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EXPLANATIONS FOR A DECISION SUPPORT SYSTEM BASED ON MCDA

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Abstract. In a military context, the process of planning operations involves the assessment of the situation, the generation of Courses of Action (COAs), and their evaluation according to significant points of view, in order to select the COA that represents the best possible compromise. To support this process, an advisor tool has been developed to assist a military Operation Centre staff in managing events and their related COAs, as well as prioritizing these COAs according to different evaluation criteria by means of a Multicriterion Decision Aid procedure. This paper describes an automated approach for explaining the ranking proposed by this decision support system.

Keywords: Explanation, justification, multicriterion decision aid, decision support system, planning process, courses of actions

1 INTRODUCTION

The Canadian Forces Operational Planning Process is a systematic approach for analyzing a situation, bringing staff expertise to bear on the relevant factors, narrowing Courses of Action (COAs), obtaining the commander's approval and developing the detailed annexes necessary to produce an executable plan [7]. Adapted to the needs of the operations, it can be used with different time constraints for different levels of planning: strategic, as well as operational and tactical ones.

This process, which is used to prepare plans and orders for operations [5], is comprised of five main stages with specific outputs [7]. The first stage is the Initiation and results in the activation of the planning staff and the commander's guidelines about the kind of planning process to achieve. The second stage is the Orientation and results in the development of the commander's planning guidance. At this stage, the commander orients his/her staff towards the determination of the nature of the problem and the confirmation of the results to be achieved. The third stage is the COA development and results in the production of the concept of operations that identifies the commander's line of action in order to accomplish his/her mission. It presents the COA that will be implemented. The fourth stage is the Plan Development and results in a set of orders based on the commander's decision to provide subordinate and supporting units with all of the necessary information to initiate the planning or the execution of operations. The last stage (the fifth one) is the Plan Review and results in a regular review of the plan to evaluate its viability. The review period of the plan depends on the evolution of the situation, the type of operation and the environment.

Since military operations are evolving into a dynamic, complex and uncertain environment, the planning process is often performed under high time pressure and stressful conditions. Under the influence of these factors, the human capacity of reasoning and judgment can be significantly reduced. To counteract this effect, Defence Research and Development Canada – Valcartier (DRDC Valcartier) is developing approaches to provide decision supports for the different stages of the planning process, and particularly the COA development stage. One important step of this stage is the global comparison of the COAs. It is usually made by considering and balancing several conflicting and incommensurable criteria. Due to the multidimensional nature of this decision-making context, a decision aid approach based on MultiCriterion Decision Aid (MCDA) methodology has been identified as appropriate. Based on this approach, a decision aid module for the selection of COAs was developed to assist a commander in prioritizing COAs. This module takes as inputs the COAs that have been developed by the staff, as well as the evaluation of each COA for the set of criteria that has been identified by the decision makers and proposes a ranking of these COAs as output. This module is part of a prototype that allows the staff to describe and share information about an operation to be planned, develop pertinent COAs, evaluate these COAs and send these results to the commander who has to determine which one of these COAs is the most appropriate.

It rapidly appeared that the users of this decision aid module would need to have access to the explanations of the proposed ranking. Even if this module visualized some intermediate results, it was considered not sufficient since most of them did not have any knowledge in MCDA. Accordingly, an investigation was initiated to provide this module with explanation facilities.

This paper describes the automated generation of explanations that we proposed for decision support systems on the basis of a MultiCriterion Aggregation Procedure (MCAP). This work describes the information that can be provided to explain the ranking proposed by the decision aid module. It does not provide explanations related to the evaluation of a COA according to some specific criteria, nor explanations that could be provided to help in using the tool.

2 MCDA PROCESS

The MCDA approach is a paradigm which is more flexible than traditional methods [10]. In contrast with traditional operational research, where we often deal with an objective function to be optimized over a set of feasible solutions, the MCDA philosophy is based on the idea of finding a solution which is “satisfactory” to the decision maker, while taking into account conflicting and non-commensurable aspects. It is particularly well adapted to ill-defined decision situations and emphasizes a decision-aiding perspective rather than decision-making.

An MCDA process is composed of several steps. The first one is structuration. It aims at identifying and formalizing the basic elements of a decision-making situation under the shape of the model (Alternatives, Attributes/Criteria, Evaluations), also represented by $(A, \Lambda/C, E)$.

In our military context, the alternatives are the COAs. A COA is defined by a set of items describing the actions that a type of resource will perform. For each action to be performed, the type and the number of resources required need to be identified, as well as their origins, destinations, times of departure and of arrival, and a complete description of the action to be performed at the destination. The identification of the criteria to consider in the selection of the COA is part of the COA development stage. For example, the analysis of an Air Operation Centre staff in dealing with events of drug smugglers violating the Canadian airspace in a peacetime context led to the identification of five factors to be considered while evaluating COAs. The first aspect is related to the ability of a COA to adapt to various possible changes that may occur while implementing a COA (*flexibility* factor). The second one is the complexity related to the COA implementation (*complexity* factor). The third one is concerned with the ability to continue (stay in) the operation (*sustainability* factor). The two other factors are the optimality of the resources employment (*optimum use of resources* factor), and the risks of mission failure as well as those associated with the mission (*risk* factor). From these factors, an MCDA analyst identified 14 criteria that represent the aspects military decision makers are thinking about when evaluating a COA (Table 1) [1].

Factor	Criterion	Concerned with
Flexibility		
	C1: Covering Operational Tasks	The ability of a COA to adapt to possible changes in operational task which may occur during its implementation
	C2: Covering Mission's Possible Locations	The ability of a COA to adapt to possible changes in the predicted mission's locations which may occur during the implementation of a COA
	C3: Covering Enemy's COA	The ability of a COA to adapt in time to possible changes in the enemy's COA that may occur during the implementation
Complexity		
	C4: Operations Complexity	The COA implementation difficulties caused by its operational requirements
	C5: Logistics Complexity	The COA implementation difficulties caused by its logistics requirements
	C6: Command and Control Complexity	The COA implementation difficulties caused by Command and Control relationships and coordination requirements in operation
Sustainability		
	C7: Sustainability	The ability to continue (stay in) the operation as a function of the on-station time associated with the COA
Optimum use of resources		
	C8: Cost of Resources	The cost of the resources being used
Risk		
	C9: Impact of the Sensors Coverage Gap	The possibility of mission failure caused by the existence of radar and/or radio gaps
	C10: Military Personnel Loss	The likelihood of military personnel loss during the mission
	C11: Collateral Damage	The possibility of collateral damage (anything but the target) during the mission
	C12: Confrontation Risk	The possibility of mission failure due to confrontation
	C13: COA Equipment Reliability	The equipment reliability and the robustness of the COA
	C14: COA Personnel Effectiveness	The effectiveness of the personnel which may be jeopardized by fatigue, stress, etc. at any moment during the mission

Table 1. List of factors and criteria

The evaluation of the different COAs according to the criteria listed in Table 1 provides the basic information (data) to make a decision. It is important to notice that, even if the criteria identified would actually represent a consensus among different decision makers, each commander would put different emphasis on different factors according to his/her own preferences related to his/her specific understanding of the situation and of the goal to achieve.

