Environ Syst Decis (2016) 36:266–276
DOI 10.1007/s10669-016-9598-1

Multi-criteria risk management with the use of *DecernsMCDA*: methods and case studies

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Published online: 10 May 2016

Abstract Emerging challenges of risk management, environmental protection, and land-use planning requires integration of stakeholder values and expert judgment. The process of decision making in situation of high uncertainty can be assisted through the use of decision support systems (DSSs). Such DSSs are often based on tools for spatial data representation (GIS) and environmental models that are integrated using multi-criteria decision analysis (MCDA). This paper presents *DecernsMCDA* implementing all major types of multi-criteria methods and tools (AHP, MAUT, Outranking) under the same user interface. In addition to providing ability for testing model uncertainty associated with selection of specific MCDA algorithms, *DecernsMCDA* implements new algorithms for parameter uncertainty analysis based on probabilistic approaches and fuzzy sets. The paper illustrates application of *Decerns*MCDA for selecting remedial alternative at radiologically contaminated sites.

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Keywords Risk management · Multi-criteria decision analysis · Decision support system · MCDA software · Uncertainty analysis

1 Introduction

Complex policy problems are often influenced by multiple and conflicting factors along with various potential alternative solutions to choose from Linkov et al. (2007). Identifying the optimal or trade-off solution in such an environment in an ad hoc manner is a difficult task that lacks transparency and is compounded by uncertainty and subjectivity inherent in any policy situation (Linkov and Moberg 2011). Such a lack of transparency is generally unacceptable in situations requiring clear communication between the decision maker and their constituents, where valuable information regarding trade-offs between risk and benefit cannot be formally described (Linkov and Moberg 2011). Instead, decision analysis serves as one method to improve transparency in the decision process while identifying the optimal policy or decision alternative in a formal manner. More specifically, decision support systems (DSSs) (or formal algorithms to conduct decision analysis) are particularly helpful in overcoming the limitations of ad hoc decision making due to the formal algorithms and frameworks used to assess decision criteria and available information (Simon 1960; Jorge et al. 2012; Marcomini et al. 2009). DSSs are particularly helpful for cases of environmental risk management and policy, where policymakers and practitioners are faced with multiple options to promote environmental welfare in a variety of technical and scientific, government, and commercial projects (Marcomini et al. 2009; Keeney and Raiffa 1976; Von

Winterfeldt and Edwards 1986; Belton and Stewart 2002; Figueira et al. 2005).

One branch of decision analysis includes multi-criteria decision analysis (MCDA) (Keeney and Raiffa 1976; Belton and Stewart 2002; Figueira et al. 2005; Linkov and Moberg 2011). MCDA's various methods allow users to evaluate a variety of factors important to a given policy decision against the identified policy solutions in order to ascertain which of these solutions is optimal for a given context (Linkov et al. 2007; Linkov and Moberg 2011). MCDA allows for the integration of quantitative and qualitative information simultaneously and is suitable for treatment and analysis of uncertainty of objective data or/and subjective judgments (Belton and Stewart 2002; Linkov et al. 2013). Such a method is particularly useful for situations where risk or benefit information is uncertain, or where decision makers must rely upon subjective opinion or judgment to amplify their assessment (Linkov et al. 2013).

The central focus of this paper is to discuss the merits and functionality of one such decision support system, *DecernsMCDA*, with a particular focus on environmental risk management cases. *DecernsMCDA* is a framework that formalizes and streamlines the multi-criteria analysis of various scientific and practical problems on choosing or ranking alternatives with the possibility to implement different MCDA methods. Additionally, *DecernsMCDA* is also a component of the spatial decision support system *DecernsSDSS*, which was developed in the international project DECERNS (*Decision Evaluation in Complex Risk Network Systems*) for decision-making support on risk management and land-use planning problems (Yatsalo et al. 2010, 2012; Linkov and Moberg 2011).

2 Method: multi-criteria decision analysis

The central aim of MCDA is to enhance a decision maker's learning and understanding of a particular decision problem alongside their own organizational preferences, values, and objectives through a structured decision analysis framework (Belton and Stewart 2002). Specifically, MCDA improves the decision-making process by accomplishing the following goals:

- the integration of the objective values with subjective judgments;
- the management of the decision-making process which is based on objective and subjective values; and
- the promotion of transparency of all the significant steps within the analysis of the multi-criteria problem.

The general MCDA process is presented in Fig. 1. The scheme in Fig. 1 illustrates an implementation of the MCDA process which is adjusted to the use of a decision assistance tool (e.g., *DecernsMCDA*), where the user is able to choose among the most widely used multi-criteria tools and methods based upon the availability of certain types of information, subject experts, or desired decision output. Included within the DECERNS tools are those methods for analysis of real-world case studies (MAVT, MAUT, AHP, TOPSIS, PROMETHEE) as well as original methods for uncertainty analysis (ProMAA, FMAVT, FMAA).

In Fig. 1, the step "Choice of MCDA method" is indicated on the same level with "Evaluation of the Criteria" (as distinct from other schemes, where the choice of MCDA method is considered implicitly or is implied at the step "Aggregating"). The choice of MCDA method will determine the quantity and types of data required. For problems with large uncertainties, probabilistic methods are often the best choice. The analyst must make sure that the available data support the technical approach. The next step uses the criterion values and generates the performance table (that includes assessments of all the criteria for given alternatives), as well as the implementation of specific approaches to the weighting process (choice of a weighting method and setting weights) and scoring (defining the suitable partial value function or preference thresholds).

Next, "uncertainty analysis" is considered after aggregation of the criterion values in accordance with the chosen MCDA method that considers uncertainty associated with weights and scores, respectively. After this, experts may recommend that the decision maker either uses the results, or returns to a previous step and continues the process of multi-criteria problem analysis until the experts are convinced that the analysis is "sufficiently robust."

