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D9.34 - Improved MCDA tool for decision making under uncertainty for panels

Lead Author: Tim Müller

With contributions from: Wolfgang Raskob

Review(s): CONFIDENCE Team at KIT and CONCERT coordination team

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Abstract

ST9.1.6 of CONFIDENCE aims to provide decision support in uncertain situations by use of multi criteria decision analysis (MCDA). The stakeholders have to define a set of potential alternatives and a set of criteria with according weights. Uncertainties of criteria have to be specified either as parametrized probability functions or as sample sets. The MCDA is then applied to this input values to supply decision support. The results will be communicated to the stakeholders by textual report and visualisation as e.g. charts or plots.

This report describes the current status of the MCDA tool with improvements on handling of uncertainties with ensemble information from simulation models or from the end users.

Content

Introduction and Goal

Decision makers often are confronted with a set of alternative measures, from which they have to choose the best one in respect to the given scenario. The Multi Criteria Decision Analysis (MCDA) is a decision support method that exactly can fulfil this task: it provides a ranking on a set of alternatives on the basis of values of contributing criteria that are important to the given scenario. The criteria can either be numerical or nominal as well as either measured or computed. In respect to these criteria the highest ranked alternative is the best one to choose.

MCDA is well established and straightforward in its application on exact and therefore fixed values. However in disaster management the circumstances for decision making are in general unknown respectively highly uncertain, especially in the beginning. The first subtask of work package 6 of the CONFIDENCE project aims to provide decision support by MCDA in uncertain situations in the beginning phase of a nuclear accident. This requires an adaptation of the MCDA methodology to process uncertain data and to communicate the consequential results. The existing MCDA tool of KIT is enhanced to provide such support for uncertainties in CONFIDENCE.

Overview on MCDA

In the following a brief overview on the methodology of MCDA is given to better understand the specific requirements for the CONFIDENCE project.

First of all MCDA requires a predefined set of alternatives $A_1, \cdots, A_n$ that will be ranked and rearranged according to a given scenario. Secondly the criteria $C_1, \cdots, C_m$ important to the scenario have to be defined in general and specifically in value for each criterion-alternative pair. In addition, to allow aggregation of the potentially widely varying criteria values, the values have to be normalized by criteria specific normalization functions $N_1, \cdots, N_m$. Finally to reflect the different importance of the criteria specific normalized weights $w_1, \cdots, w_m$ are required for each criterion. With this information the ranking value for each alternative is computed as weighted sum:

$$A_i = \sum_{k=1}^{n} w_k \cdot N_k(C_{k,i}) \quad \forall\, i \in n$$

where the criteria values $C_{k,i}$ are constants in general in determined scenarios, but can also be functions like e.g. probability functions.

