A web-based decision support system based on MAUT to deal with partial information: Selection of sport ontologies for reuse

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***Abstract*— WEB-MAUT-DSS is a web-based decision support system based on the Decision Analysis methodology. It is designed to operate in decision making contexts characterized by partial or incomplete information, accommodating uncertainty in alternative performances through probability distributions or ordinal information, as well as imprecision in the assessment of decision makers' preferences for both component utilities and attribute weights. The system supports hierarchical weight elicitation, enabling the use of different weighting methods at various levels and branches of the objective hierarchy. An additive multi attribute utility model can be directly applied to obtain overall utilities for the different alternatives. Alternatively, Monte Carlo simulation techniques are incorporated when non uniform probability distributions or ordinal information are used to describe alternative performances. Additionally, WEB-MAUT-DSS incorporates a range of sensitivity analysis tools to provide deeper insights into the robustness of the resulting evaluations. The selection of candidate sport ontologies for reuse is used to illustrate the system.**

I. INTRODUCTION

In this paper, we introduce WEB-MAUT-DSS, an improved web-based version of the *generic multi-attribute analysis* (GMAA) system ([10], [11]). It is a decision support system based on the Decision Analysis (DA) methodology ([2], [4], [14]) with an additive multi-attribute utility model to address complex decision-making problems with partial/incomplete information ([20], [7]).

WEB-MAUT-DSS explicitly addresses uncertainty in the performance or impact of the alternatives under evaluation by employing probability distributions or ordinal representations. At the same time, it accommodates imprecision in the elicitation of decision makers' (DMs) preferences, both with respect to component utility functions and attribute weights.

To assess component utilities, the system offers a direct assignment approach together with a combined application of two gamble-based elicitation methods. These procedures allow the DM to express imprecise judgments during the elicitation process, resulting in sets of admissible utility functions rather than single, fully specified ones, while also incorporating multiple consistency verification mechanisms.

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Weights are hierarchically elicited using different weighting methods. A direct assignment and a method based on trade-offs [13], were originally provided in the former GMAA system, allowing the DM to provide imprecise information. WEB-MAUT-DSS additionally incorporates weighting methods based on ordinal information. To do this, a review of weighting methods based on ordinal information and comparative analyses on their performance in the literature was performed [3].

As a result, the *sum reciprocal* (SR) method is now available in WEB-MAUT-DSS, a surrogate weighting method in which only ordinal information on weights is provided by the DM [6]. Moreover, weighting methods accounting for additional information on the strength of the differences between the ranked criteria in different forms have also been incorporated into the system. Specifically,

- the *cardinal and rank ordering of criteria* (CROC) method [15], a two-stage distance-based method that considers cardinal information about the strength of the differences,
- the method proposed in [1], which accounts for a ranking of differences and computes the centroid of a polytope (CP) delimited by constraints representing the available information on weights,
- and the *cardinal sum reciprocal* (CSR) method [5], an extension of the SR method that uses a semantic scale.

Consequently, different weighting methods may be applied across the various levels and branches of the objective hierarchy, depending on the type of information that the DMs are asked to provide and are willing or able to provide. This flexibility makes the system suitable for group decision-making, particularly within multidisciplinary contexts in which individual DMs are experts or specialists in distinct fields (e.g., social, environmental, economic impacts). In such cases, each DM would contribute to the weight elicitation process only for the criteria related to their area of expertise, rather than for the entire set of criteria [8].

An additive multi-attribute utility model is adopted to assess the set of alternatives under consideration. This modelling approach is widely regarded as appropriate for most practical decision-making contexts, for the reasons discussed in [19] and [22].

WEB-MAUT-DSS offers a range of sensitivity analysis tools that exploit the presence of imprecise information to enhance understanding of the robustness of the evaluation outcomes. These tools include the identification of non-dominated and potentially optimal alternatives, the estimation of weight stability intervals, and the application of

Monte Carlo simulation techniques to attribute weights.