When comparing two COAs (such as COA a_i and COA a_k) taking into account many criteria, a decision maker may be in one of the following situations [11]:

- He/she is indifferent between a_i and a_k, denoted $a_i \sim a_k$. This represents a situation in which the decision maker considers that both actions are equivalent.
- He/she strictly prefers a_i to a_k, denoted $a_i \succ a_k$. This represents a situation in which the decision maker prefers one of the COAs without any hesitation.
- He/she weakly prefers a_i to a_k (hesitation between indifference and strict preference), denoted $a_i \succ^f a_k$. This represents a situation in which the decision maker does not consider that both COAs are equivalent, but does not have enough reasons to justify a clear preference for a COA.
- He/she considers that a_i is incomparable to a_k (hesitation between $a_i \succ a_k$ and $a_k \succ a_i$, or the two COAs are *a priori* matchless), denoted $a_i \,?\, a_k$. This represents a situation in which the decision maker considers that, on the basis of the available information, the two COAs cannot be compared.

Then, the data supplied by the model $(A, \Lambda/C, E)$ need to be completed by introducing some elements of the decision maker's preference modelling (M). According to the multicriterion method in use, those elements are composed of, for each attribute/criterion:

- A coefficient of relative importance (c. r. i.) of criterion j (π_j): this coefficient represents the level of importance the decision maker is willing to assign to each criterion.
- An indifference threshold (q_j): it represents the highest difference between the evaluations of two COAs according to a criterion j for which the decision maker is indifferent between these two COAs, given that everything is the same otherwise.
- A preference threshold (p_j): it represents the smallest difference between the evaluations of two COAs according to criterion j for which the decision maker is able to conclude that one COA is as good as another one, given that everything is the same otherwise.
- A veto threshold (ν_j): it represents the smallest difference between the evaluations of two COAs according to criterion j for which the decision maker is not able to conclude that COA a_i is as good as COA a_k; the performance of a_k being higher than that of a_i from a value greater than ν_j, no matter the evaluations of a_i and a_k for all the other criteria.

The establishment of these values for each attribute/criterion makes it possible to obtain the "local preferences". Afterwards, these local preferences are aggregated and exploited according to the decisional problematic retained (a choice of a best alternative, a sorting of the alternatives into different categories, or a ranking of the actions), to obtain one or several recommendations at the end of the process. This is done by using a MCAP. Such methods are able to deal with the nuances brought by these different concepts. As a matter of fact, it avoids that, for a criterion, a weak preference can be considered as a strict preference, or that a preference is considered while the decision-maker is rather indifferent. Furthermore, it allows that critical aspects determined by the decision maker are directly brought to the end result.

PAMSSEM (Procédure d'Agrégation Multicritère de type Surclassement de Synthèse pour Évaluations Mixtes) [3] is the MCAP that has been identified as appropriate for our context. This MCAP takes as input a multicriterion performance table[1] (Table 2), as well as the local preferences composed of: π_j, q_j, p_j and ν_j, for each criterion. It produces a ranking of actions from the best one to the worst one, with equality eventually. PAMSSEM is a method based on the synthesis outranking approach. In this approach, the method aggregates the decision maker's preferences in building an outranking relationship that will allow to conclude that an action is *as good as* another one. In order to better understand how difficult it might be to produce explanations for PAMSSEM, we feel the need to describe the complete procedure in this paper.

		Criteria $(1 \ldots n)$				
		C_1	$\ldots$	C_j	$\ldots$	C_n
	a_1	e_{11}	$\ldots$	e_{1j}	$\ldots$	e_{1n}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
COAs $(1 \ldots m)$	a_i	e_{i1}	$\ldots$	e_{ij}	$\ldots$	e_{in}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	a_m	e_{m1}	$\ldots$	e_{mj}	$\ldots$	e_{mn}

Table 2. Multicriterion performance table

2.1 PAMSSEM

PAMSSEM is a multicriterion aggregation procedure that uses an outranking approach to aggregate the local preferences and exploits them to obtain, as a global result, a ranking of the COAs considered (Figure 1).

[1] A multicriterion performance table is a table containing, for each action, the value of evaluation according to each criterion.

Fig. 1. Graphical presentation of the results

2.1.1 PAMSSEM Aggregation Phase

The aggregation phase of PAMSSEM begins by computing a concordance index $C(a_i, a_k)$ for each pair of COAs $(a_i, a_k) \in A \times A$. This index is obtained as follows:

$$C(a_i, a_k) = \sum_{j=1}^{n} \pi_j \cdot \delta_j(e_{ij}, e_{kj})$$

where π_j is a normalized scalar representing the relative importance of the j^{th} criterion; $\sum_{j=1}^{n} \pi_j = 1$. $\delta_j(e_{ij}, e_{kj})$ is a *local outranking index* computed for each pair of COAs according to each criterion. Considering that we may have distributional evaluations, the local outranking index can be obtained by using this formula:

$$\delta_j(e_{ij}, e_{kj}) = \sum_{x_{kj}} \left(\sum_{x_{ij}} \widehat{\delta}(x_{ij}, x_{kj}) \cdot f_{ij}(x_{ij}) \right) \cdot f_{kj}(x_{kj}).$$

$f_{ij}(x_{ij})$ and $f_{kj}(x_{kj})$ are respectively the probability density functions (discrete) of x_{ij} and x_{kj}. In the case of punctual evaluation, we obtain $P(X_{ij} = x_{ij}) = f_{ij}(x_{ij}) = 1$. $\widehat{\delta}(x_{ij}, x_{kj})$ is an index computed according to the following formula (like in ELECTRE III):

$$\widehat{\delta}(x_{ij}, x_{kj}) = \begin{cases} 1 & \text{if } -q_j \leq \Delta_j \\ \frac{\Delta_j + p_j}{p_j - q_j} & \text{if } -p_j < \Delta_j < -q_j \\ 0 & \text{if } \Delta_j \leq -p_j \end{cases}$$

where $\Delta_j = x_{ij} - x_{kj} \approx e_{ij} - e_{kj}$, and $0 \leq q_j \leq p_j \leq E_j$; E_j is the maximum range of the measurement scale of the j^{th} criterion; $q_j = q_j(x_{kj})$ and $p_j = p_j(x_{kj})$, constant thresholds. The punctual evaluations can be handled by considering $f_j(x_{ij}) = 1$ if $x_{ij} = e_{ij}$ and 0 otherwise.