The following list includes a collection of topics that may be executed through MCDA (Belton and Stewart 2002):

- *screening* alternatives—a process of eliminating those alternatives that do not appear to warrant further attention, i.e., selecting a smaller set of alternatives that likely contains the "best"/trade-off alternative;
- *sorting* alternatives into classes/categories (*e.g.*, "unacceptable," "possibly acceptable," and "definitely acceptable");
- *choice/selection* "the most preferred alternative" from a given set of alternatives; and
- *ranking* alternatives (from "best" to "worst" according to a chosen algorithm);
- *designing* (searching, identifying, creating) a new action/alternative to meet goals.

Other problems may also be considered in the implementation and the use of MCDA approaches (Figueira et al. 2005; Malczewski 2004).

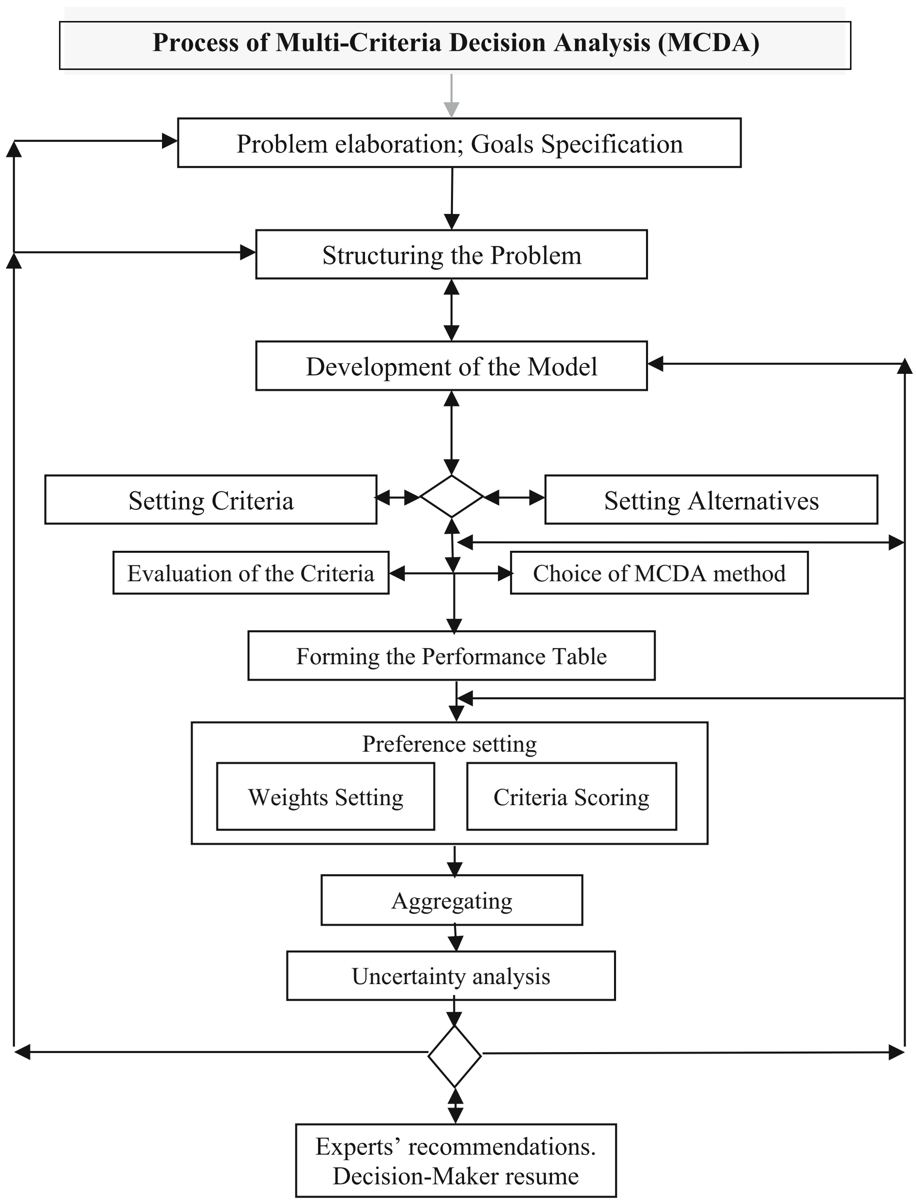


Fig. 1 Aggregated scheme of the MCDA process

Three major categories of MCDA problems can be distinguished (Figueira et al. 2005):

- multi-attribute decision making (MADM: a finite number of alternatives which are defined explicitly) versus multi-objective decision making (MODM: infinite or large number of alternatives which are defined, as a rule, implicitly);
- individual versus group decision making; and
- decisions under relative certainty versus decisions under uncertainty.

A brief description of the MCDA methods included in *DecernsMCDA* (MAVT, AHP, TOPSIS, PROMETHEE, FlowSort, MAUT, ProMAA, FMAA, and F-MAVT) is presented in the Supplementary Information section.

The application of MCDA methods for analysis of risk management problems for the period from 2000 through June 2014 is presented in Table 1. The number of *articles* where the method was used or, at least, mentioned, is based on a search in Scopus. The search looked for words associated with risk and the different MCDA methods. According to Table 1, AHP is the most widely used method and its use exceeds that of TOPSIS by a factor of four, and the MAVT/MAUT methods by ~20 times. This order in frequency is confirmed by the same analysis in ScienceDirect and Web of Science (although the corresponding numbers differ). A brief speculation along with some analysis of AHP and TOPSIS popularity is considered below in the *Discussion* section.