The paper is structured as follows. In Section 2, we show the appearance of WEB-MAUT-DSS and describe the elements displayed in the different areas. In Sections 3 to 7 we consider the different stages in the DA methodology to illustrate how they have been implemented in WEB-MAUT-DSS applied to the selection of candidate sport ontologies for reuse in an ontology development. Finally, some conclusions are provided in Section 8.

II. WEB-MAUT-DSS APPEARANCE

WEB-MAUT-DSS was developed using Shiny, a package that enables the creation of interactive web applications directly from R. The system is freely accessible at `https://vps155.cesvima.upm.es/web-maut-dss/` and operates seamlessly across different browsers and operating systems. The system includes a user guide and three illustrative real-world decision-making problems (see the bottom right of Fig. 1), one of which concerns the selection of the best knowledge resources for reuse in ontology development, the case addressed in this paper.

WEB-MAUT-DSS is structured in a main menu (at the top) and five main areas in two rows, see Fig. 1. In the first area at the top left, the objective hierarchy associated to the decision-making problem under consideration is displayed.

In the area on the top right, denoted as *Project information* area, different folders are available that provide information about the project: attributes, component utilities, local and attribute weights, alternatives and their performances, the alternative ranking, and sensitivity anlaysis tools.

All the information displayed in the different folders in the *Node information* area (on the bottom left) will be associated to the objective which is active/selected in the hierarchy (the DM has left-clicked on it). Information about user actions, as well as warning and error messages, will be displayed in the *Message* area (at the bottom center).

Finally, the *Working* area displays various contents associated with component utility assessments, weight elicitation methods, information on alternative evaluation, and sensitivity analysis tools.

III. PROBLEM DEFINITION AND STRUCTURING

Ontologies can be understood as formally defined sets of concepts and relationships that describe a particular domain and are collectively adopted by a user community. To date, a large number of ontologies have been created by different research groups, following diverse perspectives and development strategies, and employing a variety of methodologies, such as the NeOn methodology [23], along with other methods and techniques. Moreover, numerous studies have proposed sets of criteria intended to support the evaluation, comparison, and selection of ontologies. In this context, a well-structured and manageable set of criteria, together with their corresponding measurement attributes and covering multiple evaluation dimensions, is required to effectively support ontology developers in identifying the most suitable ontologies for reuse in new ontology development processes.

In this study, the NeOn Methodology is adopted to support the selection of the most appropriate knowledge resources for reuse during ontology development. According to this methodology, the reuse process is structured around four main activities. The first activity, *domain ontology search*, involves exploring libraries, repositories, and registries in order to identify candidate domain ontologies that may fulfill the requirements of the ontology network under construction. The second activity, *domain ontology assessment*, focuses on determining whether the identified candidate ontologies are suitable for supporting the development of the ontology network. The third activity, *domain ontology selection*, aims at identifying the domain ontologies that best meet the development needs. Finally, *domain ontology integration* consists of incorporating the ontologies selected in the previous activity into the ontology being developed. Further details regarding these activities are provided in [23], [12].

WEB-MAUT-DSS allows the DM to build an objective hierarchy, starting from an overall objective and decomposing it into intermediate and lowest level objectives. These objectives can be flexibly added and removed through interactive menus.

A total of eleven criteria, structured around four main objectives, are defined to support the selection of the most appropriate knowledge resources for reuse, as illustrated in Fig. 1. The objective referred to as *understandability effort* (Understand) reflects an estimation of the workload required to comprehend a candidate ontology. This objective is further decomposed into two subcriteria: availability and *quality of documentation* (A/Q Document), which evaluates the existence of communicable materials describing both the ontology and its development process, and *code clarity* (Code Clar.), which assesses the extent to which the ontology code is easy to read, understand, and modify.

Code clarity is further decomposed into three distinct subcriteria. The first, *naming understandability* (Nam. Underst), evaluates the degree to which the names of ontology elements are clear and meaningful. The second, *code documentation* (Code Documen), examines whether the ontology source code is accompanied by adequate explanatory documentation. The third, *pattern conformance* (Patterns), assesses the extent to which the ontology has been developed following established ontology design patterns (ODPs).