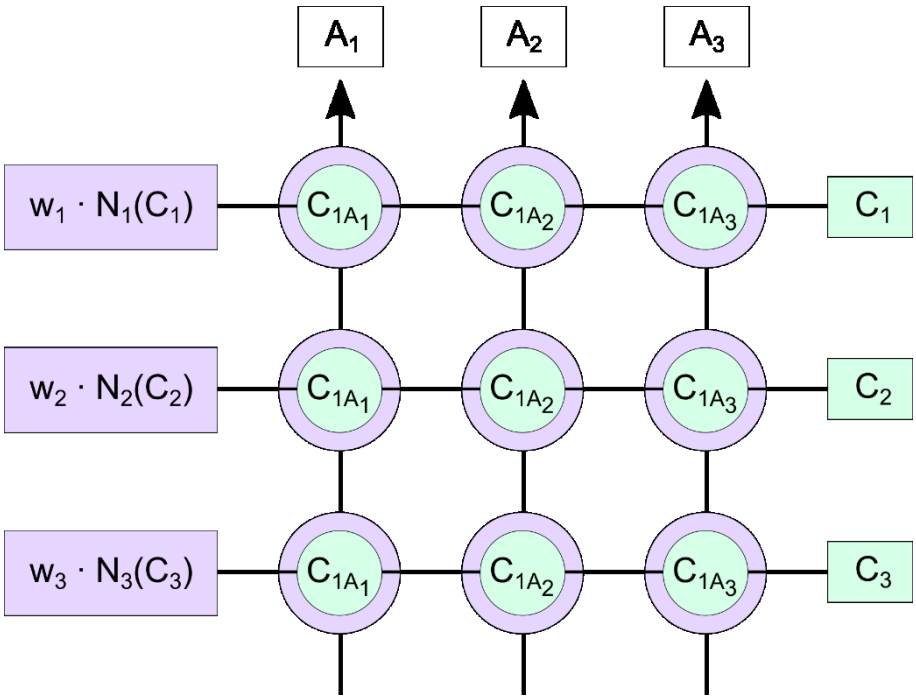

Figure 1. Each criterion C provides a value for each alternative A. The values are normalised (N), weighted (w) and summed to a ranking value for the according alternative.

In general two possibilities exist to introduce uncertainties in this equation: first the weights may contain variances if their source contains uncertainty. This can happen if e.g. some stakeholders have different opinions on the importance of criteria and therefore introduce variance into the weights. Secondly and more importantly the criteria values may not be distinct, but uncertain by measurement errors or incorrect assumptions. In both cases this results in a statistical distribution of the values, e.g. the constant values of the $C_{k,i}$ are replaced by probability functions $C_{k,i}\ (x)$.

It is difficult to derive functions for the alternatives A_i including the probabilities, especially since the normalization N_k depends on all the criteria functions for the given alternative. Therefore an acceptable workaround in this situation is to create a sample set, i.e. to repeatedly perform a single

MCDA on fixed criteria values by drawing a random sample from the probability functions, recalculating the normalisation functions, and collecting the results of the ranking. Consequently, the sample set of rankings will reflect probability distributed rankings with properties like means or variances. Assuming a sufficiently large sample count adequate accuracy is achieved.

Following this approach two tasks are immediately apparent: first the definition and manipulation of probability functions of criteria and second the communication respectively visualisation of the probability distributed rankings of the alternatives.

Uncertainties and MCDA in CONFIDENCE

Many different types of uncertainties are known like stochastic uncertainties, model uncertainties, or social uncertainties to name a few. They are have various impacts onto the chain of decision making. A general overview for uncertainties especially the ones relevant for CONFIDENCE is given in the internal document “The Various Meanings of Uncertainty” by French et. al. [French 2018].

For decision support by MCDA some of these uncertainties like e.g. weather or source term composition are pre-processed by tools like e.g. JRodos and result in ensemble sets. These ensemble sets will be further processed and used as one input part for decision making with the MCDA tool.

The other input part are the different preferences of the involved stakeholders. These preferences are identified and discussed during several CONFIDENCE workshops. The common goal of preference finding is the definition of some single weights for each criterion agreed by all stakeholders. However the MCDA allows uncertainty in weights by defining the preferences as sample sets per criterion, thus including the different opinions of stakeholders in the analysis.

The actual analysis of input values affected by uncertainty is performed by randomly sampling criteria values and weights from the two input parts and aggregating the results over many loops. As result each alternative is provided with several attributes like estimated mean rank, variance in rank, rank count, etc. These attributes are presented textual as report and graphical as graphs and plots.

This following sections provides details on how to use MCDA in the context of CONFIDENCE. During upcoming workshops the presented suggestions and solutions may be still refined or changed according to the recommendations of the stakeholders, yet their general nature in the context stays valid.

Origin of potential alternatives

MCDA requires a set of alternatives to provide decision support upon. For CONFIDENCE several sources for sets of alternatives are possible:

- Predefined and fixed alternatives given by the stakeholders that are stored and maintained in a database
- Automatic pre-selection of alternatives by software tools like the JRodos system according to the scenario and given context
- Alternatives derived in a consensus seeking session and further processing in a decision support system

In all cases the potential alternatives have to be defined by the stakeholders at some time, especially if e.g. additionally alternatives should be considered that are not part of pre-processing tools like JRodos.