From a purist point of view, it is required to consider an ordinal criterion as a true criterion. In this case, we have $q_j = p_j = 0$. The local concordance index is then obtained as follows:

$$\delta_j(x_{ij}, x_{kj}) = \begin{cases} 1 & \text{if } 0 \leq \Delta_j \\ 0 & \text{if } 0 > \Delta_j. \end{cases}$$

For the sake of processing uniformity for the cardinal and ordinal evaluations, we suggest a slight modification in the computation of the concordance index for the ordinal criteria (when the number of levels of the ordinal scale > 3) as follows:

$$\delta_j(x_{ij}, x_{kj}) = \begin{cases} 1 & \text{if } 0 \le \Delta_j \\ \frac{1}{2} & \text{if } -1 \le \Delta_j < 0 \\ 0 & \text{if } \Delta_j < -1 \end{cases}$$

where Δ_j is the inter-level difference. The measurement theory proscribes the computation of this difference for ordinal scales. However, without the suggested modification, the ordinal criteria will be treated as true criteria, which will give these criteria more importance within the aggregation process. It is then *acceptable* in our military context to consider the information obtained according to these criteria as slightly more than ordinal.

The aggregation phase also involves the computation of another index: a *local discordance index*. This index is computed for each criterion and for each pair of COAs $(a_i, a_k) \in A \times A$. The local discordance index $D_j(a_i, a_k)$ states the opposition of the criterion j to the assertion that a_i outranks a_k. This index is computed according to the following formula (for distributional evaluations):

$$D_j(e_{ij}, e_{kj}) = \sum_{x_{ij}} \left(\sum_{x_{kj}} \widehat{D}_j(x_{ij}, x_{kj}) \cdot f_{kj}(x_{kj}) \right) \cdot f_{ij}(x_{ij})$$

where $D_j(a_j, a_k) = D_j(e_{ij}, e_{kj})$; and

$$\widehat{D}_j(x_{ij}, x_{kj}) = \begin{cases} 0 & \text{if } -p_j \le \Delta_j \\ -\frac{(\Delta_j + p_j)}{\nu_j - p_j} & \text{if } -\nu_j < \Delta_j < -p_j \\ 1 & \text{if } \Delta_j \le= \nu_j \end{cases}$$

where $\nu_j = \nu_j(x_{kj})$ is the veto threshold; $\nu_j > p_j$. Note that the value of this threshold can be influenced by the importance of the j^{th} criterion. The veto threshold ν_j is introduced to control the level of compensation. For example, suppose that, in order to intercept a drug smuggler, the commander has to consider two COAs: a_i and a_k. COA a_i involves largely more losses of lives than a_k. A veto threshold on the criterion *risk of losses of lives* will prevent a_i to globally outrank a_k, even if a_i is at least as good as (even better than) a_k on the other criteria. The veto threshold may vary with the position of the evaluation on the measurement scale associated to the criterion $j(\nu_j(e_{ij}))$.

From a purist point of view, it is difficult to compute discordance indices or define a veto threshold in the case of ordinal criteria (true criteria). Here again, if we want to assure a uniform processing for the ordinal and cardinal evaluations, we suggest computing local discordance index for the ordinal criterion as follows:

$$\widehat{D}_j(x_{ij}, x_{kj}) = \begin{cases} 0 & \text{if } -\frac{\ell_j+1}{2} \le \Delta_j \\ \min\left[1 - \xi(\pi_j) \cdot \left(\Delta_j + \frac{\ell_j+1}{2}\right)\right] & \text{if } \Delta_j < -\left(\frac{\ell_j+1}{2}\right) \end{cases}$$

where ℓ_j is the number of levels of the measurement scale associated with the j^{th} ordinal criterion; $\ell_j > 3$. Δ_j is the inter-level difference, and $\xi(\pi_j)$ is a non-decreasing function of the relative importance of the j^{th} criterion. This function could be, for instance, linear or exponential; $\xi(\pi_j) = 0.2(1 + \pi_j/2)$, or $\xi(\pi_j) = 0.2(2 + e^{\pi j/2})$, ...

Then, PAMSSEM aggregates the concordance and the local discordance indices to establish an *outranking degree* $\sigma(a_i, a_k)$ for each pair of COAs $(a_i, a_k) \in A \times A$. As suggested by Rousseau and Martel [9], these degrees can be obtained as follows:

$$\sigma(a_i, a_k) = C(a_i, a_k) \cdot \prod_{j=1}^{n} \left[1 - D_j^3(a_i, a_k)\right] \Rightarrow 0 \le \sigma(a_i, a_k) \le 1$$

where $\sigma(a_i, a_k)$ represents a "*consistency*" level of the conclusion that "the COA a_i globally outranks the COA a_k", taking into account the evaluation on all criteria. For example, if $\sigma(a_i, a_k) \approx 1$, then the conclusion "$a_i$ outranks a_k" is very well established.

It is important to mention that the aggregation and exploitation phase of PAMSSEM authorizes the possibility to have incomparability; it is possible that, at the same time, a_i does not outrank a_k, and a_k does not outrank a_i. This result is mainly due to the introduction of the discrimination and veto thresholds. Note also that we have: $a_i \succ a_k$ if a_i outranks a_k, and a_k does not outrank a_i and $a_i \sim a_k$ if a_i outranks a_k, and a_k outranks a_i.

2.1.2 PAMSSEM Exploitation Phase

The exploitation of the outranking relations consists in making a synthesis of this outranking matrix to provide a recommendation. In our decision aid module, this recommendation consists in ranking the COAs. This exploitation may be obtained by introducing the concept of entering and leaving flows of PROMÉTHÉE. For each COA a_i, we compute its leaving flow $\sigma^+(a_i)$ and its entering flow $\sigma^-(a_i)$ as follows:

$$\sigma^+(a_i) = \sum_{\forall a_k \neq a_i} \sigma(a_i, a_k)$$

$$\sigma^-(a_i) = \sum_{\forall a_k \neq a_i} \sigma(a_k, a_i).$$

The leaving flow represents the overall relative strengths of the COA a_i, and the entering flow represents its overall relative weaknesses. Note that the values of these flows can change if a COA is introduced or removed to/from the set **A**. On the basis of these two flows, it is possible for example to obtain a complete pre-order. This pre-order is the result of computing for each COA a_i a net flow $\Phi(a_i) = \sigma^+(a_i) - \sigma^-(a_i)$, and then ranking the COAs of **A** according to a decreasing order of the net flow.

3 USER NEEDS: EXPLANATIONS/JUSTIFICATIONS

One aspect considered as key to the acceptability of decision support systems is the possibility for those systems to provide explanations. As mentioned by Alvarado:

"We should not accept advice from human experts who cannot explain or defend their own points of view. Similarly, we should not accept advice from computer systems that lack this ability" [2]. Accordingly, we have investigated the possibility of providing our decision aid module with automated functionalities for the generation of explanations.

