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Considering Interactions among Multiple Criteria for the Server Selection

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Abstract

Decision-making about server selection is one of the multi-criteria decision-making (MCDM) processes where interactions among criteria should be considered. The paper introduces and develops some solutions for considering interactions among criteria in the MCDM problems. In the frame procedure for MCDM by using the group of methods, based on assigning weights, special attention is given to the synthesis of the local alternatives' values into the aggregate values where the mutual preferential independence between two criteria is not assumed. Firstly, we delineate how to complete the additive model into the multiplicative one with synergic and redundancy elements in the case that criteria are structured in one level and in two levels. Furthermore, we adapted the concept of the fuzzy Choquet integral to the multi-attribute value theory. Studying and comparing the results of the example case of the server selection obtained by both aggregation approaches, the paper highlights the advantages of the first one since it does not require from decision makers to determine the weights of all possible combinations of the criteria and it enables the further use of the most preferred MCDM methods.

Keywords: interaction, multi-criteria decision-making, preferential dependence, server

1. Introduction

Multi-criteria decision-making (MCDM) methods have already turned out to be very applicable in business practice (for an overview see [5], [6]). This paper introduces some possible solutions for considering interactions among criteria in the MCDM problems. They should be considered in measuring the global phenomena like globalization, sustainable development and (corporate) social responsibility, as well as in solving other complex problems like the house purchase decision [7], sensor networks [16] and software architecture [13], and in server selection, as well.

If the criteria can interact with each other, not only the weights on each criterion (i.e. the criterion on the lowest hierarchy level – attribute) but also weighting on subsets of criteria should be considered (see e.g. [13], [16]). Marichal [12] defines and describes three kinds of interaction among criteria that could exist in the decision-making problem: correlation, complementary, and preferential dependency. Positive correlation can be overcome by using a weight on a subset of criteria $w_{k,l}$, such that $w_{k,l} < w_k + w_l$, where w_k and w_l are the weights of two criteria, and the sub-additive feature overcomes the overestimate during the criteria evaluation; when negative correlation occurs, the weight on a subset of criteria $w_{k,l}$ will be super-additive, given by $w_{k,l} > w_k + w_l$ [16]. In a complementary type of interaction, one criterion can replace the effect of multiple criteria – the importance of the criteria pair k,l is close to the importance of having a single criterion k or l [16]. In preferential dependence, the decision maker's preference for selecting an alternative is given by a logical comparison (for details see [16]). When such complex interactions exist among criteria, several authors [12], [13], [16] recommend the use of a well-defined weighting function on a subset of criteria rather than single criterion during global evaluation. For example, fuzzy logic has some suitable tools to solve MCDM problems by aggregating criteria. Grabisch and Labreuche [9] pointed out that an important feature of fuzzy integral is the ability of representing a range of interaction among criteria: from redundancy to synergy, which allows for considering both negative and positive interactions among different criteria. Since fuzzy integrals (e.g. Choquet integral) are able to model the interaction among criteria in a flexible way [9], they have already been made use of as a tool for criteria aggregation [9], [12], [13], [16]. In Section 2.2, we adapted the concept of the fuzzy Choquet integral to the Multi-Attribute Value Theory (MAVT).

Moaven [13] pointed out that dealing with interacting criteria was a kind of difficult issue. An overview of the most preferred and commonly used leading decision-analysis literature (see e.g. [1], [2], [7]) can let us report that decision-analysis theorists and practitioners tend to avoid interactions by constructing independent (or supposed to be so) criteria. We have already presented the frame procedure for MCDM by using the group of methods, based on assigning weights [6]; in synthesis, the additive model is used where the mutual preferential independence of criteria is assumed [4], [7]. However, the synthesis by the additive model may hide synergies and redundancies. The frame procedure [6] can be adapted to the problem's particularities. To complete the frame procedure for MCDM with interactions among criteria, we recommend the up-grade of the currently used traditional methods [10], [15] based on the top-down or bottom-up hierarchy: besides establishing the criteria's importance in order to define the weights of the criteria, the importance of the group of criteria should be expressed in order to assess the importance of the synergic or redundancy effects of the considered group; based on the proposed transformation of the additive model into the multiplicative one with synergic elements in [7], we delineate how to complete the additive model into the multiplicative one with synergic and redundancy elements in Section 2.1.