Integration effort (Integration) represents an estimation of the amount of work required to incorporate a candidate ontology into the ontology under development. This dimension takes into account several aspects, including the *adequacy of knowledge extraction*, which reflects how easily reusable components can be identified within the candidate ontology; the *adequacy of naming conventions*, which assesses whether both ontologies adhere to compatible rules for naming ontology elements; and the *adequacy of the implementation language*, which evaluates whether the languages used are identical or, at minimum, capable of expressing comparable knowledge at the same level of granularity.

Finally, *reliability* concerns the extent to which ontology developers can place confidence in a candidate ontology for

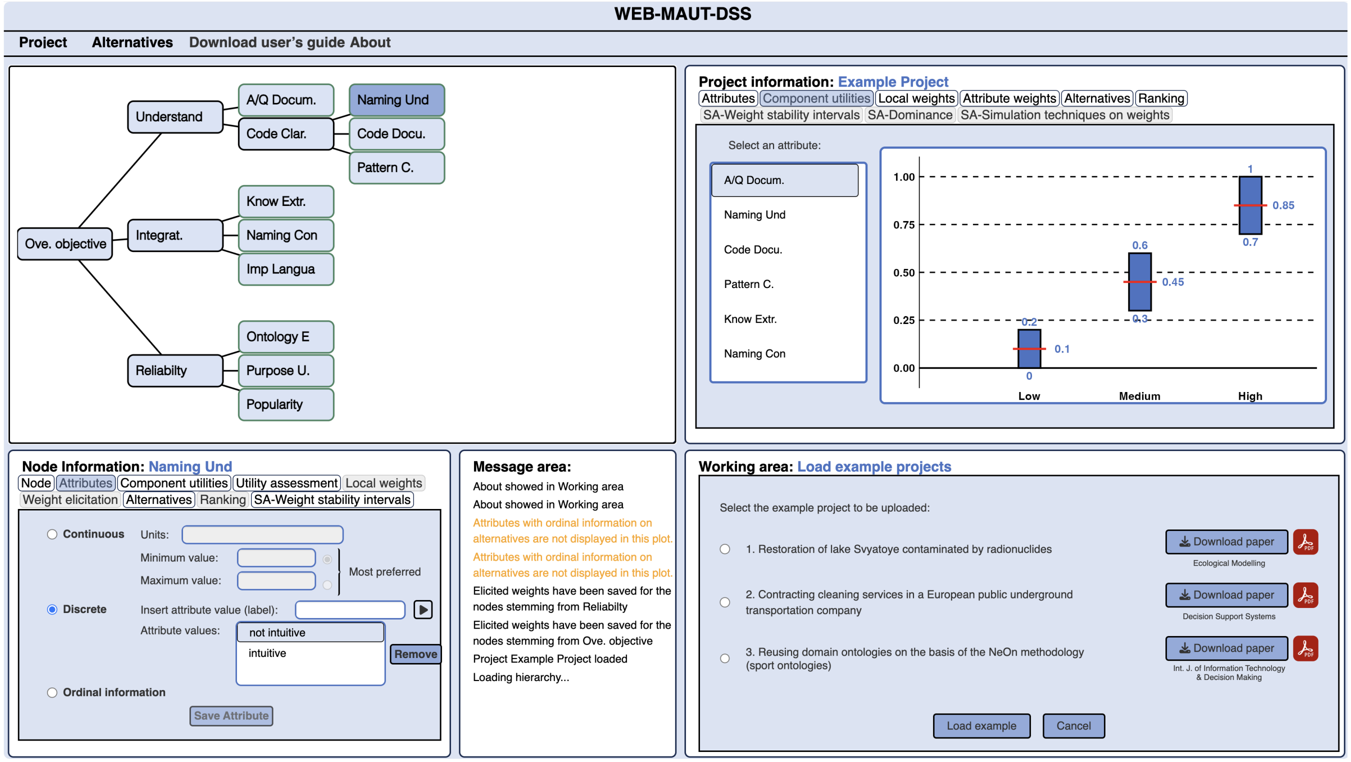

Fig. 1. WEB-MAUT-DSS appearance

reuse. This dimension is assessed through several factors, including *ontology evaluation*, which examines whether the ontology has undergone an adequate validation process; intended use, since the *planned application* of the ontology may influence perceptions of its trustworthiness; and *popularity*, which reflects the degree to which the ontology has been adopted in existing projects, applications, or other ontologies.