Notice that the end users of such system are the ones responsible to select the evaluation criteria considered for the comparison as well as to identify their respective thresholds. Based on the comments obtained from eventual end users, two different types of users were identified for our decision aid module: those having knowledge of multicriterion analysis and those having no knowledge of multicriterion analysis. For those having knowledge of MCDA, the need was to have access to intermediate results in order to be able to understand the proposed end result. These users were rather looking for different forms of presentation of these intermediate results: graphical or not.

If presenting intermediate results seems to be satisfactory to those having a good background in MCDA, they were not very useful for users without this specialized background. These users had no knowledge associated with the terminology neither the MCDA concepts. Accordingly, they were not really interested in having access to the intermediate results such as the concordance matrix, the discordance matrices and the outranking matrix. In fact, they were not really interested in knowing how this ranking was obtained. They were rather interested in finding reasons that make this ranking the best possible compromise. Accordingly, producing justifications using intuitive terminology and concepts seems to be the best way to provide explanations to these users.

Only few publications address the possibility of providing explanation to analytical decision support system based on MCDA. Henriet [4], one of them, has developed a classification method based on MCDA with an automated facility that provides explanations. He has identified two types of explanation for an end user. The first one is called positive explanations, and aims at justifying the affectation of an option to a category. The second one is called negative explanations, and aims at justifying the non-affectation of an option to a category. Then, three different interlocking levels of explanations are used based on the intermediate results provided by its MCDA method. The first level explains the affectation as well as the non-affectation using the indifference degrees. The second level explains the indifference between two actions using global concordance and discordance degrees. The third level refines the previous one by using "mono-criterion" concordance and discordance degrees. For each one of these levels, templates have been defined for positive as well as for negative explanations.

Other work addresses the problematics of providing explanations for methods based on multiattribute theory (e.g. [6, 8]). Here again, they have worked to produce qualitative and textual explanations from quantitative results representing the intermediate results obtained from the application of the mathematical models.

The next sections describe the approach we propose for providing automated explanation mechanisms for our decision aid module. Considering the needs of two types of users, it presents some explanations that could be provided to MCDA "expert", and some justifications that could be provided to an MCDA novice.

4 EXPLANATION FOR MCDA "EXPERTS"

In order to be informed how a ranking is obtained, we have identified three types of information that can be provided to people having a background in MCDA methods. First, there is the presentation of the method used (PAMSSEM in our case), then the intermediate results and finally, the impact of these intermediate results as well as the initial input values on the ranking obtained. Since this information will be provided to people with MCDA knowledge, it is appropriate to use MCDA terminology.

4.1 Presentation of PAMSSEM

A global description of PAMSSEM can be presented for those interested in knowing about this procedure. One small paragraph presenting the five (5) major steps of PAMSSEM can look like:

Step I: Concordance indices are calculated based on ELECTRE III method.

Step II: Discordance indices are calculated for each criterion (considering the preference, indifference and veto thresholds).

Step III: An outranking index is calculated for each pair of COAs.

Step IV: The outranking indices are exploited, for example, as in PROMÉTHÉE II, in order to obtain a complete pre-order.

Step V: The complete pre-orders are presented as the ranking of the COAs.

4.2 Presentation of Intermediate Results

It is expected that, for people having a background in MCDA, presenting intermediate results will provide the information needed to answer most of their questions. The challenge here consists in providing the intermediate results in different ways. The simplest way to present this information, which is also probably one of the most efficient, is to use matrices.

As an illustration case, suppose that we have the multicriterion performance matrix presented in Table 3. By executing PAMSSEM, we obtain the Concordance Matrix (Table 4) at step I, the discordance matrices (Table 5) at step II, and the outranking matrix (Table 6) at step III.

If we use the exploitation of PROMÉTHÉE II (PAMSSEM II), we obtain a complete pre-order (Table 7). The final ranking can be presented as in Figure 2, where arrows represent a preference relationship and lack of arrow represents the incomparability.

	COA1	COA2	COA3
Criterion 1 (Maximize) Cardinal Coefficient of Relative Importance: 0.33 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: 2.5	3.0	6.0	4.0
Criterion 2 (Maximize) Cardinal Coefficient of Relative Importance: 0.13 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: $1.0 \cdot 10^{10}$	6.0	5.0	3.0
Criterion 3 (Maximize) Cardinal Coefficient of Relative Importance: 0.54 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: $1.0 \cdot 10^{10}$	6.0	5.0	7.0

Table 3. Multicriterion performance table

	COA1	COA2	COA3
COA1	1.0	0.67	0.13
COA2	0.33	1.0	0.46
COA3	0.87	0.54	1.0

Table 4. Concordance matrix

4.3 Presentation of the Impact of Initial and Intermediate Data

Initial and intermediate data can be used to justify a ranking by presenting the impact they may have on the end result. Then, five (5) different elements have been identified for justifying that a COA outranks another one. They are 1) the entering and leaving flows, 2) the net flow, 3) the outranking matrix, 4) the criteria and 5) the evaluation results of each COA for each criterion. Even if all this information has already been presented to the users, we need to find a way to present it in a more obvious way to the user, so he can directly see its impact on the final ranking. Then,

Fig. 2. Presentation of the ranking with PAMSSEM II

Discondance Matrix for Criterion 1			
	COA1	COA2	COA3
COA1	0.0	1.0	0.0
COA2	0.0	0.0	0.0
COA3	0.0	0.66666667	0.0

Discondance Matrix for Criterion 2			
	COA1	COA2	COA3
COA1	0.0	0.0	0.0
COA2	0.0	0.0	0.0
COA3	$2.0 \cdot 10^{-10}$	$1.0 \cdot 10^{-10}$	0.0

Discondance Matrix for Criterion 3			
	COA1	COA2	COA3
COA1	0.0	0.0	0.0
COA2	0.0	0.0	$1.0 \cdot 10^{-10}$
COA3	0.0	0.0	0.0

Table 5. Discordance matrices

	COA1	COA2	COA3
COA1	1.0	0.0	0.13
COA2	0.33	1.0	0.46
COA3	0.87	0.38	1.0

Table 6. Outranking matrix

the emphasis of this part of the work was to identify different ways to present this information.

4.3.1 The Entering and Leaving Flows

The entering flow can be considered as the weaknesses or the dominated character of an action and the leaving flow as the force or dominant character of an action. These two elements of information can be used to demonstrate that a COA globally outranks one or many other COAs. For example, by presenting the leaving flow on the Y-axis and the entering flow on the X-axis, as in Figure 3, it is possible to identify zones such as recommended COAs, intermediate COAs and weak COAs. These zones need to be defined previously with the help of deci-

Action	Ranking	Entering Flow	Leaving Flow	Net Flow
COA3	1	0.59	1.25	0.66
COA2	2	0.38	0.79	0.41
COA1	3	1.2	0.13	−1.07

Table 7. Complete pre-order obtained using PAMSSEM II

sion makers as well as of MCDA analysts by using simulation cases, for example.