2.1 *DecernsMCDA* tools

The following tools of *DecernsMCDA* are also used to implement the included MCDA methods and the decision-making process:

- *Value tree* is a tool for structuring multi-criteria problem through developing a hierarchical set of goals/criteria and alternatives with a possibility of subsequent editing, as shown in Fig. 2; the value tree is also used for loading, representation, and editing model data (criterion values for the defined alternatives, partial value/utility functions, and weight coefficients);
- *Performance table* is intended to contain criterion data and model data for the defined alternatives. Within *DecernsMCDA,* an extended *performance table* is implemented, as shown in Fig. 3, and it includes not only the matrix of criterion data against alternatives, but also a description of criterion, data dimension, and weight coefficients.

Table 1 Number of *articles* in Scopus database for 2000–2014 in which MCDA method was mentioned: numerator—the method and words associated with risk management are mentioned in TAK (Tittle-Abstract-Keywords); denominator—words associated with risk management are mentioned in TAK, and the method is mentioned in full text of an article

	AHP	TOPSIS	PROMETHEE	MAVT/MAUT
Scopus	762/1841	152/486	38/173	29/102

- *Value path* provides graphics of criterion values for alternatives; a special tool has been developed for analysis of *domination* among alternatives (alternative $\boldsymbol{a}_1$ is dominated by $\boldsymbol{a}_2$, if for each of the criteria given, $\boldsymbol{a}_2$ is not worse then $\boldsymbol{a}_1$, and at least for one of the criteria $\boldsymbol{a}_2$ exceeds $\boldsymbol{a}_1$).
- tools for *weight sensitivity analysis* (for MAVT, MAUT, AHP, TOPSIS, PROMETHEE); and tools for
- *value/utility function sensitivity analysis* (for MAVT, MAUT, ProMAA, FMAA, F-MAVT).

For analysis of a specific multi-criteria problem, *DecernsMCDA* users can compare several alternative MCDA methods, provided corresponding data are available.

The tools for choosing a particular multi-criteria method and setting weights allow creation of the *different scenarios* for their analysis and comparison within a multi-criteria problem under consideration.

2.2 Application of *DecernsMCDA*

DecernsMCDA was used to select an area for housing development in a region (Yatsalo et al. 2010). Using GIS functions of *DecernsSDSS*, screening of potential alternatives (lands of the given region) is carried out with the use of 11 criteria (proximity to major roads, distance from rail roads, proximity to major rivers or lakes/ponds, distance from wetlands, proximity to the towns, and several other criteria) with subsequent analysis of 5 alternatives against 5 criteria. In another application, *DecernsMCDA* was