Section 3 brings an example case of the selection of the most suitable server. The initial MCDM model, based on the mutual preferential independence among criteria, is completed with the interactions among the higher lever criteria; the results of the completed model are compared with the ones obtained with the Choquet integral, and the ones obtained with the initial additive model. In Section 4, we highlight the research findings arising from the comparison of different aggregation approaches, based on the additive model, the model, completed into the multiplicative one by considering positive and negative interactions between criteria, and the Choquet integral, and discuss difficulties regarding the judgments about the criteria importance.

2. Considering Interactions in MCDM, based on Assigning Weights

2.1. The Completion of the Additive Model into the Multiplicative One

We have already developed and presented the frame procedure for MCDM (by using the group of methods, based on assigning weights) that complements intuition and helps us to master interdisciplinary cooperation on formal and informal principles [6]. We concluded that the problems should be approached step-by-step [6]: *Problem definition, Elimination of unacceptable alternatives, Problem structuring, Measuring local alternatives' values, Criteria's weighting, Synthesis, Ranking,* and *Sensitivity analysis*. When defining a problem, relevant criteria and alternatives should be described. Some of them do not fulfill the requirements for the goal fulfillment and should therefore be eliminated. A complex problem which consists of a goal, criteria, very often some levels of sub-criteria, and alternatives is structured in a hierarchical model. The local values of alternatives can be measured by e.g. value functions, pair-wise comparisons or directly; the criteria's importance can be expressed by using the methods based on ordinal (e.g. SMARTER), interval (e.g. SMART, SWING) [10] and ratio scale (e.g. AHP) [15]. When measuring the local values of alternatives and expressing the judgments of the criteria's importance, professionals of several fields that are capable of interdisciplinary co-operation should be involved. In synthesis, the additive model is used when calculating the global (i.e. aggregate) alternatives' values [2], [4]; such synthesis may hide synergies, and so does the alternatives' ranking. Several types of sensitivity analysis enable decision makers to investigate the sensitivity of the goal fulfillment to changes in the criteria weights (e.g. gradient and dynamic sensitivity) and to detect the key success or failure factors for the goal fulfillment (e.g. performance sensitivity).

In the Multi-Attribute Value (or Utility) Theory (MAVT or MAUT) and the methodologies that were developed on its bases (e.g. Simple Multi Attribute Rating Approach – SMART [10], the Analytic Hierarchy Process – AHP [15]), the additive model is usually used when obtaining the aggregate alternatives' values in synthesis as the sum of the products of weights by corresponding local alternatives' values. When the criteria are structured in one level only, the aggregate alternatives' values are obtained by

$$v(X_i) = \sum_{j=1}^{m} w_j v_j(X_i), \quad \text{for each } i = 1, 2, \dots, n, \tag{1}$$

where $v(X_i)$ is the value of the i^{th} alternative, w_j is the weight of the j^{th} criterion and $v_j(X_i)$ is the local value of the i^{th} alternative with respect to the j^{th} criterion.

The use of the additive model (1) is not appropriate when there is an interaction among the criteria. In order to apply the model we need to assume that mutual preferential independence exists among the criteria (see e.g. [4], [7]). The first criterion is preferentially independent of the second criterion if we prefer the alternative that is more suitable with respect to the first criterion, irrespective of the values of the second criterion; however, both alternatives have to have equal values with respect to the second criterion. If we also found that the second criterion is preferentially independent of the first criterion, then we could say that the two criteria are mutually preferential independent [7]. If mutual preferential independence does not exist, decision makers or evaluators usually return to the hierarchy (value tree) and redefine the criteria so that the criteria which are mutually preferential independent can be identified. In the occasional problems where this is not possible, other models are available which can handle the interactions among the criteria that express redundancy and synergy. According to Goodwin and Wright [7], the most well known of these is the multiplicative model. Let us suppose that the MCDM problem is being solved with respect to two criteria only – this simplification is made to explain the bases of multiplicative models; as proposed in [7], the value of the i^{th} alternative $v(X_i)$ is

