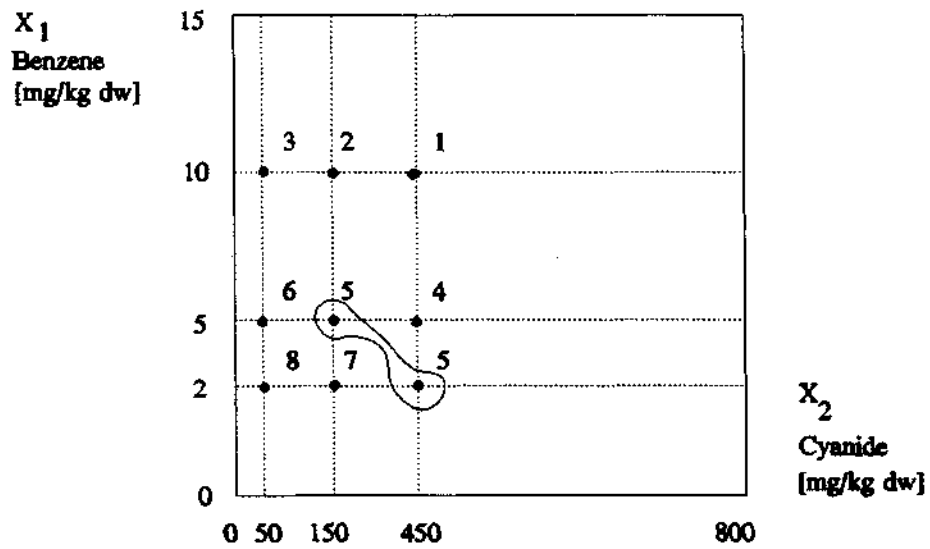


Figure 8. Set of 2c-alternatives for  $X_1$  (benzene) and  $X_2$  (cyanide). The numbers represent cleaning-up priorities: 1 is the highest.

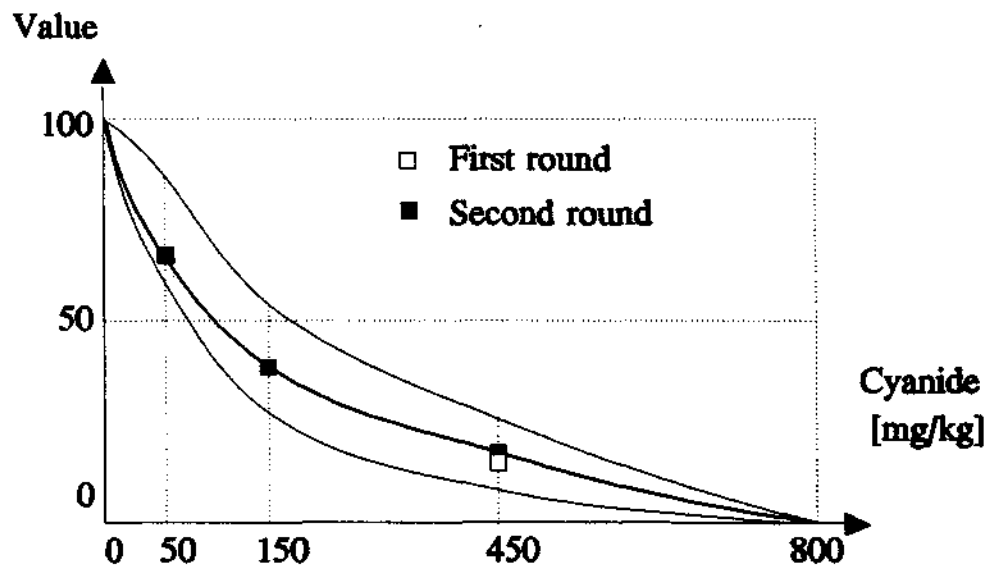


Figure 9. Cyanide value function. Results after the first and second round.

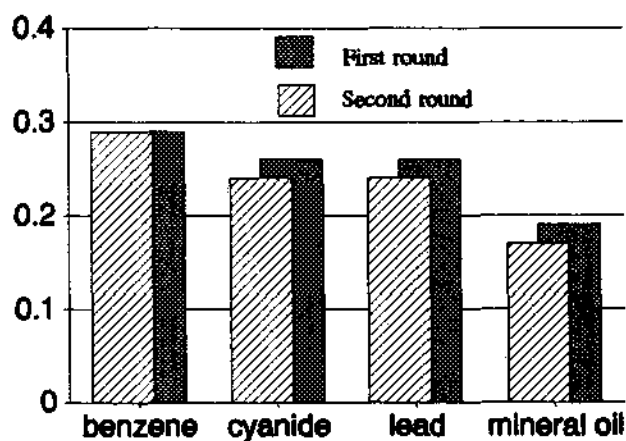


Figure 10. Weights after the first and second round.