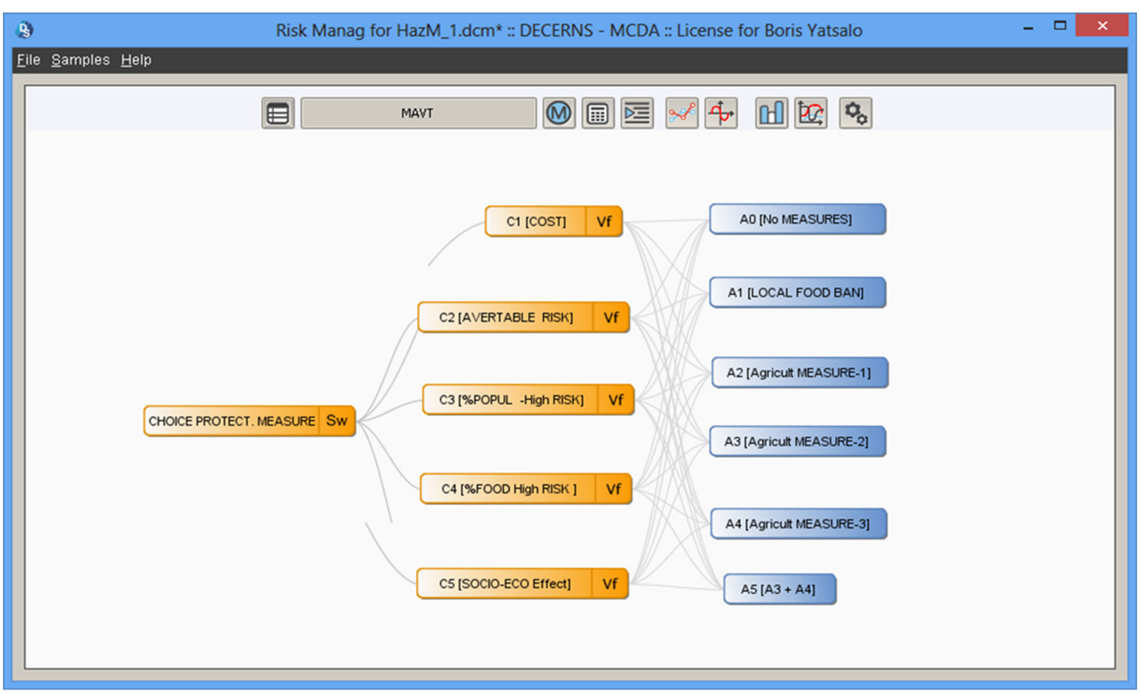


Fig. 2 *DecernsMCDA*: value tree

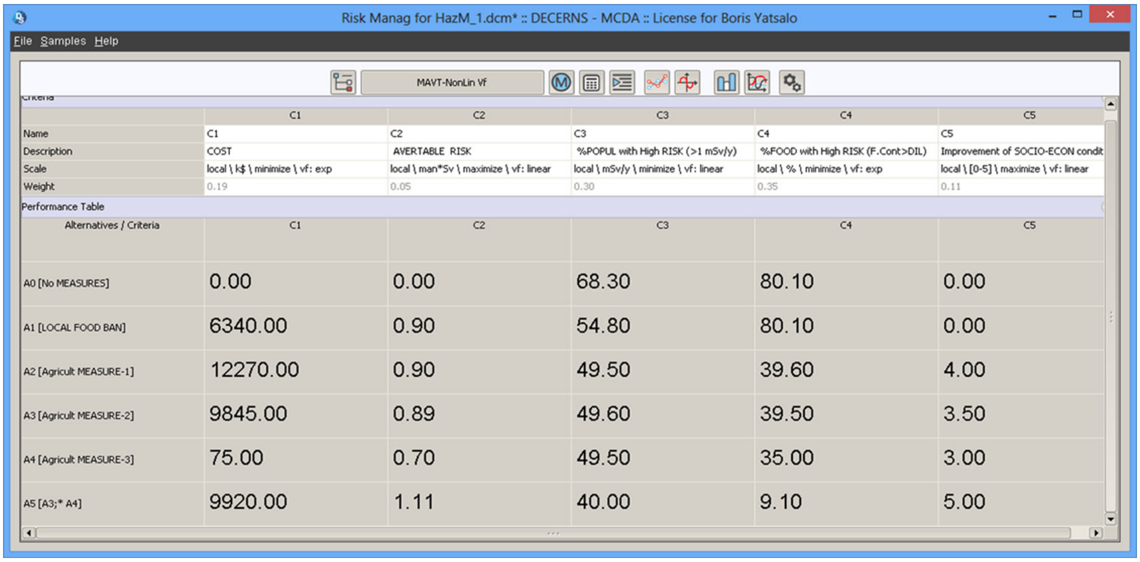


Fig. 3 *DecernsMCDA*: performance table

analyzed remediation measures for contaminated sites (Yatsalo et al. 2012). In this project, six alternatives/protective measures for remediation of radioactively contaminated territories after the Chernobyl accident were analyzed with the use of five criteria (cost, dose, and two criteria connected with contamination of agricultural products, and socioeconomic criteria).

2.3 Application of *DecernsMCDA* within the case study on the choice of remediation measures

This section presents an application of several MCDA methods for analysis of the case study on the choice of remediation measures (protective measures or countermeasures, CMs) for land with radioactive contamination, resulting from the Chernobyl accident. Use of DSSs and multi-criteria analysis of remedial measures after a nuclear accident were implemented in a series of papers (Yatsalo et al. 1998; Bäverstam et al. 1997).

In 2009, a two-day workshop was organized with the goal to present to experts and potential stakeholders and customers the DSSs, including *PRANA DSS* (Yatsalo et al. 1998) and GIS-MCDA tools, developed within the DECERNS project (Yatsalo et al. 2012), to analyze the problems of the rehabilitation of contaminated territories and land-use planning. During the workshop, participants made use of multi-criteria analysis to assess a set of remedial measures.

Workshop participants focused discussion on the Novozybkov district (Bryansk region, Russian Federation), which is one of the most contaminated districts in Russia after the Chernobyl accident (Yatsalo et al. 2012; Bäverstam et al. 1997). Contamination of the Novozybkov district with ^{137}Cs (the most important radionuclide for radiation analysis) ranges from 1 to 5 Ci/km^2 (37–185 kBq/m^2) up to 40–70 Ci/km^2, and in more than 50 % of settlements, the mean dose to the local population exceeded 1 mSv/y in 2000–2006 if no CMs were implemented. According to the existing standards (Bäverstam et al. 1997), the implementation of CMs for this district is a necessary step within radiation protection of the local population and improvement of the general quality of life in the contaminated territory.

The choice of the method(s) within this specific case study is motivated by different reasons, including the availability of input information, experts' willingness and degree of input into the elicitation exercise, and the availability of corresponding software tools (Linkov and Moberg 2011). Within this case study, experts and analysts agreed to utilize the various methods contained within DecernsMCDA, with the exception of AHP. The ranking alternatives by different MCDA methods were accepted by experts as satisfying their expectations, which is considered as an additional argument concerning correctness of the steps implemented through the process of decision analysis. Other methods may have been relevant for use in this case, yet discussion among experts noted that the approaches provided by DecernsMCDA were sufficient and provided robust cross-comparison of decision outputs.

2.3.1 Alternatives

Experts discussed several protective strategies to remediate contaminated territories. All strategies were aimed toward decreasing the doses to the local population either directly (e.g., banning milk) or through diminishing contamination of agricultural produce. Both approaches contributed to the reduction in internal doses. Reduction in external doses was not considered in this case study as measures for external dose reduction were performed in some of the most contaminated settlements during the first years after the Chernobyl accident.

According to the model assessments, the contribution of milk to the internal dose to the rural population in Novozybkov district constitutes 30–70 % (if no CMs are implemented), and the contribution of internal dose to the total dose constitutes more than 50 % for about 90 % of rural settlements (Bäverstam et al. 1997; Yatsalo et al. 1998). Some experts involved in the analysis of countermeasures within the case study supported measures to ban the consumption of private/local milk. Other experts supported the implementation of agricultural CMs. Such CMs lead to a decrease in contamination in agricultural produce and subsequent reduction in internal doses. In this connection, some specialists suggest CMs in animal husbandry (adding ferrocyne to feed), while other experts in agriculture stated the need for combined measures to treat pastures and hayfields. For the latter, this measure is not only important for the reduction in grass/hay (and then milk and meat) contamination, but also to contribute to the improvement of agricultural lands as a whole.

Several experts also suggested using mathematical models (computer systems) to assess risk values (produce contamination level, doses to the local population) for subsequent justification of selecting CMs. However, other experts are skeptical concerning model estimations. These experts suggest using the established tactic of managing agriculture based on the degree of contamination (5–15, 15–40, and >40 Ci/km^2) (Bäverstam et al. 1997; Yatsalo et al. 1998).