Besides determination of the alternatives there are no further requirements as there is no interpretation of the “meaning” of an alternative. Loosely speaking in the context of MCDA an alternative definition serves just as a label for the ranking and a set of criteria values.

Determining and defining decision criteria

The most important part to perform MCDA for CONFIDENCE is the definition of appropriate criteria. Examples for such criteria are “affected area”, “affected people”, etc. Once identified, the criteria have to be specified in an appropriate way to be processed by MCDA. Uncertain criteria can be specified in two different ways:

- As a sample set of numerical or nominal values. Statistically representative criteria values for an alternative have to be collected either by measurement if possible or by empirical knowledge of the stakeholders. In general larger sets are more representative and therefore preferable.
- As a parametrized probability function. An expert for the criterion range of the alternative has to specify the function type (e.g. normal distribution) and the parameters (e.g. mean and standard deviation). While this approach is quite accurate it is in general almost impossible to specify the correct function and parameters.

Independently from the specification during the ensemble creation in every single turn a criterion value is randomly sampled from either the set or the probability function and processed by the MCDA algorithm.

The definition and specification of criteria will be discussed in workshops, assuming no documentation on appropriate criteria exists yet. The stakeholders have to discuss and conclude potential criteria and, in the end, the findings have to be summarized in a requirements document.

On a side node the default method for normalization of criteria values is generic and most likely does not require special treatment.

Including preferences: weighting of criteria

Additionally to the specification of the criteria their weight, i.e. their amount of contribution to the final ranking has to be defined. While for a start equal weights are possible, distinguished weights will improve the accuracy of the ranking as it reflects the preferences of stakeholders in respect of the criteria. Several methods to state the weight of a criterion are available: define absolute values between 0 and 1, or 1 to 10 respectively, apply nominal values like “low”, “medium”, “high”, or even use sophisticated methods like the Analytical Hierarchical Process (AHP) [AHP 2018] where criteria are evaluated pairwise. These statements can be computed into the required normalised weights.

Determining such weights is an interactive process of a group of stakeholders, where everyone in the group has to make concessions on their personal preferences and to agree on the consolidated weights. Hence, while it is possible to use a questionnaire to retrieve the weights, the most accurate way is to discuss the weights in a workshop after the criteria have been defined and to document the agreements.

MCDA Tool for CONFIDENCE

To address uncertainties by MCDA in CONFIDENCE the existing MCDA tool of IKET has been significantly improved in several ways. The structure of the tool was adapted to allow definition of functional respectively probabilistic criteria values as well as sample sets as input values. Accordingly the analysis flow was adapted to work with the changed input structure. Additionally visualisation methods have been developed to display probabilistic input and output values textual and as charts. Last but not least a new user interface is provided for controlling the evaluation of ensemble sets.

The MCDA tool is capable of batch processing input data in XML format. At this time an external tool is being implemented to pre-process input data from JRodos and to automatically perform an MCDA. The following sections describe the manual input of values and weights with uncertainty as well as interactive management and visualisations.

Input of criteria values and weights with uncertainty

Figure 2 shows a screenshot of the MCDA tool with the window “Values” in the lower left. Uncertain values are defined as probabilistic distributions, including sample sets. The table shows all criteria values to be probabilistic except for one constant value. Only one of the weights is defined as uncertain. Probabilistic values are indicated by the character P and bold font. The tooltip in the screenshot shows the criteria value of “Number of workers” for the alternative “Low waste” to be a normal distribution with mean of 700 and standard deviation of 100.