For each lowest level objective, the DM must specify an attribute that quantitatively or qualitatively represents the extent to which that objective is met. Attributes may be continuous, discrete, or ordinal (see the bottom left of Fig. 1). Continuous attributes require the specification of units, ranges, and preferred endpoints; discrete attributes require listing possible values; and ordinal attributes will later require ranking alternatives according to their performance.

Discrete attributes were established in all lowest-level objectives but in *code documentation* in which continuous attributes with range $[0, 100]$, representing the percentage of commented elements; *ontology evaluation*, with range $[0, 21]$, representing the number of pitfalls present in the candidate ontology; and *ontology evaluation* in which ordinal information was considered.

Additional information on these criteria and their attributes is provided in [12]. The associated project to be uploaded to WEB-MAUT-DSS is available at `https://doi.org/10.5281/zenodo.20067514`.

IV. ALTERNATIVES AND PERFORMANCE MANAGEMENT

Sports multimedia content can be described semantically using sport ontologies. Nine candidate sport ontologies have been considered for reuse during the development of a sports ontology:

- *Athlete* models the athletics domain, including concepts like athletes and several Olympic sports competitions.
- *Baseball* describes baseball teams, players, games and pitches, catches, etc.
- *OnteSem* (OSO) models differ Olympic sports, divided into summer and winter sports. The ontology also lists medal winners.
- *OntoSem* describes different sports, such as soccer, basketball, and volleyball.
- *Rissen* ontology describes the world of football.
- *Soccer* describes the basic concepts of soccer. The ontology defines actions during a match, types of players or types of pass and so on.
- *Soccer Tsinakari* models agents, objects, events, places, time points and periods involved in soccer games.
- *SoccerV2* describes most of concepts that are specific to soccer: players, rules, field, supporters, etc. It is used to annotate videos in order to produce personalized summaries of soccer matches.
- UNSPSC (United Nations Standard Products and Services Code) includes an equipment-based taxonomy of sports.

WEB-MAUT-DSS supports the management of decision alternatives and their performances. Alternatives can be created, modified, or removed manually (see Fig. 2), or they may be uploaded from an Excel file. Different probability distributions can be used to represent alternative performances for attributes with a continuous scale, whereas in the case of ordinal information, the relative position of each alternative with respect to the others must be provided.

Fig. 2 shows the sports ontology performances for the 10 criteria considered in WEB-MAUT-DSS.

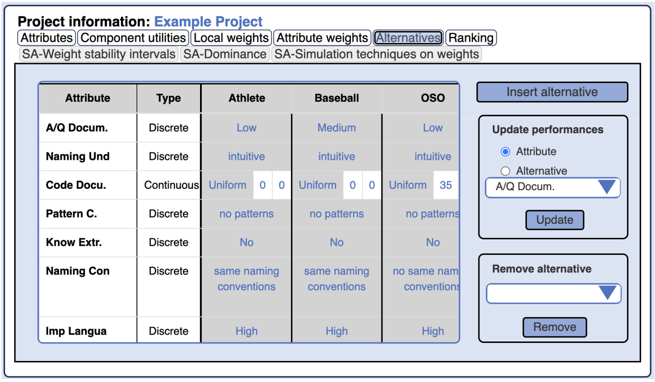

Fig. 2. Candidate ontologies and their performances

V. QUANTIFYING THE DMS' PREFERENCES

A. Component Utility Assessment

WEB-MAUT-DSS accounts for discrete and continuous attributes in the component utility assessment (see the top right of Fig. 1). In the case of a discrete attribute, imprecise component utilities can be entered by means of intervals for each possible attribute value. If the attribute under consideration is continuous, then two assessment methods can be used to build up a component utility function, a direct assessment and a lottery-based method.