$$v(X_i) = w_1 v_1(X_i) + w_2 v_2(X_i) + w_{1,2} v_1(X_i) v_2(X_i), \quad \text{for each } i = 1, 2, \dots, n, \tag{2}$$

where w_1 is the weight of the first and w_2 is the weight of the second criterion, $v_1(X_i)$ is the local value of the i^{th} alternative with respect to the first and $v_2(X_i)$ is the local value of the i^{th} alternative with respect to the second criterion; (2) is written by following an example in [7]. The last expression in the above sum (2), which involves multiplying the local alternatives' values and the weight of the synergy between the first and the second criterion $w_{1,2}$, represents the interaction between the first and the second criterion that expresses the synergy between these criteria.

The sum of the weights in (1) equals one: $\sum_{j=1}^{m} w_j = 1$, and so does it in (2), as well. In order to complete the additive model (1) into the multiplicative one (2), one has to determine the weight of the synergy between the first and the second criterion $w_{1,2}$, and then recalculate the weights of initial factors:

$$\begin{aligned} w_{1,M} &= (1 - w_{1,2}) w_{1,A}, \\ w_{2,M} &= (1 - w_{1,2}) w_{2,A}, \end{aligned} \tag{3}$$

so that the sum of the weights of initial factors and the one of the synergy between them equals one in (2):

$$w_1 + w_2 + w_{1,2} = 1 . \tag{4}$$

In (3), $w_{1,\mathrm{A}}$ is the weight of the first and $w_{2,\mathrm{A}}$ is the weight of the second criterion in the additive model (1), whereas $w_{1,\mathrm{M}}$ is the weight of the first and $w_{2,\mathrm{M}}$ is the weight of the second criterion in the multiplicative model (2).

If the weights of initial factors and the one of the synergy between them are normalized (which is usual in using the computer supported MCDM methods), (2) can be used when there is a (positive) synergic interaction between the criteria. However, there are also negative (redundancy [13]) interactions between the criteria. To consider both positive and negative interactions in (2), we recommend the following procedure. To emphasize the effect of the synergy and redundancy (i.e. negative synergy), the above mentioned recalculation (3) of the weights of initial factors is not needed. Let us assume that a synergic element is an "added value" to the aggregate value, obtained by an additive model (1). When there is a positive interaction (i.e. synergy) between the criteria, the product of the local alternatives' values and the weight of the synergy between the first and the second criterion can be added to the sum (1). When there is a negative interaction between the criteria, the product of the local alternatives' values and the weight of the interaction between the first and the second criterion can be deducted from the sum (1). Such simplification might allow decision makers to use the most preferred computer supported multi-criteria methods, based on the additive model, to obtain the aggregate values, improved for positive and negative interactions between criteria; it might allow them to compare the alternatives' aggregate values, obtained without considering synergic and redundancy elements, with the alternatives' aggregate values, improved with these elements.

When the criteria are structured in two levels, the aggregate alternatives' values are obtained by

$$v(X_i) = \sum_{j=1}^{m} w_j \left(\sum_{s=1}^{p_j} w_{js} v_{js}(X_i) \right), \qquad \text{for each } i = 1, 2, \ldots, n, \tag{5}$$

where p_j is the number of the j^{th} criterion sub-criteria, w_{js} is the weight of the s^{th} attribute of the j^{th} criterion and $v_{js}(X_i)$ is the local value of the i^{th} alternative with respect to the s^{th} attribute of the j^{th} criterion. When there are interactions among the criteria on the lowest hierarchy level that belong to the higher level criterion, and / or the ones among the criteria on the higher hierarchy level, we recommend decision makers to consider the following procedure:

- By considering the local alternatives' values and the attributes' weights, obtain the alternatives' values with respect to the higher level criteria. When there are interactions among the attributes, improve the obtained alternatives' values.
- By considering the alternatives' values with respect to the higher level criteria, improved for the interactions among the attributes, and the higher level criteria's weights, obtain the aggregate alternatives' values. When there are interactions among the higher hierarchy level criteria, improve the obtained alternatives' values.