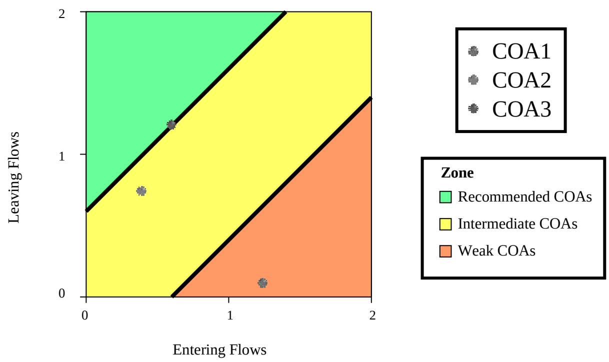

Fig. 3. Presentation of the entering and leaving flows

4.3.2 The Net Flow

The net flow is obtained from the entering and leaving flows, the net flow being the difference between the strength (leaving flows) and the weakness (entering flows) of the action. The net flow can be used to show that a COA outranks the others COAs; cf. Figures 4 and 5.

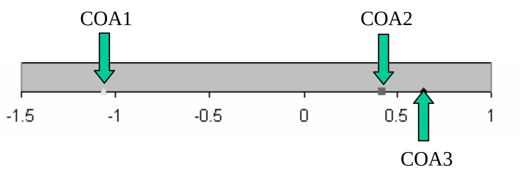

Fig. 4. Presentation of the net flows using a scale

4.3.3 The Outranking Matrix

The outranking matrix is a mXm matrix expressing the outranking degree of a COA against another one. Since the values of this matrix present how a COA outranks another one, it can be used to show how the other COAs place themselves in relation to a particular COA. For example, if we put, on the Y-axis, the level of how a particular COA a_i outranks the others COAs a_k, and, on the X-axis, the value of how the other COAs a_k outrank this particular COA a_i (Figure 6), we can identify different zones that will help understand these results. Decision makers and MCDA analysts can use simulation cases to identify different zones: a zone containing the

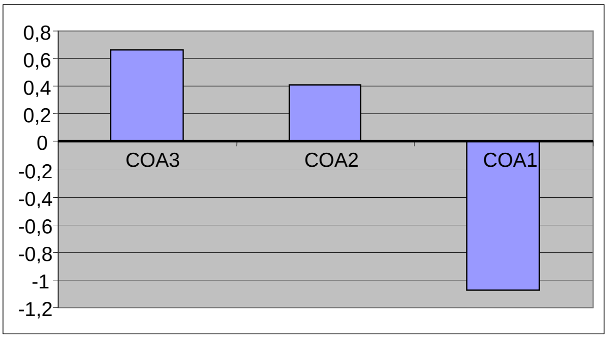

Fig. 5. Presentation of net flows using column chart

COAs strongly outranked by the COA a_i, zone containing the COAs weakly outranked by the COA a_i, a zone containing the COAs indifferent to the COA a_i, zone containing the COAs not comparable to the COA a_i, a zone containing the COAs that weakly outrank the COA a_i, and a zone containing the COAs that strongly outrank the COA a_i.

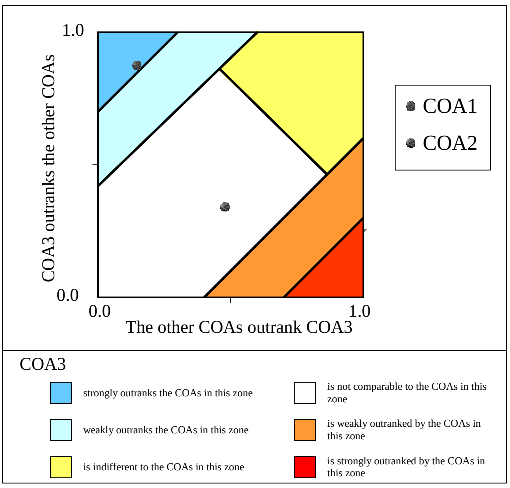

Fig. 6. Presentation of outranking matrix

4.3.4 The criteria

Since the criteria can be used to support the statement that the COA a_i outranks the COA a_k, it may be useful to put some emphasis on the criteria supporting the statement and those invalidating the statement. So, for each criterion that supports the statement, we can present the value of the associated outranking index

($\widehat{\delta}(x_{ij}, x_{kj})$) which corresponds to the strength of this support (called degree in Figure 7). The maximum that this value can reach is the value of the coefficient of relative importance of the criterion. The concordance index $C(a_i, a_k)$ can be used to present the global level of support that all supporting criteria provide (called concordance in Figure 7). In the same way, for all the criteria that invalidate the statement, we can provide the local discordance index ($D_j(a_i, a_k)$) which represents its weakness (called *degree* in Figure 7). The level of correction that this criterion provides to the outranking degree corresponds to $[1 - D_j^3(a_i, a_k)]$ (which is called the *correction* in Figure 7). Then, the overall strength of invalidation associated to all the discordant criteria is represented by $\prod_{j=1}^{n} \left[1 - D_j^3(a_i, a_k)\right]$ (which is called the *correction factor* in the Figure 7). Finally, to summarize all this, we can also provide the outranking degree $\sigma(a_i, a_k)$ that corresponds to the strengths of support for this statement.

Detailed Comparison	
Conclusion: COA3 outranks COA1	
Hypothesis: COA3 outranks COA1	Outranking: 0.87
2 concordant criteria	Concordance: 0.87
Criterion1	Degree: 0.33 on: 0.33
Criterion3	Degree: 0.54 on: 0.54
1 discordant criterion	**Correction factor**: 1
Criterion2	**Degree**: 0 **correction**: 1
Hypothesis: COA1 outranks COA3	Outranking: 0.13
1 concordant criterion	Concordance: 0.13
Criterion2	Degree: 0.13 on 0.13
2 discordant criteria	**Correction factor**: 1
Criterion1	**Degree**: 0 **correction**: 1
Criterion3	**Degree**: 0 **correction**: 1

Fig. 7. Presentation using criteria

The presentation of the associated weight (Figure 8) is also needed to put in perspective the influence of each criterion on the overall ranking.