The direct assessment approach is applied when the DM possesses substantial expertise regarding a given attribute and has a clear understanding of the form of its component utility function. In this procedure, the DM is requested to specify up to five points within the attribute's value range together with their associated utility levels. Based on this information, a piecewise linear utility function is subsequently constructed. It should be noted that the method also allows the introduction of imprecise utility values, which results in a set of admissible utility functions rather than a single, exact function. Fig. 3 illustrates the piecewise linear utility function associated with *code documentation* in the context of selecting candidate sport ontologies for reuse.

The lottery-based approach is adopted in situations where the DM has limited familiarity or expertise with the subject under evaluation. This method integrates two slightly adapted utility elicitation techniques: the fractile procedure, which is based on certainty equivalence, and the extreme gambles approach, which relies on probability equivalence. WEB-MAUT-DSS detects possible inconsistencies arising from both the CE and PE elicitation processes and proposes

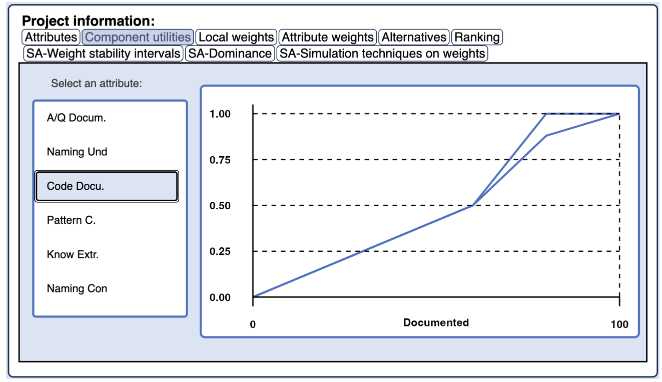

Fig. 3. Component utility function for *code documentation*

corrections to the values supplied by the DM. Furthermore, the system verifies that the intersection of the utility function sets obtained from the two methods is non-empty across the entire domain.

The component utilities used in the selection of candidate sport ontologies for reuse are available in the example project in WEB-MAUT-DSS, including ordinal information (ranking from the candidate ontology with the best performance to the one with the worst) in *ontology evaluation* attribute.

B. Weight elicitation

Weights are elicited in a hierarchical manner through the application of multiple weighting techniques [8]. Both the direct assignment approach and trade-off-based methods [13] enable the DM to express imprecise judgments when determining local weights throughout the objective hierarchy. In addition, WEB-MAUT-DSS includes weighting procedures that rely on ordinal information. Under the *sum reciprocal* (SR) method, the DM is required to provide only the relative ordering of the weights [6]. In contrast, the *cardinal and rank ordering of criteria* (CROC) method demands supplementary cardinal input concerning the intensity of the differences among the ranked criteria. These differences may be expressed either through explicit rankings of their magnitudes [1] or by using qualitative terms drawn from a semantic scale [5].

Fig. 4 shows how the semantic scale has been used to elicit weight for the three main objectives in the selection of candidate sport ontologies for reuse.

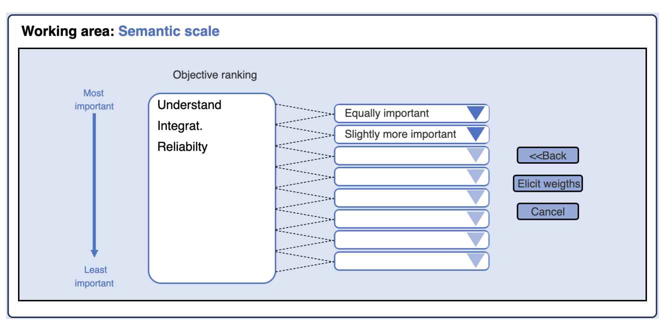

Fig. 4. Using a semantic scale to represent the strength of the differences

A direct assignment was used to elicit the weighs of the objectives stemming form *understandability effort Integration effort* and *code clarity*, see Table I, whereas ordinal information with the semantic scale was considered for *reliability* (*ontology evaluation* is slightly more important than *purpose of use*, which is more important than *popularity*).