Taking into account different stakeholders' interests and arguments of the experts, the following alternatives for rehabilitation of the contaminated territory in Novozybkov district were explored:

A_0: No CMs are implemented;

A_1: Banning local milk consumption in all settlements where model estimates of mean milk contamination exceed the corresponding Derived Intervention Level (DIL, 100 Bq/kg);

A_2: Implementation of combined measure for all pastures and hayfields (except water-meadow pastures/hayfields) in the zone above 5 Ci/km^2;

A_3: Implementation of combined measure for all pastures and hayfields (except water-meadow pastures/hayfields) where model estimates of milk contamination exceed (i.e., after grazing grass/hay from a pasture/hayfields) corresponding DIL;

A_4: Implementation of ferrocyne during the year (for milk cows) if model estimate of milk contamination from a used pasture/hayfield can exceed corresponding DIL;

A_5: Implementation of combined measure for all pastures and hayfields (except water-meadow pastures/hayfields) where model estimates of milk contamination can exceed corresponding DIL, and implementation of ferrocyne if model estimate of milk contamination for a used pasture/hayfield can still (after combined measures) exceed corresponding DIL

2.3.2 *Criteria*

The indicated alternatives are evaluated with the use of the following criteria discussed and suggested by experts:

- C_1—*Cost* of the CMs/protective strategy implementation ($C_1 \rightarrow$ min);
- C_2—Avertable risk value through model assessment of the *avertable collective dose* of the local population in the region as a result of the protective strategy implementation ($C_2 \rightarrow$ max);
- C_3—*portion of the local population* in the region that live in settlements with mean internal dose above the given level (1 mSv/yr) after the protective strategy implementation ($C_3 \rightarrow$ *min*);
- C_4—*portion* of *private milk* with contamination above existing DIL after the protective strategy implementation ($C_4 \rightarrow$ min);
- C_5—improvement of the general *socioeconomic and psychological situation* as a result of the protective strategy implementation ($C_5 \rightarrow$ max).

2.3.3 *Models*

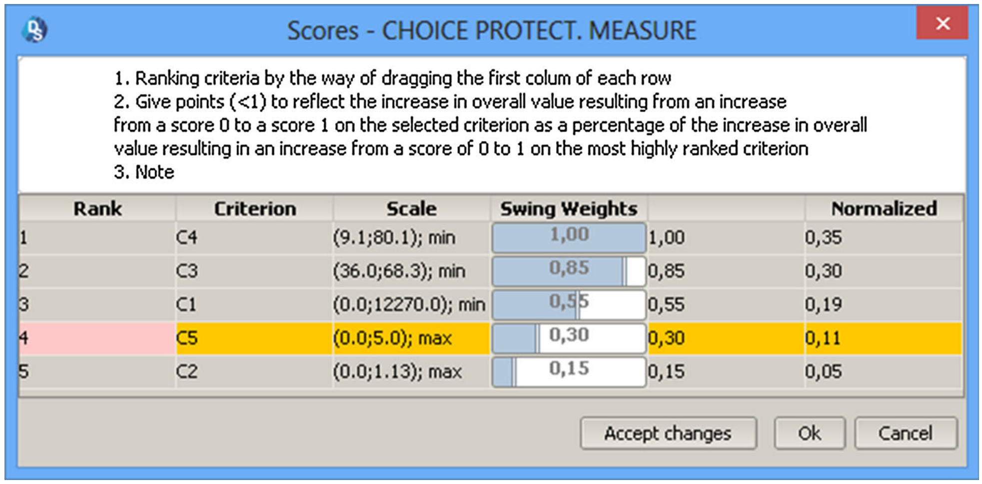
The following models have been used in *DecernsSDSS* for case study investigation on the optimization of countermeasure structure (Yatsalo et al. 1998, 2012):

- models for assessing contamination of agricultural and forest products;
- models for assessing internal and external doses to the local population (mean dose to the population of each settlement in the region); and
- models for assessing the results of CMs implementation.

All the indicated models were developed and used for practical assessments within the *PRANA* project (Yatsalo et al. 1998). Corresponding computer modules were adjusted for implementation in *DecernsSDSS* for this case study.

Six experts, including an MCDA analyst to guide the process, took part in implementation of multi-criteria decision analysis of the problem on "the choice of