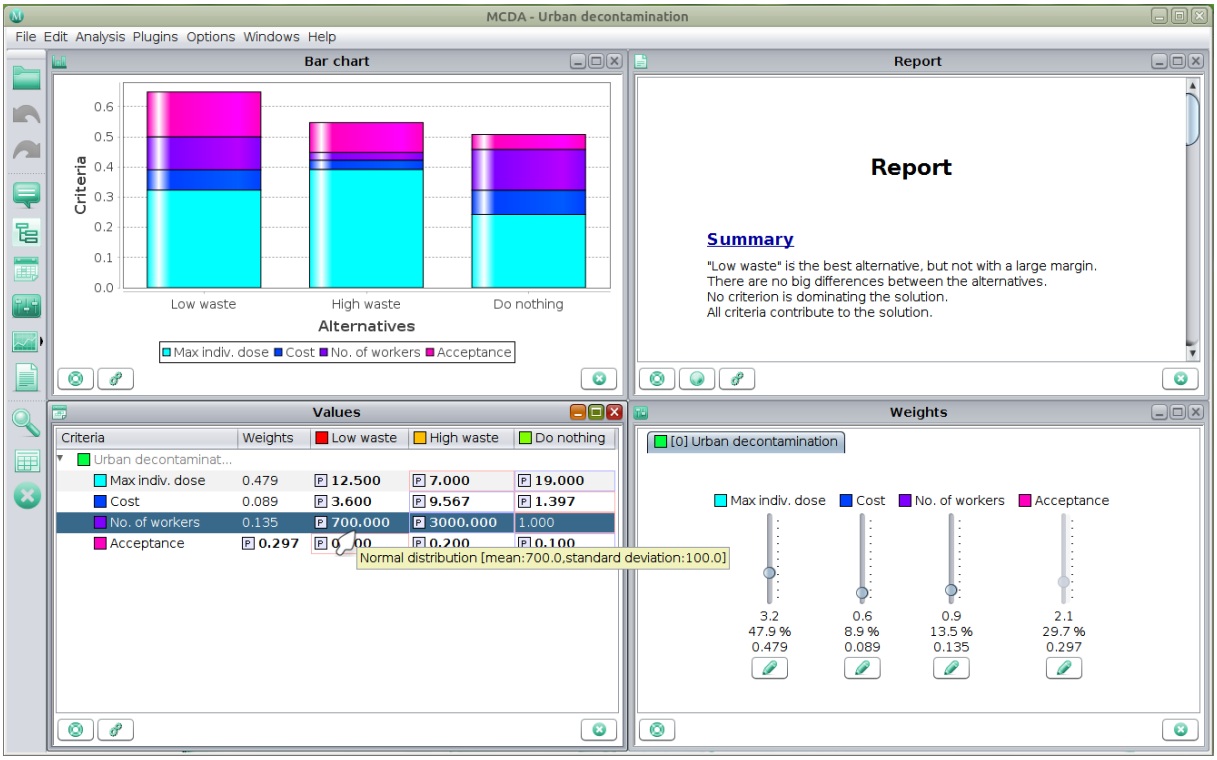

Figure 2. Screenshot of the MCDA tool. The window "Values" displays values and weights. Entries affected by uncertainty are marked in bold and the character P (probabilistic).

To allow changing these values the MCDA tool provides an explicit user interface for defining probabilistic functions. The interface is the same for values and weights. It is triggered in the window “Values” by context (right) mouse click on the according value. Figure 3 shows the according user interface defining a normal distribution.

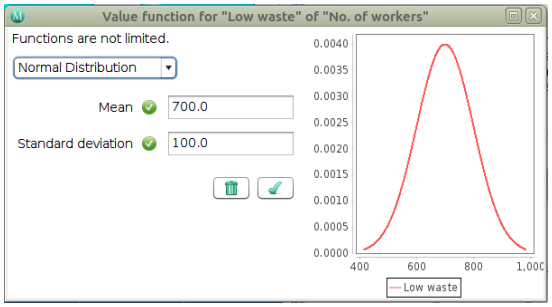

Figure 3. User interface to define uncertain criteria values or weights. Several distribution functions can be selected from the combo box. Each function requires individual parameters to be set.