4.3.5 The evaluation results

Finally, since the evaluation results of each COA for each criterion (Figure 9) are at the root of the ranking, it is worthwhile to present them to the user. One way to do it

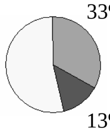

Fig. 8. Presentation of the criteria

is to define, for each criterion, different zones in a bar diagram. These zones are built based on the value of a COA that is used as a reference. These zones can be used to put in evidence how this reference COA is considered when being compared to other COAs. Accordingly, we can define a zone where the reference COA is so good that the performances of the COAs of this zone can not be globally considered as good as the performance of the reference COA, no matter their performance on the other criteria. A zone can be defined where the reference COA is good enough so the COAs of this zone are penalized when being compared to the reference COA. A zone can be defined where the reference COA is clearly as good as the performances of the COAs of this zone. However, in this case, there is a hesitation when considering the performances of these COAs as good as the performance of the reference COA. A zone can be defined where the reference COA is as good as the performances of the COAs of this zone. Besides, the performances of the COAs of this zone are also considered as good as the performance of the reference COA. A zone can be defined where the reference COA is considered, with hesitation, as good as the performance of the COAs of this zone; whereas the performances of these COAs are clearly as good as the performance of the reference COA. A zone can be defined where the reference COA is not considered as good as the performances of the COAs of this zone. Accordingly, the reference COA is penalized when compared with these COAs. Finally, a zone can be defined where the reference COA is not good enough so it can not be globally considered as good as the COAs of this zone, no matter the performance of the reference COA for the other criteria.

5 EXPLANATIONS FOR NOVICES IN MCDA

Considering the work of Wick and Thompson [14] on reconstructive explanations as well as of Southwick [12] on deep explanations, it appeared that the different concepts underlying a particular MCDA procedure could be used to build intuitive justification. This is consequential to the work of Henriet [4] on building explanations using the different degrees involved in the calculation of their MCDA procedure. Accordingly, we propose to generate the justifications after the ranking has been produced. However, we are going to use intermediate results and present the related concepts and relations that are the basics of the MCDA procedure.

In our case, PAMSSEM is based on a synthesis outranking approach. With this approach, we are trying to aggregate the decision maker's preferences by building an outranking relation that will make it possible to conclude that a COA is at least

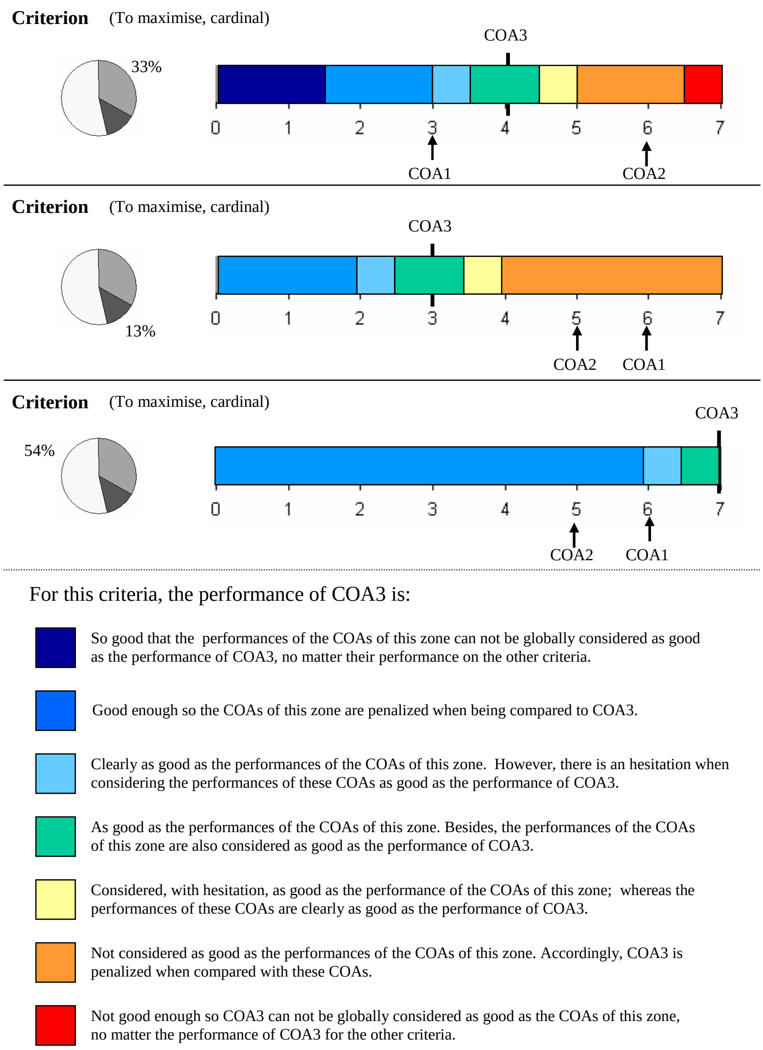

Fig. 9. Graphical presentation of the criteria results in function of COA3

as good as another COA. In building this synthesis outranking relation, we try to identify the conditions that support or reject the proposal that COA a_i is as good as COA a_k. We are dealing with the notion of concordant coalition as well as with the notion of discordant criterion. Furthermore, if the difference between the evaluation of COA a_k and COA a_i is greater than the veto threshold, then we have to reject the proposal that COA a_i is as good as COA a_k. These concepts are supported by the use of a concordance matrix, discordance matrices and an outranking matrix. Accordingly, the challenge is to present these concepts in an intuitive way.

5.1 Construction of the Justifications

We propose five different levels of justification to support the statement "the COA a_i is preferred to the COA a_k". To be more precise, we try to present the information that supports the fact that "COA a_i is as good as COA a_k" and that "COA a_k is not as good as COA a_i". The first level draws attention to the pieces of evidence supporting these statements. The second one highlights the level of importance of these pieces of evidence. The third one emphasizes the impact of indifference and preference thresholds. The fourth one gives prominence to the impact of veto threshold. The fifth one puts the emphasis on the impact of the criteria that do not support the proposition.

Each one of these levels wants to address a specific outranking sub-concept by exploiting initial as well as intermediate results. Depending on the sub-concepts concerned, the end user may have more or less difficulties to understand and/or accept a level of justification. For example, it may be more obvious to agree that a COA having higher value for his evaluation criteria is preferred to another one than that a COA is not preferred due to the veto threshold of a criterion. Then, considering the notions behind these concepts, it might be harder to understand a justification related to the level 4 than a justification related to the level 2.

In order to justify a proposition, the strategy suggested is to verify all these levels, from level 1 to level 5. The justification is built using canned text models that have been proposed for each level. A graphical view of those results such as in Figure 9 can also be proposed.

5.1.1 Level 1: Evidence Supporting the Statement

There is a piece of evidence supporting that "COA a_i is as good as COA a_k" each time that, for a criterion, the evaluation of COA a_i is greater than or equal to the evaluation of COA a_k minus the indifference threshold. It is also important to know the pieces of evidence that contradict our statement. These are obtained by verifying, for each criterion, if the evaluation of COA a_k is greater than or equal to the evaluation of COA a_i minus the indifference threshold. Accordingly, the criteria for which the decision-maker is indifferent between these two COAs will be considered as pieces of evidence supporting both parts ("COA a_i is as good as COA a_k" as well as "COA a_k is as good as COA a_i"). Since this may be considered confusing for an end user, we have decided to present these criteria as pieces of evidence that do not invalidate nor confirm any statement (since those will not really impact the final ranking). Therefore, we will present the pieces of evidence supporting that "COA a_i is better than COA a_k" and "COA a_k is better than COA a_i" instead of presenting the pieces of evidence supporting that "COA a_i is as good as COA a_k", and "COA a_k is as good as COA a_i".