Fig. 4 *DecernsMCDA*: weighting criteria using swing method



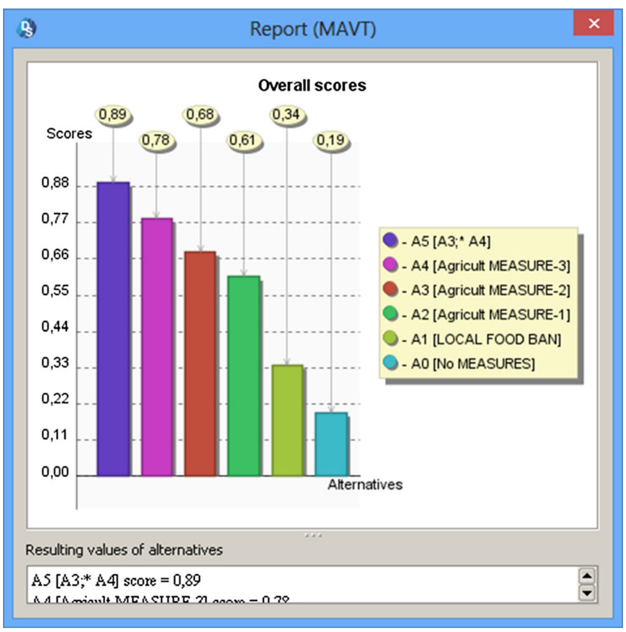


Fig. 5 *DecernsMCDA*: MAVT ranking

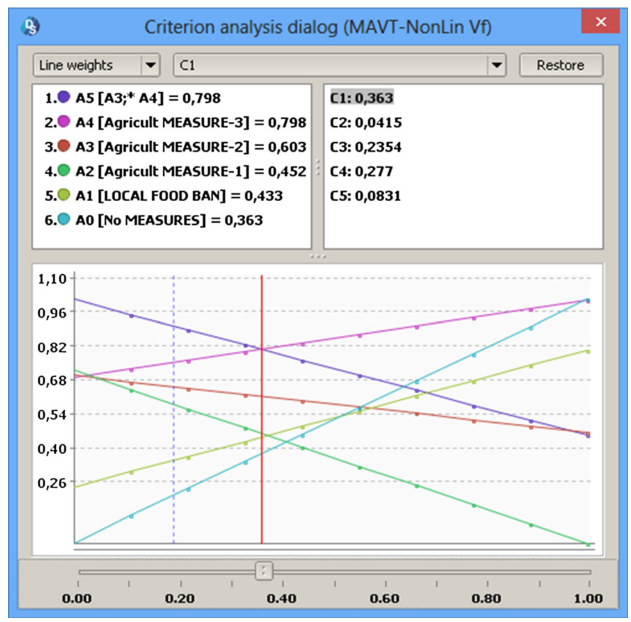


Fig. 6 *DecernsMCDA*: weight sensitivity analysis

restoration measures" in accordance with the scheme of Fig. 1. The developed value tree and performance table for this multi-criteria problem are presented in Figs. 2 and 3.

The analysis was started with the MAVT method; weight coefficients were suggested after discussion using the swing-weighting method, as shown in Fig. 4. Partial value functions were considered as linear ones for criteria C_2, C_3, and C_5. For criteria C_1 and C_4, nonlinear decreasing partial value functions were set taking into account that the basic part of high criterion value of $V(x)$ (when x changes from C_{min} to C_{max} for these two criteria) is connected with relatively inexpensive measures and with a small fraction of agricultural produce contaminated above established DIL.

Taking into account the MCDA experts' remarks and discussion concerning the uncertainty in setting weights and value functions, the group decided that extensive sensitivity analysis on the weights and value functions should be performed in accordance with the steps of the decision-making process, Fig. 1. The overall objective of this exercise within this MCDA study is to rank decision alternatives according to the five performance criteria.

Ranking of alternatives according MAVT is presented in Fig. 5. The base case evaluation of all criteria demonstrates a superiority of the alternative A_5 above all other alternatives with A_4 ranked second. Weight sensitivity analysis, as shown in Fig. 6, shows that an increase of w_1 for the cost criteria (w_j is a weight of the criterion C_j) from 0.2 up to 0.36 (while

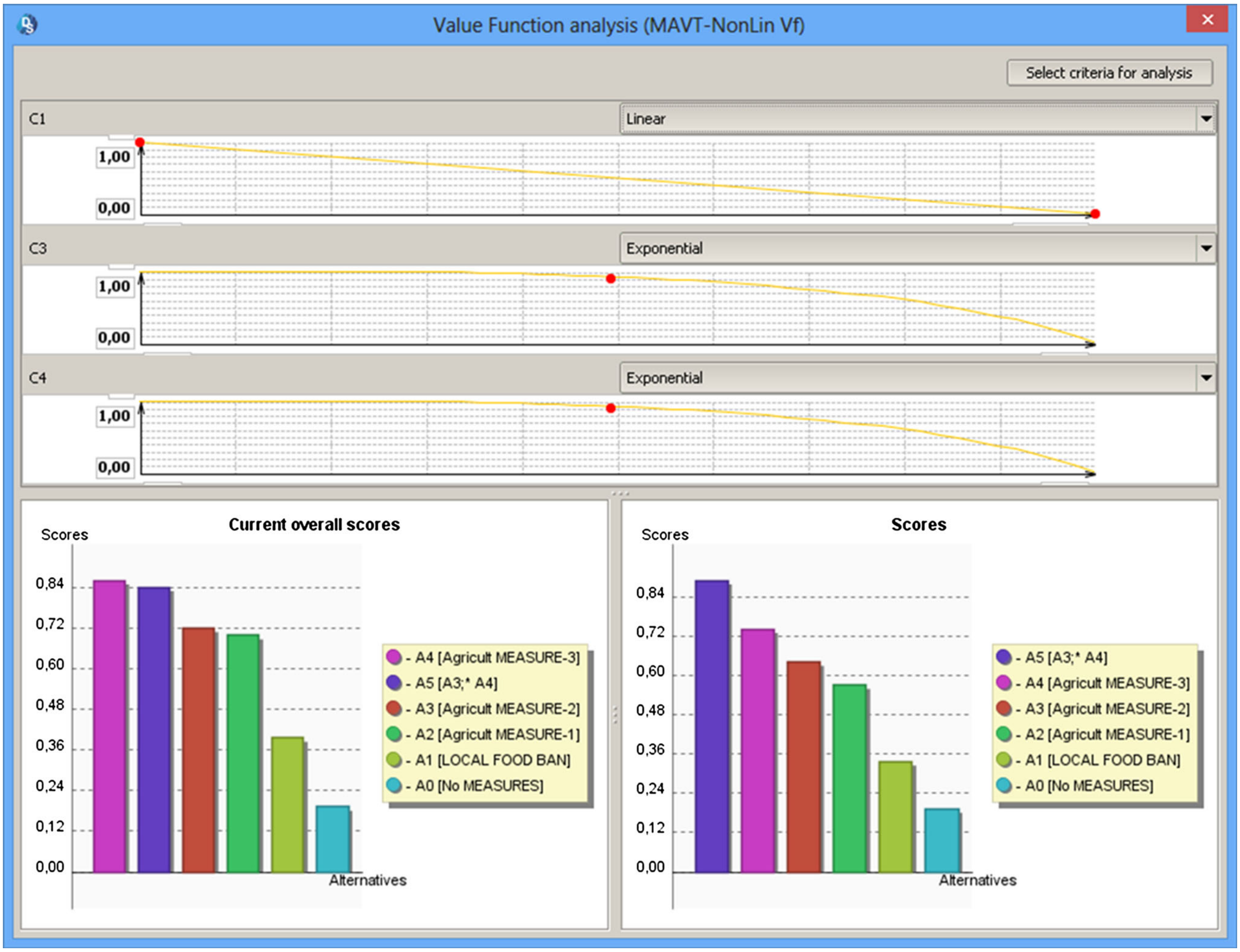


Fig. 7 *DecernsMCDA*: value function sensitivity analysis (*right-hand picture* basic ranking, *left picture* ranking according to changed partial value functions)