2.2. The Choquet Integral

Until a decade ago and recently, the most often used aggregation operators were the weighted arithmetic means [12]. Since these operators were not able to model satisfactorily interactions among criteria, they have been used (mostly, as discussed in Sections 1 and 2.1) in the presence of independent criteria. Let us consider a finite set of alternatives X and a finite set of criteria K in a MCDM problem. In order to have a flexible representation of complex interaction phenomena between criteria, it is useful to substitute to the weight vector w a non-additive set function on K allowing to define a weight not only on each criterion, but also on each subset of criteria. For this purpose, the concept of fuzzy measure has been introduced [12]. A suitable aggregation operator, which generalizes the weighted arithmetic mean, is the discrete Choquet integral.

Proposed in capacity theory [3], the concept of the Choquet integral was used in various contexts, among them in non-additive utility (value) theory [8], [12]. Let us adapt its definition to the MAVT. Following [8] and [12], this integral is viewed here as an m-variable aggregation function; let us adopt a function-like notation instead of the usual integral form, where the integrand is a set of m real values, denoted $v = (v_1, \ldots, v_m) \in \Re^n$. The (discrete) Choquet integral of $v \in \Re^n$ with respect to w is defined by

$$C_w(v) = \sum_{j=1}^{m} v_{(j)}\left[w(K_{(j)}) - w(K_{(j+1)})\right], \tag{6}$$

where $(\cdot)$ is a permutation on K – the set of criteria, such that $v_{(1)} \leq \ldots \leq v_{(m)}$, where $K_{(j)} = \{(j), \ldots, (m)\}$.

3. Example Case

3.1. Server Selection, based on the Mutual Preferential Independence among Criteria

The MCDM model for the selection of the most suitable server was built in a Slovenian Information Technology (IT) company (that deals with system integration, and hardware and software support) with the aim to present possible solutions to their current and potential customers. The frame procedure for MCDM based on assigning weights was followed. The servers which can be offered to small and medium-sized companies are described as alternatives [11]: IBM System x3200 M2 Model 4368AC1 (Alternative 1), IBM System x3400 Model 7975AC1 (Alternative 2), IBM System x3650 M2 Model 7947AC1 (Alternative 3), IBM System x3550 M2 Model 783912U (Alternative 4), whereas IBM System x3850 M2 Model 7233AC1 was eliminated. The criteria hierarchy presented in Figure 1 includes the 'capacity' (Processor, Memory, Internal Hard Disk), 'costs' (Price, Consumption, Height) and 'service quality' attributes (Guarantee, Availability, Supervising).

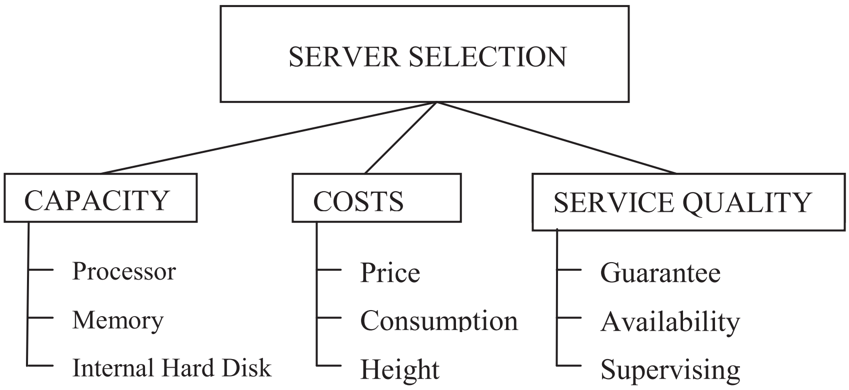

Figure 1. The criteria hierarchy.