In general the explicit probabilistic distributions of values and weights are unknown, however samples of a distribution are available most of the time. Figure 4 shows a discrete distribution selected where as a notional example 26 stakeholders have given their preference for the criterion “Acceptance”. The preferences are collected in buckets and outline the underlying unknown distribution.

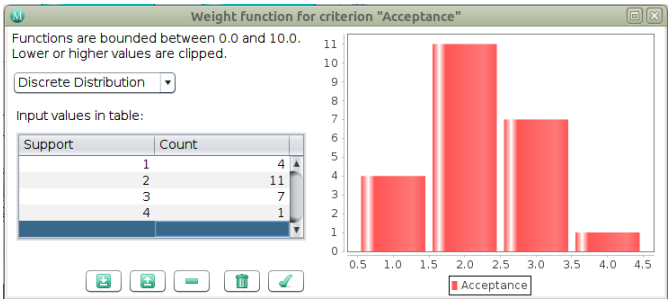

Figure 4. Example of a discrete distribution based on a sample set.

Managing ensembles

The default analysis of the MCDA tool is performed by using the means of the defined uncertainties for criteria values and weights. This already provides a ranking of and some insight in the performance of the alternatives. However even more helpful is the information on the standard deviation and stability of the results. This can be achieved by an ensemble evaluation.

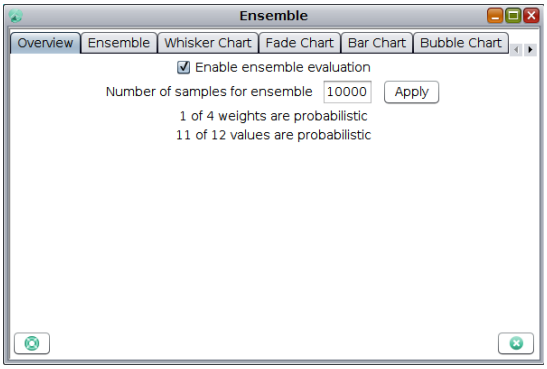

Figure 5. Ensemble control window.

Figure 5 shows the control window for ensemble evaluation. The first tab shown allows, besides summarizing some information, to enable respectively disable ensemble evaluation and to change the number of samples in the ensemble set. The enable switch is especially convenient as any change in weights or structure of the MCDA requires another ensemble evaluation cycle, which for large sets (100000+) starts to take several seconds. The other tabs present the results in different ways.

Many means are known to communicate numerical, uncertain results. The MCDA tool provides several preselected ones and uses them to present the outcome of the ensemble evaluation to the stakeholders. During the past workshops the stakeholders gave already feedback and suggestions to improve the MCDA tool, most of which were integrated so far. Nevertheless in future workshops the stakeholders may require additional visualisation methods if they think of them to be superior to the presented ones. The MCDA tool can then be adapted to their wishes as much as possible, depending on available resources.

The following sub sections present the visualisation methods for uncertainties that have been integrated so far.

Simple bar charts

Bar charts are a commonly used method to visually compare values of entities. Distinct values are reflected in different heights of bars. For the ensemble evaluation the bar height represents the mean value of an alternative ranking value. The upper and lower lines indicate the standard deviation of the ranking value.

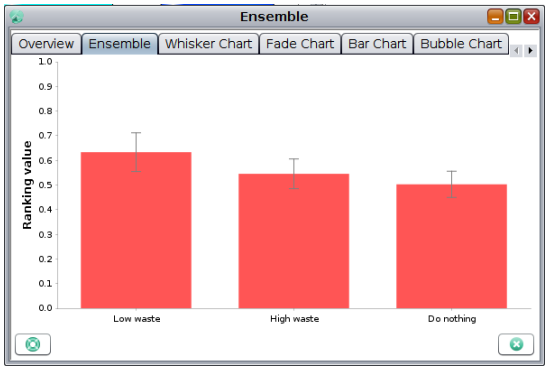

Figure 6. Simple bar chart indicating mean and variance of rank values of alternatives.