decreasing all other weights in proportion to their original values) leads to the change of the "best" alternative from A_5 to A_4. Some experts, who consider the economic criterion as a very important one, consider such a weight scenario as possible/justified. Alternative A_5 remained the preferred alternative when changing other weights.

Value function sensitivity analysis was carefully performed for all the criteria. In the case when partial value function for criterion C_1, $V_1(x)$, is linear (or close to linear), and partial value functions $V_3(x)$ and $V_4(x)$ are essentially nonlinear, Fig. 7, the alternative A_4 can exceed A_5. The experts agreed that such a nonlinearity for the indicated criteria may be considered as too artificial, although it did demonstrate that preference of the alternative A_5 under A_4 is sensitive to the selected value functions.

Other methods were also used for analysis of this problem. The following approach/scenario concerning input data is implemented for comparison of the results by the most widely used multi-criteria tools and methods.

In these analyses, the weight coefficients were the same as for MAVT (for ProMAA, FMAA, and FMAVT, they were considered as average values for distributed/fuzzy weights), and extensive weight sensitivity analysis as well as value function sensitivity analysis was conducted.

According to TOPSIS method, ranks of alternatives A_4 and A_5 are very sensitive to the weight of criterion $C1_5$ as shown in Fig. 8. Using the PROMETHEE-I/II methods (with a usual preference function for criterion C5 and linear type of preference functions for other criteria), these two alternatives are considered as "the best" ones and A_4 exceeds A_5 if weight of economic criterion C_1 is above 0.39.

Extensive uncertainty treatment both for criterion values and for weight coefficients was performed with the use of ProMAA, FMAVT, and FMAA. When using these methods, the range in the change of criterion values and weight coefficients was considered as ±10–±30 % (except MAUT, where weights were the same as for MAVT). Uniform distributions for weight coefficients and uniform/

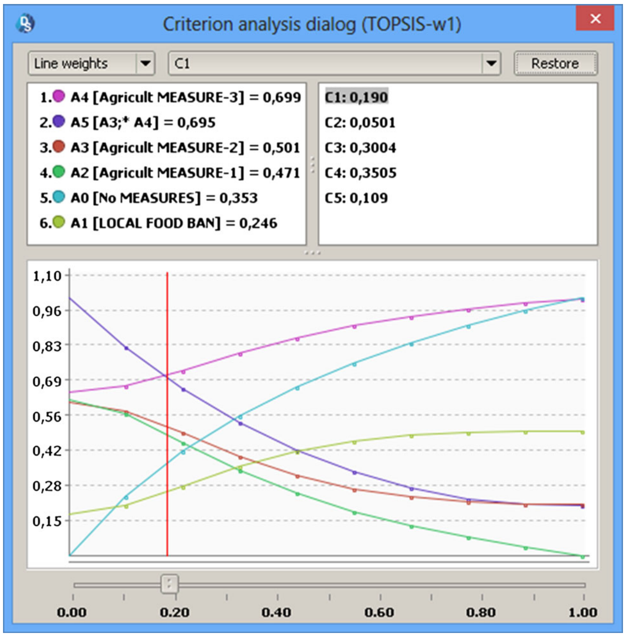


Fig. 8 Weight sensitivity analysis in TOPSIS

normal distributions (and non-random values for C_5) for criterion values were taken for ProMAA and MAUT; triangular and trapezoidal fuzzy numbers were used within FMAA and FMAVT. The results of rank analysis for these methods are close to those in MAVT, but sensitivity analysis demonstrates competitiveness of alternative A_4 against A_5. A value function sensitivity analysis in ProMAA is presented in the Supplemental Information.

The results of ranking alternatives $A_0,\ldots, A_5$ based on the implementation of different MCDA methods are presented in Table 2. This also takes into account the results of sensitivity analysis (in each cell of the table. the rank of the alternative according to the MCDA method is indicated).

3 Discussion

The implementation of MCDA methods within this case study was carried out by the MCDA analyst with participation of experts/stakeholders in all steps of multi-criteria problem analysis in accordance with the scheme of Fig. 1. For this case study, the results of ranking alternatives for advanced methods (ProMAA, FMAA, and FMAVT) generally agree with the ranking for MAVT.

We should stress here that there is no unique and "correct" approach to elicitation of model parameters (partial value/utility functions, preference functions, weight coefficients and their probabilistic and/or fuzzy "distributions") for MCDA methods and to subsequent comparison of the outcomes by different methods (see a comprehensive survey in Riabacke et al. 2012 with analysis of descriptive and prescriptive approaches to decision analysis). However, we consider the suggested scenario for such a comparison, described in Sect. 2.3, as justified in our case due to several reasons, including (1) the involvement of decision analysis experts concerning input data for different MCDA methods, and (2) the concordance of the output results to substantiate ranking alternatives.