The model suggested for this level of justification is as follows:

1. Count the number of criteria where the evaluation of COA a_i is greater than the evaluation of COA a_k plus the indifference threshold: α.

2. Count the number of criteria where the evaluations of COA a_k is greater than the evaluation of COA a_i plus the indifference threshold: β.
3. Count the number of criteria where the difference of the evaluation between the COA a_i and the COA a_k is inferior or equal to the indifference threshold: γ.
4. Present these statements to the user:
   - There is α pieces(s) of evidence that COA a_i is better than COA a_k. The criterion(criteria) supporting this(these) piece(s) of evidence is(are): ...
   - There is β piece(s) of evidence that COA a_k is better than COA a_i. The criterion(criteria) supporting this(these) piece(s) of evidence is(are): ...
   - There is γ piece(s) of evidence that COA a_i is indifferent to COA a_k. The criterion(criteria) supporting this(these) piece(s) of evidence is(are): ...

5.1.2 Level 2: Level of Importance of This Evidence

If the level of importance of the criteria supporting that "COA a_i is as good as COA a_k" is greater than the importance of the criteria supporting the negation of our statement, we have a second level of evidence. However, to reinforce the pieces of evidence provided in level 1, we will look at the level of importance of the criteria supporting that "COA a_i is better than COA a_k" and "COA a_k is better than COA a_i".

The model suggested for this level of justification is as follows:

1. Sum the c. r. i. of all criteria that the evaluation of COA a_i is greater than the evaluation of COA a_k plus the indifference threshold: Σ^+.
2. Sum the c. r. i. of all criteria that the evaluation of COA a_k is greater than the evaluation of COA a_i plus the indifference threshold: Σ^-.
3. If Σ^+ is greater than Σ^-: present the following statement to the user at the end of the statements presented for level 1:
   - COA a_i is preferred to COA a_k because the relative importance of the criteria supporting the evidence that COA a_i is better than COA a_k ($= \Sigma^+$) is greater than the relative importance of the criterion supporting the inverse relation ($= \Sigma^-$).

5.1.3 Level 3: Impact of Indifference and Preference Thresholds

If we have criteria for which the evaluation of COA a_k is greater than the evaluation of COA a_i but this difference of evaluation is smaller than the preference threshold and greater that the indifference threshold, then we are in the situation of weak outranking. In PAMSSEM, this weak outranking contributes to support the fact that the relation COA a_i is as good as COA a_k. Then, such weak outranking becomes weak evidence supporting the fact that COA a_i is as good as COA a_k. As in the model presented in level 1, it is also interesting to present the pieces of evidence that weakly contradict our statement. To do that, we verify if we have criteria for which the evaluation of COA a_i is greater than the evaluation of COA a_k but this difference of evaluation is smaller than the preference threshold and greater that the indifference threshold. Then such weak outranking becomes weak evidence supporting the fact that COA a_k is as good as COA a_i.

The model suggested for this level of justification is:

1. Among the β piece(s) of evidence that COA a_k is better than COA a_i, identify (*WeakCriteriafori*) and count the number (ζ) of those that the difference of evaluation, in favour of COA a_k, is smaller than the preference threshold and greater than the indifference threshold. The (ζ) weak evidence(s) constitutes (an) additional supporting piece(s) of evidence to the α previous one(s) that the COA a_i globally outranks the COA a_k.
2. At the end of the paragraph presenting the β piece(s) of evidence that the COA a_k is better than COA a_i, add this statement:
   - This piece of evidence (among these pieces of evidence, (ζ) of them (*Weak-Criteriafori*)) contributes(contribute) to weakly support the fact that the COA a_i is as good as the COA a_k.
3. Among the α piece(s) of evidence that COA a_i is better than COA a_k, identify (*WeakCriteriafork*) and count the number (η) of those that the difference of evaluation, in favour of COA a_i, is smaller than the preference threshold and greater that the indifference threshold. The (η) weak evidence(s) constitutes also (an) opposing piece(s) of evidence to the α previous one(s) by supporting the fact that "the COA a_k globally outranks the COA a_i".
4. At the end of the paragraph presenting the á piece(s) of evidence that COA a_i is better than COA a_k, add this statement:
   - This piece of evidence (among these pieces of evidence, (η) of them (*Weak-Criteriafork*)) contributes(contribute) to weakly support the fact that the COA a_k is as good as the COA a_i.
5. And, at the end of all the statements provided previously, add this statement:
   - The (α) piece(s) of evidence supporting the fact that COA a_i is better to the COA a_k, added to the existence of the ζ weak piece(s) of evidence supporting the fact that "the COA a_i is as good as COA a_k" contributes to justify the statement that the COA a_i is preferred to the COA a_k.

5.1.4 Level 4: Impact of Veto Threshold

If we have at least one criterion for which the evaluation of COA a_i is greater than that of the COA a_k of the veto threshold value, then we know that the COA a_i can not be considered as good as the COA a_k.

The model suggested for this level of justification is:

1. Identify the criteria (*VetoCriteria*) that the evaluation of COA a_i is greater than that of the COA a_k of the value of the veto threshold.
2. Present this statement to the user:

   - COA a_k cannot be considered as good as COA a_i since there is(are) one(several) criterion(a) (*VetoCriteria*) for which the evaluation of COA a_i is greater than the evaluation of COA a_k from the veto threshold value.

5.1.5 Level 5: Impact of Not Supporting Criteria

Level 5 puts the emphasis on the impact of the criteria that do not support the proposition.

The model suggested for this level of justification is:

1. If Levels 2, 3, 4 were not applicable to provide any pieces of justification.
2. Present this statement to the user:

   - There is no simple justification to support this statement. We suggest you to consult the explication module for expert in order to see the impact of the β opposing pieces of evidence on the ranking.

5.1.6 Illustration Cases

As a first illustration case, suppose that we have the multicriterion performance matrix presented in Table 3. The application of PAMSSEM on this matrix results in the complete pre-order presented in Figure 2. If the user asks "Why COA3 is before COA2 in the ranking?", the system will provide the following justification:

- There is 1 piece of evidence that COA3 is better than COA2. The criterion supporting this evidence is: Criterion3 (0.54).
- There are 2 pieces of evidence that COA2 is better than COA3. The criteria supporting this evidence are: Criterion1 (0.33) and Criterion2 (0.13).
- COA3 is preferred to COA2 because the relative importance of the criteria supporting the pieces of evidence that COA3 is better than COA2 (= 0.54) is greater than the relative importance of the criterion supporting the inverse relation (= 0.46). (See Figure 9.)