TABLE I
INFORMATION PROVIDED BY DMS IN THE DIRECT ASSIGNMENT

Objectives	Weights of objective stemming from them
understand. effort	*documentation availability and quality* [0.4,0.5] *code clarity* [0.5,0.6]
integration effort	*adequacy of knowledge extraction* [0.35,0.45] *adequacy of naming conventions* [0.15,0.25] *adequacy of the implem. language* [0.35,0.45]
code clarity	*naming understandability* [0.3,0.4] *code documentation* [0.3,0.4] *pattern conformance* [0.25,0.35]

The overall attribute weights for the decision problem are subsequently derived by multiplying the local weights along the path from each lowest-level objective up to the global objective, as illustrated in Fig. 5. It should be noted that the resulting average weights are normalized to sum to one, both in Table I and in Fig.5.

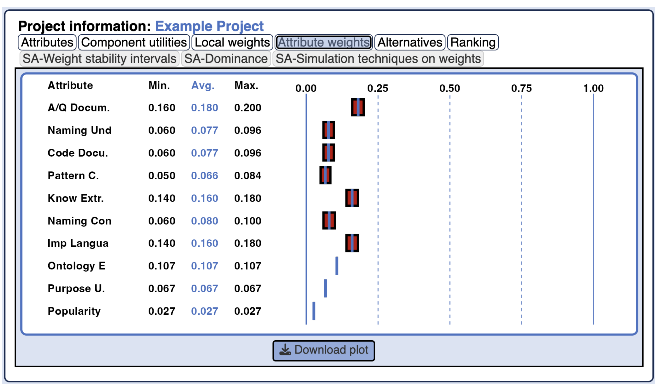

Fig. 5. Attribute weights over the decision

VI. EVALUATION OF ALTERNATIVES

An additive multi attribute utility function ([19], [22]) is used to evaluate the alternatives, but its implementation depends on how uncertainty in the alternatives' performances is represented. When intervals are provided, the model computes the minimum, average, and maximum overall utility for each alternative. The ranking is based on the average utilities, while the minimum and maximum values offer insights into the robustness of the resulting order.

If, instead, non uniform probability distributions or ordinal information are used to describe alternative performances, WEB-MAUT-DSS employs Monte Carlo simulation. In this process, not only the performances but also the component utilities and weights are randomly generated according to their respective probability distributions, ordinal statements, or intervals. The system then produces a multiple boxplot displaying the distribution of ranking positions for each alternative across all simulation runs, see Fig. 6.

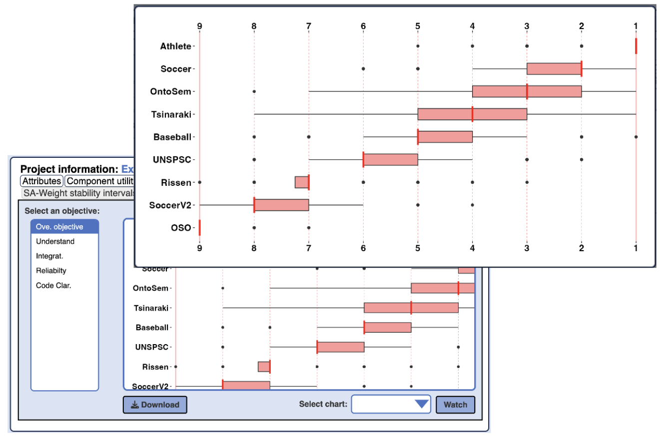

Fig. 6. Evaluation of alternatives: simulation process

Additionally, the system provides several graphical tools to support a more detailed interpretation of the evaluation results, such as stack bar charts, comparative bar charts (Fig. 7), radar charts, and comparative radar charts.