On the bases of experiences and detailed data from the principal, engineers in the considered IT company responsible for pre-sales support expressed their judgments about the criteria's importance. Although the methods for the weights determination are not given a special emphasis in this paper, let us explain that the importance of the first level criteria was assessed with the SWING method, based on the interval scale (for a detailed explanation see e.g. [10], [4]): 100 points were given to the change from the worst to the best 'capacity', which is considered the most important criterion change. With respect to this change importance, 60 points were given to the change from the highest to the lowest 'costs', and 40 points were given to the change from the worst to the best 'service quality' level. The importance of the attributes of 'capacity' and 'service quality' was determined with the SWING method, as well, whereas the importance of the attributes of 'costs' was assessed directly. The weights of the attributes – second level criteria, and (first level) criteria are presented in Table 1.

First level criteria	Weights of the first level criteria	Second level criteria	Weights of the second level criteria
CAPACITY	$w_1 = 0.5$	Processor	$w_{11} = 0.3$
		Memory	$w_{12} = 0.5$
		Internal Hard Disk	$w_{13} = 0.2$
COSTS	$w_2 = 0.3$	Price	$w_{21} = 0.4$
		Consumption	$w_{22} = 0.45$
		Height	$w_{23} = 0.15$
SERVICE QUALITY	$w_3 = 0.2$	Guarantee	$w_{31} = 0.2$
		Availability	$w_{32} = 0.5$
		Supervising	$w_{33} = 0.3$

Table 1. The criteria structure and the weights for the selection of servers.

Appendix A presents the alternatives' data with respect to the criteria on the lowest hierarchy level, together with the methods, used for the measurement of the local alternatives' values. To evaluate alternatives with respect to 'memory' and 'guarantee', engineers in the considered IT company compared preferences to alternatives by pairs, and to evaluate alternatives with respect to 'availability' and 'supervising', they used the direct method[1] (Appendix A). They evaluated the considered server solutions with respect to the 'service quality' attributes by using increasing value functions, and to the 'costs' attributes by using decreasing value functions. The alternatives' values with respect to the higher level criteria and the aggregate alternatives' values obtained by (5) are presented in Table 2.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Value with respect to 'capacity' v_1	0.343	0.382	0.656	0.283
Value with respect to 'costs' v_2	0.762	0.275	0.144	0.260
Value with respect to 'service quality' v_3	0.144	0.192	0.514	0.514
Aggregate alternative's value v	0.429	0.312	0.474	0.322
Rank	2.	4.	1.	3.

Table 2. The alternatives' values, obtained with the additive model.

Studying the results in Table 2, obtained with the additive model, can let us report that Alternative 3 is the most appropriate alternative.

3.2. Server Selection considering Synergy and Redundancy among Criteria

Regarding the experiences of the sales department in the considered IT company it can be concluded that the customers' (especially top) managers that make the servers purchase decisions are not interested in the details concerning interactions among criteria on the first

[1] Numerical values were assigned to verbal evaluations.

hierarchy level (i.e. among attributes); oriented to holistic solutions, managers are much more interested in the interactions among higher level criteria, in this case among 'capacity', 'costs' and 'service quality'.

3.2.1. *Application of the Additive Model, completed into the Multiplicative One*

On the bases of experiences and detailed data from the principal, engineers in the considered IT company responsible for pre-sales support evaluated that there is synergy between 'capacity' and 'costs'. This means that $w_1 + w_2 + w_{1,2} > 0.8$ (see Table 1); note that $w_1 + w_2 + w_{1,2} = 0.9$, $w_{1,2} = 0.1$. They evaluated that there is redundancy between 'capacity' and 'service quality': $w_1 + w_3 + w_{1,3} < 0.7$ (see Table 1); note that $w_1 + w_3 + w_{1,3} = 0.55$, $w_{1,3} = -0.15$. Further, note that there is neither synergy nor redundancy between 'costs' and 'service quality': $w_2 + w_3 + w_{2,3} = w_2 + w_3 = 0.5$, $w_{2,3} = 0$ (see Table 1). Considering these synergic and redundancy elements, the aggregate alternatives' values, presented in Table 3, are obtained by:

$$v(X_i) = v(X_i)_A + w_{1,2}v_1(X_i)v_2(X_i) - w_{1,3}v_1(X_i)v_3(X_i),\ i = 1, 2, 3, 4, \quad (7)$$

where $v(X_i)_A$ is the aggregate value of the i^{th} alternative, obtained by the additive model (see Table 2).