In this example, the levels 1 and 2 have been exploited.

If the user asks "Why COA2 is before COA1 in the ranking?", the system will provide the following justification:

- COA1 cannot be considered as good as COA2 since there is one criterion (Criterion1) for which the evaluation of COA2 is greater than the evaluation of COA1 from the veto threshold value.

In this example, the level 4 has been exploited.

The second test case described in Table 8 will make it possible to test levels 1 and 3 of our approach. The ranking obtained by using PAMSSEM is presented in Figure 10. If the end user wants justification for "why COA1 is before COA2", the system will give this information:

- There is 1 piece of evidence that COA1 is better than COA2. The criterion supporting this evidence is: Criterion3 (0.30).
- There is 1 piece of evidence that COA2 is better than COA1. The criteria supporting this evidence are: Criterion2 (0.37). This piece of evidence also contributes to weakly support the fact that COA1 can be as good as the COA2.
- There is 1 piece of evidence that COA1 is indifferent to COA2. The criterion supporting this evidence is: Criterion1 (0.33).
- The piece of evidence supporting that COA1 is better to the COA2, added to the existence of the weak piece of evidence supporting that COA1 can be as good as the COA2 contributes to justify the statement that the COA1 is preferred to the COA2.

	COA1	COA2	COA3
Criterion 1 (Maximize) Cardinal Coefficient of Relative Importance: 0.33 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: 2.5	3.0	3.2	4.0
Criterion 2 (Maximize) Cardinal Coefficient of Relative Importance: 0.37 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: $1.0 \cdot 10^{10}$	6.0	6.8	3.0
Criterion 3 (Maximize) Cardinal Coefficient of Relative Importance: 0.3 Preference Threshold: 1.0 Indifference Threshold: 0.5 Veto Threshold: $1.0 \cdot 10^{10}$	6.0	5.0	7.0

Table 8. Test case 2

Fig. 10. Result of test case 2

5.2 Types of Requests for a Justification

Three types of requests have been identified for providing intuitive justification (Figure 11):

- Why a COA is the first one in the ranking?
- Why a COA is the last one in the ranking?
- Why a COA is before another one in the ranking?

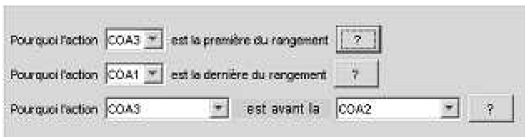

Fig. 11. Interface

Given that there are usually three to five COAs to be compared, the strategy considered appropriate for the first type of request is to justify why the first COA is preferred to all other COAs, avoiding a duplication of statements. Similarly, the strategy used for the second request is to justify why all other COAs are preferred to the last one, avoiding a duplication of statements. The strategy for the third one has already been described in the previous section. Even if these strategies would need to be improved, they have the advantage to cover a good set of possibilities.

The five aspects that Swartout and Moore [13] have identified for a good explanation (reliability, understandability, sufficiency, low construction overhead, efficiency) can be used to qualify the explanations proposed in this work. First, since the explanations for MCDA "experts" are based on intermediate results, we can consider that these explanations are reliable. However, for the novice, it is not completely true since we are providing elements of information as justifications. Second, in order to be able to determine if the explanations produced by our approach are understandable, we need to validate them with end users. Even if we have not made a formal validation of the explanations proposed in our approach, we have been able to gather comments from non-experts in MCDA. To these people, the intuitive justifications presented were a lot more understandable of any of the matrices or figures proposed in the "expert" module. But, is it enough? We still do not know. Third, we need to verify whether the amount and quality of knowledge is sufficient for the end users. Again, since we have not validated our approach with end users, we are not able to determine whether this aspect is satisfied. Fourth, since our explanations are built after the system has provided the final ranking, and that intermediate results are used, we can say that our approach has a low construction overhead (meaning that the time consumed and degree of difficulty to generate explanations can be qualified as low). Fifth and last, we can say that our approach does not degrade the run time efficiency of the system for the same reason as the one mentioned previously. This confirms that, as it is expected for an ongoing R&D activity, there is still a lot of work to be done.

6 CONCLUSION

To support the decision-making processes that address military command and control problems, DRDC Valcartier is investigating semi-automated decision support systems. Since, in such a context, several conflicting and quite incommensurable criteria need to be considered and balanced to make wise decisions, MCDA appeared to be appropriate to our problematics. While developing a prototype in order to demonstrate the feasibility of such concepts, possible end users explicitly indicate the need to have access to explanations related to the ranking provided by such tool. An approach to provide this module with explanation facilities has been described in this paper.

The proposed approach considers two types of end users: 1) a person with good background in multicriterion decision analysis; 2) a person with no background in multicriterion decision analysis. As one could expect, those two different types of users correspond to two different profiles since their needs are very specific. Essentially, in the first case, the user wants to have access to intermediate results. These can be presented using matrices or graphics depending on whether the user wants to know the intermediate values or the impact of these values on the overall ranking. In the second case, the lack of knowledge in MCDA causes that providing intermediate results would not satisfy the user's needs. These people are rather looking to have justifications of the ranking proposed. However, these justifications need to be provided in an intuitive format, so presenting the concepts under the MCAP rather than the mathematical models.

We have proposed explanations for these two different types of users. The strategy used consists in verifying five levels of explanation abstraction and provide the canned text associated with them. Even if these are primitive ones, we think that it is a good start in the right way, even if we still do not know if these explanations would really be efficient. In fact, we have not validated them yet with the end users. The validation step is a very sensitive one, because if the explanations are not good enough, the end users may loose trust in the explanation facilities, and in the worst case, in the result ranking provided by the system. Since it is difficult to have access to end users, we need to be sure that the proposed explanations are good enough before presenting them to the user community. That is why we felt the need to refine them again before validating them with the end user community.

One may argue that the two types of profiles that have been identified in this work are not appropriate. As a matter of fact, these two types of profiles can be considered as the two extreme types of profiles that may be needed. Eventually, explanation mechanisms should be able to adjust their explanations to each individual profile automatically.

Finally, it is interesting to notice that the users can use these explanations to validate and refine the MCDA parameters values. Indeed, by considering the effects (impacts) that these values may have on result ranking, the decision maker may decide to adjust them. So, in an interactive way, the explanations provided to the users can be used as a refinement mechanism to set the decision maker's preferences.

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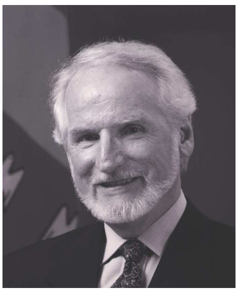

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