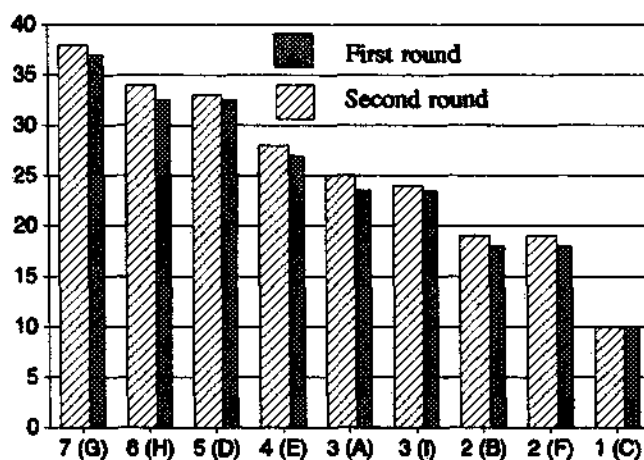


Figure 11. Overall values of the 2c-alternatives based on  $X_1$  (benzene) and  $X_2$  (cyanide). The numbers at the bottom are the cleaning-up priorities and the letters in brackets are the names of the 2c-alternatives (cf. Figure 5).

The major difficulties in this assessment concerned the estimation of value region and the evaluation of value functions. The reliability of this set of data was low compared to the rest of the elicitations. The value functions were accepted since they respected qualitative assumptions on their shape but in particular because together with the weights they provide correct orders of the 2c-alternatives.

Worthwhile mentioning is also the expert's attitude towards the assessment procedure: as far as results were provided and the link between orders of alternatives (2c-alternatives) and functions was made clear, the confidence in the procedure and in the value functions model significantly increased. This, in turn, made the assessment faster and easier.

## 10. Conclusions

The assessment of expert-based value functions for environmental pollutants highlights the need for new elicitation procedures. The main inconveniences of traditional procedures concern the direct quantitative assessment of values and the lack of connection between the elicitation phase and the selection phase, where the value functions are used to discriminate among alternatives. The procedure presented in this paper provides tools to overcome these difficulties. It integrates direct and indirect estimations and extensively uses qualitative data. The effect is that the expert's confidence in the assessment significantly increases and the results are robust. It should be mentioned however, that the assessment can be rather time consuming and painstaking for large problems, which can be seen as an unavoidable tradeoff between simplicity of assessment and reliability and robustness of results.

## References

- Aiking, H., H.A.J. Govers, R.W.Keulen, P.A.H. Hermens, R. Jelles (1989). 'A general approach to environmental health impact assessment in The Netherlands', in: D.D. Hemphill (ed.), *Trace substances in environmental health-XXII*. University of Missouri, 98-108.
- Beinat, E., (1992). *An interactive procedure to assess value functions for environmental quality*. Institute for Environmental Studies, Free University, Amsterdam.
- Bogetoft, P., P. Pruzan (1991). *Planning with multiple criteria*. Amsterdam: North Holland.
- Brown, R.M., N.I. McClelland, R.A. Deininger, M.F. O'Connor (1972). 'A water quality index : crashing the psychological barrier', in: W. Thomson, ed., *Indicators of environmental quality*. New York: Plenum Press, 173-182.
- Fishburn, P.C. (1967). 'Methods of estimating additive values', *Management Science*. 13:435-453.
- French, S. (1988). *Decision theory: an introduction to the mathematics of rationality*. Chichester: Ellis Horwood.
- Jacquet-Lagrez, E. (1990). 'Interactive Assessment of preferences using holistic judgements; the Prefcalc system', in: Bana e Costa ed., *Readings in multiple criteria decision aid*. Berlin: Springer, 335-350.

- Jacquet-Lagrange, E., J. Siskos (1982). 'Assessing a set of utility functions for multicriteria decision-making, the UTA method', *European Journal of Operational Research*, 10:151-164.
- Janssen, R. (1992). *Multicriteria decision support for environmental management*, Kluwer: Dordrecht.
- Keeney, R.L., H. Raiffa (1976). *Decision with multiple objective: preferences and value tradeoffs*. New York: John Wiley & Sons.
- Nijkamp, P., P. Rietveld (1986). 'Multiobjective decision analysis in regional economics', in: P. Nijkamp ed., *Handbook of regional and urban economics*. Amsterdam: North Holland, 493-541.
- Nijkamp, P., P. Rietveld, H. Voogd (1990). *Multicriteria evaluation in physical planning*. Amsterdam: North Holland.
- Soil Clean-Up Guideline (1983). *Leidraad Bodemsanering* (in Dutch), The Hague: Staatsuitgeverij.
- von Winterfeld, D., W. Edwards (1986). *Decision analysis and behavioural research*. Cambridge: Cambridge University Press.
- Weber, M. (1985). 'A method of multiattribute decision making with incomplete information', *Management Science*, 11:1365-1371.
- Zeleny, M. (1982). *Multiple criteria decision making*, New York: McGraw Hill.

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