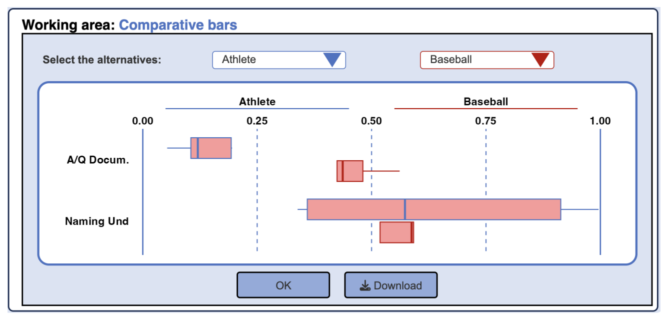

Fig. 7. Comparative multiple box-plots

VII. SENSITIVITY ANALYSIS

Sensitivity analysis (SA) serves as a cognitive support mechanism that encourages the DM to explore the problem more thoroughly and provides additional evidence regarding the robustness of the obtained outcomes. Such analyses cannot be carried out when alternatives are assessed solely through Monte Carlo simulation approaches, as is the case in the evaluation of candidate sport ontologies for reuse.

WEB-MAUT-DSS integrates a variety of SA functionalities, including conventional SA methods, the estimation of weight stability ranges, the identification of non-dominated and potentially optimal alternatives, and the application of Monte Carlo simulation techniques to attribute weights.

For any selected objective, WEB-MAUT-DSS determines the associated *weight stability interval* [17], defined as the range within which the mean value of a weight may vary without modifying the overall ordering of the alternatives.

WEB-MAUT-DSS exploits the presence of imprecise information in both the evaluation of component utilities and weights, as well as the uncertainty associated with alternative performance values, in order to conclusively eliminate inadequate alternatives [18]. The identification of *non-dominated* and *potentially optimal alternatives* requires the solution of several non-linear optimization problems [16].

When *Monte Carlo simulation* is applied to attribute weights, the weights are randomly generated, enabling the statistical examination of a large number of weight combinations and thereby offering deeper insight into the model's recommendations. In this context, multiple statistical indicators related to the ranking positions of each alternative are calculated, and the results are visualized through combined box and violin plots for all alternatives.

Three distinct weighting schemes are considered. First, attribute weights can be produced entirely at random. Second, the rank-order weighting approach incorporates partial or complete ordinal information provided by the DM, with weights generated in accordance with the specified ranking. Third, the response distribution weighting scheme derives attribute weights by randomly sampling from weight intervals obtained through previously applied weighting methods.

VIII. CONCLUSIONS

WEB-MAUT-DSS improves upon the GMAA system in several ways. First, it is a portable, web-based decision support system that works across different browsers and operating systems, whereas GMAA required local installation and was only available for Windows and required setting specific font sizes and screen configurations for proper use.

WEB-MAUT-DSS is more user-friendly, structured into five main areas: information on the objective hierarchy, the active/selected node, the entire project, a working area, and a message area. This structure allows for different types of information to be displayed simultaneously.

The *Message* area facilitates interaction with the DM by reporting the actions performed, as well as displaying warning or error messages related to the information entered by the DM.

From a functional perspective, the main advantage of WEB-MAUT-DSS lies in its handling of uncertainty regarding alternative performances and the weight elicitation process. It offers different probability distributions to represent uncertainty about the alternative performances, in addition to the uniform distribution (intervals). Moreover, it allows the provision of ordinal information.

Additionally, four weighting methods have been incorporated, based on ordinal information and possible supplementary details about the strength of the differences between the ranked criteria. This enhances the weight elicitation process, making it more comfortable for the DM. As a result, different weighting methods can be applied at various levels and branches of the objective hierarchy, depending on the information the DMs are willing or able to provide

Finally, Monte Carlo simulation has been incorporated to evaluate the alternatives when probability distributions other than the uniform distribution, or ordinal information, are used to represent their performances.

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