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Aggregate alternative's value *v*	0.448	0.312	0.433	0.308
Rank	1.	3.	2.	4.

Table 3. The alternatives' values, obtained by considering synergic and redundancy elements with the additive model, completed into the multiplicative one.

Studying the results in Table 3, obtained by considering synergic and redundancy elements with the additive model, completed into the multiplicative one, can let us report that Alternative 1 is the most appropriate alternative.

3.2.2. *Application of the Choquet Integral*

In the concept of fuzzy logic, a synergic element is not considered as an added value to the value, obtained by the additive model; the weights of the synergy and redundancy do not only complement the sum of the importance of initial factors. As already mentioned in section 3.2.1, it has been evaluated that there is synergy between 'capacity' and 'costs': this means that $w_{1,2} > w_1 + w_2$; note that $w_1 + w_2 = 0.8$ (see Table 1), and in the concept of the Choquet integral $w_{1,2} = 0.9$. It has been evaluated that there is redundancy between 'capacity' and 'service quality': $w_{1,3} < w_1 + w_3$; note that $w_1 + w_3 = 0.7$ (see Table 1), $w_{1,3} = 0.55$. Further, note that there is neither synergy nor redundancy between 'costs' and 'service quality': $w_2 + w_3 = 0.5$ (see Table 1). Table 4 presents the Choquet integrals for the example case of the selection of the most suitable server, obtained by (6). For instance, for Alternative 1, where $v_3 < v_1 < v_2$ (see Table 2), we have

$$C_w(v_1, v_2, v_3) = v_3[w_{3,1,2} - w_{1,2}] + v_1[w_{1,2} - w_2] + v_2w_2, \quad (8)$$

where $w_{3,1,2} = 1$. Following (6), the Choquet integral for other alternatives can be expressed. However, as the ranking of the alternatives' values with respect to the first level criteria in Table 2 differs for each of the considered alternatives, we cannot use (8) as the common formula for calculating the Choquet integral in the example case; it should be expressed for each alternative by considering (6).

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Choquet integral *C*	0.449	0.320	0.419	0.319
Rank	1.	3.	2.	4.

Table 4. The alternatives' values, obtained by considering synergic and redundancy elements with Choquet integral.

Studying the results in Table 4, obtained by considering synergic and redundancy elements with the Choquet integral, can let us report that Alternative 1 is the most appropriate alternative.

3.3. Comparison of the Results, obtained by Different Aggregation Approaches

Studying and comparing the results, presented in Table 2, Table 3 and Table 4 can let us report that the consideration of synergic and redundancy elements in MCDM about the most appropriate server changes the alternatives ranking: the ranks of the first and the second alternatives are interchanged, and so are the ranks of the third and the fourth alternatives, as well. Furthermore, it has to be emphasized that the alternatives ranking on the bases of the completed model by considering synergic and redundancy elements into the multiplicative one is the same as the one based on the results of the Choquet integral (see Table 3 and Table 4).