Box and whiskers charts

To visualize probability distributions of values a box and whiskers diagram is often used. In contrast to the bar chart, the bars are not show. The box indicates the q1 and q3 quantiles. The whiskers indicate the minimum and maximum values. Sometimes mean, median and outliers are also displayed e.g. as lines respectively dots or stars.

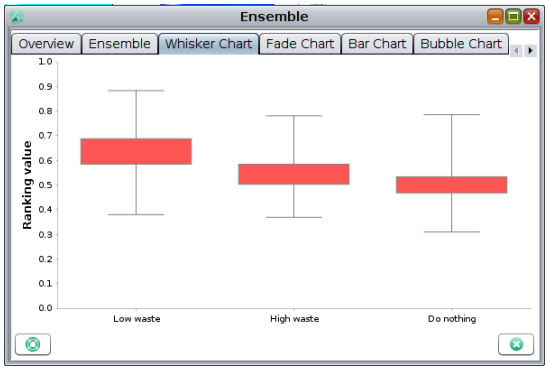

Figure 7. Box-and-whiskers-diagrams are well established for visualisation of uncertainties. The box and lines of a bar indicate quantiles (variances), minimum, and maximum of an uncertainty range.

Gradient color bars

While box and whiskers diagrams contain all necessary information, they are probably not easily understood. Recently more intuitive visualisation methods were suggested, e.g. where a fixed amount

of “water colour” is spread over a given area reflecting the value of an entity the colour intensity. Varying intensity and fading gradients can support the intuitive comprehension of the uncertainty. Figure 8 shows the same facts as Figure 7 but in gradient colouring.

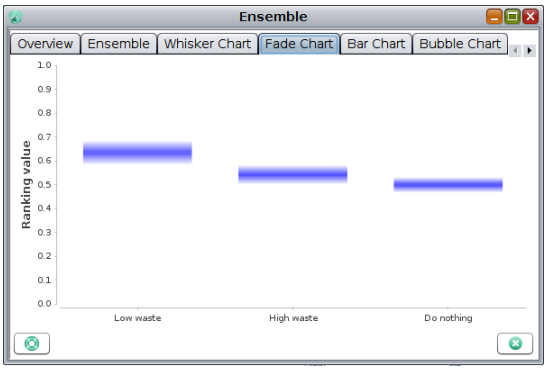

Figure 8. The uncertainty of a value displayed as a fixed amount of water colour spread over the corresponding area. More certain values therefore appear darker.

Ranking bar chart

Using bar charts or box and whiskers to visualize the standard deviation is a straightforward approach. Nevertheless it implies a fact which is not actually true: that the rankings are not correlated. Changing a criterion value influences all other criteria values due to normalisation and as a result the rankings are correlated.

Of real interest in this context are not the absolute ranking values but how often a specific alternative is better than the others. Therefore counting wins, or even better, counting placements of alternatives provides much better insights. These values can be visualised as ranking bar chart. Figure 9 shows the comparative ranking of alternatives for an ensemble set with 100000 samples.

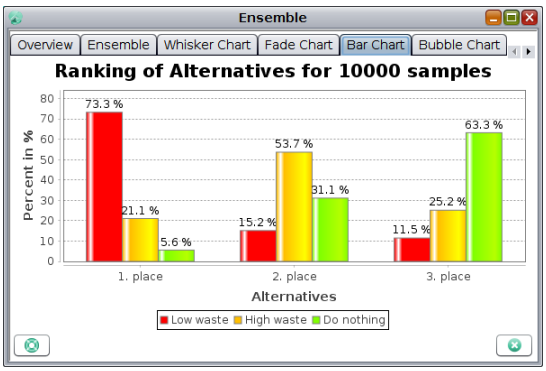

Figure 9. Ranking bar chart. The alternative “Low waste” ranked first place in 73.3 percent of all analyses, second place 15.2 percent of all analyses, and third place 11.5 percent of all analyses. Apparently selecting the alternative “Low waste” is the best choice as it ranks first place most of the time.