Table 2 Choice of remediation measures: ranks of alternatives A_0–A_5 according to the MCDA methods

Method/alternative	A0	A1	A2	A3	A4	A5
MAVT	6	5	4	3	2	1
TOPSIS	5	6	4	3	1–2	2–1
PROMETHEE-I/II	6	5	4	3	2	1
MAUT	6	5	4	3	2–1	1–2
ProMAA	6	5	4	3	2–1	1–2
FMAA	6	5	4	3	2–1	1–2
FMAVT	6	5	4	3	2–1	1–2

The analyses allowed the experts the opportunity to take part in the practical use of indicated methods and helped them to compare the results and analyze the causes that impacted the ranking. The use of multiple MCDA methods and sensitivity analysis reduced or eliminated many disagreements between experts concerning weight coefficients for different criteria and the shape of partial value functions. Additionally, implementation of different MCDA methods and transparency of their use helped participants of the workshop to reach a trade-off in setting all the key parameters of the model for the choice/ranking of remedial measures. After seeing the results of the sensitivity analysis, experts agreed that the initial weight of relative importance for the total cost of implementation of the remediation measure should be increased.

Based on the results of using different MCDA methods, the group made the decision to recommend implementation of either A_4 or A_5 alternatives depending on the economic and social situation in the region. The experts involved in rehabilitation of radioactively contaminated territories after the Chernobyl accident pointed out that remediation measures A_1, A_2, and A_4 were all used in the contaminated regions according to formal recommendations without complex intercomparison of different protective measures/alternatives and without implementation of models for prediction of agricultural produce contamination and assessing doses to the local population (because such models were not formally adopted for official use).

One of the arguments in favor of using several MCDA methods when analyzing multi-criteria problem is connected with implementation of TOPSIS for the choice of the remediation measure, as shown in Fig. 8. An advantage of using the

TOPSIS methods includes limited input (weight coefficients only, in addition to assessing criteria for all alternatives) from the experts/decision maker and quick identification of "the best" alternative. According to some investigations, TOPSIS criteria weights typically affect the outcomes less than the number of alternatives or criteria (Yunna and Geng 2014). However, the conclusion that TOPSIS outcomes are robust enough (in comparison with other methods) concerning changing weights is incorrect in the general case. Figure 8 demonstrates that the choice between two "best alternatives" A_4 and A_5 is sensitive to change of weight w_1 (cost of remediation measure). If experts use only TOPSIS for analysis of the problem, alternative A_4 would be chosen as preferred in comparison with A_5.

Most experts in MCDA stress that no single superior MCDA method exists for all decision situations and that all of the methods may be considered appropriate depending on the problems to be solved. There are several reasons that AHP has a significant advantage in popularity compared with other MCDA methods. One of them is there are several existing software packages with effective implementation of AHP. The second very important reason is the simplicity of using the AHP method. Many AHP users attempt to minimize the work with "complex and vague" analyses (e.g., implementation of swing-weighting process along with evaluation of the types of value functions) and restrict these steps of MCDA process by a "simple comparison of alternatives and criteria in the given ratio scale." The third reason for the increasing of AHP popularity is the *positive feedback* from the existing level of AHP usage.

DecernsMCDA is also used within the educational course on Methods and Systems for Decision Making Support at the Obninsk University (Obninsk Institute of Atomic Energy at the National Research Nuclear University MEPHI, Obninsk, Moscow). The first author of this article carried out the analysis of students' preference for MCDA method (each student is required to solve their MCDA problem using *DecernsMCDA* software and then present their analysis at an open seminar). Students from the Economic and Management department preferred TOPSIS (about 50 %), because "it is the most simple and quick method," and AHP ($\sim$30 %), as "it allows the user to compare criteria and alternatives in a simple verbal scale without problems found in other methods requiring weighting and value functions setting." Students from Information Systems department gave the opposite results: About 40 % of students prefer MAVT/MAUT, $\sim$30 %—FMAVT/FMAA/ProMAA, $\sim$15 %—PROMETHEE, and 15 %—TOPSIS and AHP. The reason for such a difference may be explained by the Information Systems students having a better understanding of probability and fuzzy theory; disinclination to use a "black box/AHP" or "very simple TOPSIS method"; willingness to spend more time for a deep analysis of the multi-criteria problem (swing weighting, value functions setting, extended sensitivity analysis, and uncertainty treatment); among them, a wish to use "more complicated" methods to present a more thorough analysis was also important to several students.

The analysis of the "popularity of different MCDA methods" for the students cannot be directly compared with data presented in Table 1. In the case with the students, the effects of availability of different methods in one software package, the influence of "group preferences," and several other reasons have an influence on the results of this analysis. However, the conclusion that the experts'/users' specialty/profession as well as availability of corresponding software plays a role (in addition to the role of the problem features) in the choice of the MCDA method for analysis of the multi-criteria problem may be obtained.

4 Conclusion

One of the key differences of *DecernsMCDA* from other systems, discussed in Table 1, is the inclusion of several of the most popular MADM methods/models in a single framework. The architecture of the system allows flexible transition from one multi-criteria method to another one, and comparison of the results for subsequent decision making. Additionally, *DecernsMCDA* contains a range of original MCDA methods (ProMAA, FMAA, FMAVT) for uncertainty treatment and analysis, including uncertainty of criterion values and weight coefficients with the use of probabilistic and fuzzy sets methods. The tools included in *DecernsMCDA* provide the widest range of options to analyze multi-criteria/MADM problems in support of decision making.

The strength of *DecernsMCDA* is the wide range of MCDA analysis tools contained on a single software platform. The software can be used on desktop and web systems which facilitates its use for education and training. Increased training will lead to improved practical skills on structured/systems analysis of problems based on multiple criteria and multiple alternatives as well as to propagation of transparency and tolerance when substantiating and choosing decisions based on trade-off and co-ordination of different views. *DecernsMCDA* has been demonstrated for practical applications and will assist in meeting greater demands for improved decision analysis.

Acknowledgments We thank all our colleagues from DECERNS team for their participation in development of the described system. This study was supported in parts by the US Army Corps of Engineers. Permission was granted by the USACE to publish this material.

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