4. Conclusions

The example case in Section 3 illustrates that considering synergic and redundancy elements can essentially change the alternatives ranking. Although the ranking of the alternatives in this case is the same irrespective of the approach used for considering interactions among criteria, the additive model, completed into the multiplicative one by considering synergy and redundancy turns out to be more appropriate by comparison with the Choquet integral. When using the Choquet integral approach, the weights of synergy or redundancy for all possible combinations of the criteria with respect to the criterion on the higher hierarchy level must be determined. For each alternative, one has firstly rank the alternative's values with respect to the criterion on the observed level and then – with respect to the determined ranking - take into the account only some of the determined weights as explained in Section 2.2. Moreover, the ranking of the alternative's values can differ for each of the considered alternatives (which is the case in Section 3.2.2). On the other hand, the additive model, completed into the multiplicative one does not require from the decision makers to determine the weights for all possible combinations of the criteria with respect to the criterion on the higher hierarchy level; he / she can consider less synergic or redundancy elements. Furthermore, the ranking of the alternative's value with respect to the criterion on the observed level as the pre-step of using the appropriate formula (which is the case when approaching to considering synergy and redundancy with Choquet integral) is not needed. Once the weights of the synergy and redundancy between criteria are determined, decision makers can use the same formula (e.g. (7) in Section 3.2.1) for all alternatives.

With the additive model, completed into the multiplicative one by considering synergic and redundancy elements without normalizing weights, decision makers can research the impact of the synergic and redundancy elements on the aggregate alternatives' values; they can compare the aggregate values obtained with considering synergic and redundancy elements with the ones without them.

Studying and comparing the additive model (1) and the one completed into the multiplicative one (2) it can be concluded that the latter (2) does not require additional effort when measuring the local alternatives' values with respect to each attribute. The local alternatives' values measured directly or by making pair-wise comparisons or by using value functions [6] can be used in both models.

Although supported by several computer supported methods, the criteria's weighting is an exacting step in practice. Professionals of several fields that are capable of interdisciplinary co-operation should be involved in this step. Group priorities' establishing is well supported by the group-decision making upgrades of computer programs that have been most preferred for individual MCDM in the last – almost three – decades [5]. Because very often the decision makers are not aware of the relationships among different factors taken into account for the goal fulfillment, intuition comes into forefront when establishing the judgments on importance. However, the judgments' expression about the importance of the synergies or redundancies among factors requires additional efforts for decision makers to determine the appropriate weights. Since systematic procedures can not compensate for the lack of knowledge or limited abilities of decision makers, an important task is given to the requisitely holistic use of decision logic, heuristic principles, information and practical experience.

Some of the traditional multi-criteria methods based on assigning weights allow for consideration of several factors that can be structured in one or more criteria levels. Decision makers have to select viewpoints to be considered – from many available – and structured, including interactions among them. In the paper delineated possibilities allow decision makers to use the most preferred computer supported multi-criteria methods, based on the additive model, to obtain the aggregate values, and to improve them for positive and negative interactions between the criteria.

Appendix A: Alternatives' Data with Respect to the Attributes

	Data type	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Measuring local alternatives' values
Processor	Quantitative: Processor benchmark	3495	3743	4900	1602	Value function, LB: 900, UB: 5200
Memory	Quantitative, measurement unit: GB	2	4	8	2	Pair-wise comparisons
Internal Hard Disk	Quantitative, measurement unit: GB	1500	900	1200	2000	Value function, LB: 600, UB: 2000
Price	Quantitative, measurement unit: US $	3105	5318	11204	5503	Value function, LB: 2000, UB: 12000
Consumption	Quantitative, measurement unit: W	400	670	675	675	Value function, LB: 370, UB: 675
Height	Quantitative, measurement unit: U	5	5	2	5	Value function, LB: 1, UB: 5
Guarantee	Quantitative, measurement unit: year	3	1	3	3	Pair-wise comparisons
Availability	Qualitative, verbal evaluation	Satisfactory	Good	Very good	Very good	Direct method
Supervising	Qualitative, verbal evaluation	Existent	Satisfactory	Good	Good	Direct method

Symbols: GB – gigabyte, US $ – United States Dollar, W – watt, U – rack unit, LB – lower bound, UB – upper bound; Alternative 1 – IBM System x3200 M2 Model 4368AC1, Alternative 2 – IBM System x3400 Model 7975AC1, Alternative 3 – IBM System x3650 M2 Model 7947AC1, Alternative 4 – IBM System x3550 M2 Model 783912U
Sources: [11], [14], own experience of the observed company's pre-sales support engineers

Table A-1. The alternatives' data and the methods, used for the measurement of the local alternatives' values.

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