Ranking bubble chart

The same fact can be displayed as bubbles instead of bars as displayed in Figure 10. The ranking percent is represent by the size of the bubbles.

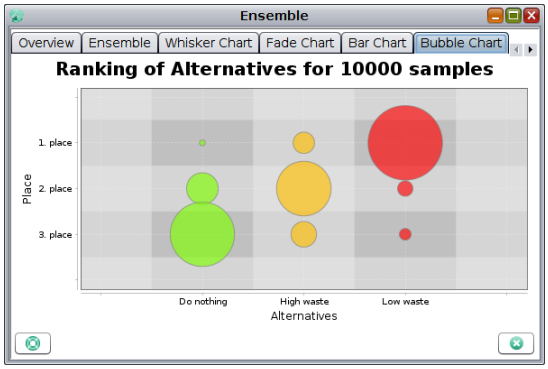

Figure 10. Displaying ranking percentage as bubbles. The best choice is located at the top right.

Other viable visualisation methods may be histograms, scatterplots, etc. They can be integrated if the stakeholder identify the need for them during the remaining workshops of CONFIDENCE.

Verbalized reports

The MCDA tool is able to verbalise the numerical results in human readable text. So far the results of the ensemble evaluation are textual presented as shown in Figure 11.

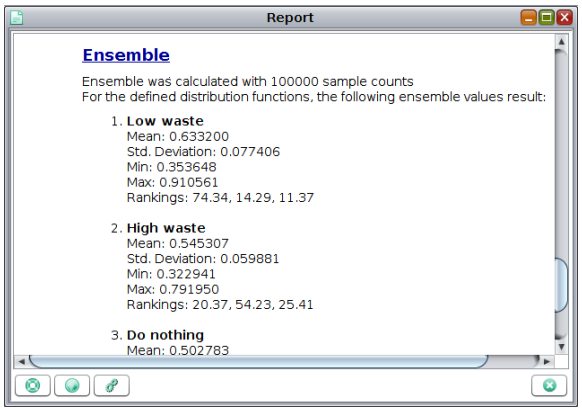

Figure 11. Textual report of an ensemble evaluation.

In general it is possible to provide a textual interpretation of the ensemble evaluation, yet the implementation will require exact definitions in corporation with the stakeholders and is probably too time consuming. As an example using the bubble chart above, an adequate phrase could be: “The alternative “Low waste” is suggested as it is a stable choice and ranks best most of the time”. The stakeholders have to decide if verbalised reports should be investigated and in that case have to provide specifications for acceptable wording, e.g. in the mentioned example under which conditions to use the terms “stable”, “most of the time”, etc.

Evaluation

A basic evaluation of the enhanced MCDA tool has been provided by the workshop in Dublin as the tool was presented there. The CONFIDENCE community commented on the functionality and suggested improvements. The suggestions included an automated connection to JRodos, which is probably addressed during the enhancement of JRodos in CONFIDENCE, and usability improvements like colour management for colour blind and black-white printers, which is already implemented in the current version.

The functionality itself and the visualisation of results was very well received. The MCDA tool in its current state can therefore be used in the upcoming workshops to determine stakeholder preferences

and actual decision criteria. If during this workshops the stakeholders identify additional requirements the tool will be further improved according to the resources available.

Availability of the MCDA package

The MCDA tool is available from the following web address: https://portal.iket.kit.edu/projects/MCDA/MCDA.html

The package contains tutorials and documentation. The tools was developed as open access and can be used by the whole research community.

Literature

[AHP 2018] "Analytic hierarchy process"; Wikipedia; https://en.wikipedia.org/wiki/Analytic_hierarchy_process

[French 2018] "The Various Meanings of Uncertainty"; S. French, S. Haywood, D. Oughton, J.Q. Smith, C. Turcanu; CONFIDENCE Internal Report; 2018