Criteria weighting by using the 5Ws & H technique

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Abstract

Background: This paper introduces the use of the 5Ws & H technique, which is the creative problem solving technique based on who, what, when, where, why and how questions, for the establishing of the criteria weights in multi-criteria decision-making (MCDM). **Objectives:** The main goal of this paper is to adapt and complete the steps of the 5Ws & H technique, usually used in the problem definition phase, to establish the importance of criteria by the methods based on an interval scale. It also aims to verify the applicability of the proposed approach in the selection of the most appropriate blade. **Methods/Approach:** In terms of prescriptive approach, the creative 5Ws & H technique was used in the weighting step of the frame procedure for MCDM. During synthesis, the additive model was used, whereas interactions among criteria were considered by using the discrete Choquet integral. **Results:** The first result is a theoretical statement of the weighting scheme for a new decision mechanism. The second result is the application of this scheme in a real-world case-study. Considering interactions among criteria strengthened the decision-making basis in the selection of the most appropriate blade. **Conclusion:** The creative 5Ws & H technique proved useful in criteria weighting.

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Introduction

When solving problems with multi-criteria decision-making (MCDM) methods, decision makers are encouraged to follow one of the MCDM procedures. The frame procedure of MCDM for the group of methods based on assigning weights (Čančer, 2008) includes the following steps:

Step 1: Problem definition. Creative thinking techniques (e.g. W, 5 Ws & H, why, five whys, cognitive mapping, outcome checklists, mind mapping etc.) can be used to find and describe a problem (Pečjak, 2001). In the context of MCDM, this step involves the description of relevant criteria and alternatives.

Step 2: Elimination of unacceptable alternatives. We assess all possible alternatives; some of them do not fulfill the requirements for the goal fulfillment and should therefore be eliminated.

Step 3: Problem structuring. When the problem is accurately described, this step transforms into hierarchy structuring – the term used by Saaty (1999): each problem consists of a goal, criteria, very often some level of sub-criteria, and alternatives.

Step 4: Measuring local alternatives' values. On the basis of the expressed judgments about the preferences to alternatives, the values of the alternatives with respect to each criterion on the lowest level, are calculated. The local values of alternatives can be measured by value functions, pair-wise comparisons or directly (Belton and Stewart, 2001; Bouyssou, et al., 2000).

Step 5: Criteria weighting. The criteria's importance can be expressed by using the methods based on ordinal (e.g. SMARTER), interval (e.g. SWING and SMART) and the ratio scale (e.g. AHP), or by direct weighting (Belton and Stewart, 2001; Bouyssou, et al., 2000). Professionals in several fields that are capable

of interdisciplinary co-operation (Mulej, 2006) should be involved in this step.

Step 6: Synthesis. In synthesis, the additive model is usually used where the reciprocal preferential independence of criteria is assumed (Bouyssou, et al., 2000).

Step 7: Ranking. By alternatives ranking, we can select the most appropriate alternative(s), eliminate the alternative(s) with the lowest aggregate value, or compare the alternatives with respect to their aggregate values.

Step 8: Sensitivity analysis. 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).

The procedure was well-verified in practice (Čančer, 2008), but lacked the support of the criteria weighting techniques. Namely, expressing judgements about the criteria's importance is a kind of difficult issues for decision makers. To eliminate this deficiency, in terms of prescriptive approach, the main goal of this paper is therefore to adapt and complete the steps of the 5Ws & H technique, which is the creative problem solving technique based on questions (Cook, 1998), to establish the weights of criteria by using the methods based on the interval scale: SMART (Edwards, 1977) and SWING (von Winterfeldt and Edwards, 1986), and of the subsets of them. This paper also aims to verify the applicability of the proposed approach in the selection of the most appropriate blade. In synthesis, the additive model (Belton and Stewart, 2001; Kojadinovic, 2004) was firstly used to obtain the aggregate alternatives' values, and then the discrete Choquet integral (Grabisch, 1995; Marichal, 2000) was used to consider interactions among criteria.

This paper aims to answer the following research questions: (1) RQ1: How to adapt and complete the steps of the creative 5Ws & H technique to establish the weights in the frame procedure for MCDM by using the methods based on the interval scale? and (2) RQ2: Does the consideration of interactions among criteria strengthen the decision-making basis in the selection of the most appropriate blade?

The innovative aspect of this paper is that it extends the use of creative approaches to criteria weighting – one of typically analytical steps of MCDM where synergies and redundancies among criteria are considered. By compiling the main features of the considered creative and quantitative MCDM methods, we proposed the process of establishing the judgments about the criteria's importance by the 5Ws & H technique, together with the frame questions for the SMART and the SWING method. The applicability of the proposed approach is introduced via a practical case – the selection of the most appropriate blade.

Weighting and Aggregation Tools in MCDM

The most common aggregation tool that is used in MCDM is the weighted arithmetic mean. Under the assumption of independence among criteria, it requires the assignment of a weight to each criterion (Kojadinovic, 2004). This step is usually carried out by decision makers and thus reflects their point of view on the multi-criteria decision problem (Kojadinovic, 2004). Since, in practical applications, decision makers very often tell the relative importance of criteria directly with difficulty, the criteria's importance can be expressed by using several methods (Belton and Stewart, 2001). In this paper, special attention is given to the use of the methods for establishing the judgements on criteria's importance, based on the interval scale. In SMART (Edwards, 1977), a decision maker is first asked to assign 10 points to the least important criterion change from the worst criterion level to its best level, and then to give points (≥ 10, but ≤ 100) to reflect the importance of the criterion change from the worst criterion level to the best level relative to the least important criterion change. In SWING (von Winterfeldt and Edwards, 1986), a decision maker is asked first to assign 100 points to the most important criterion change from the worst criterion level to the best level, and then to assign points (≤ 100, but ≥ 10) to reflect the importance of the criterion change from the worst criterion level to the best level relative to the most important criterion change. In SMART and SWING (Edwards, 1977; von Winterfeldt and Edwards, 1986; Belton and Stewart, 2001), the weight of the j^{th} criterion, w_j, is obtained by:

$$w_j = \frac{t_j}{\sum_{j=1}^{m} t_j} \tag{1}$$

where t_j corresponds to the points given to the j^{th} criterion, and m is the number of criteria. When the criteria are structured in two levels (which is the case in the practical example dealing with in this paper), the weight of the s^{th} attribute of the j^{th} criterion, w_{js}, is in SMART and SWING obtained by:

$$w_{js} = \frac{t_{js}}{\sum_{s=1}^{p_j} t_{js}} \tag{2}$$

where tjs corresponds to the points given to the sth attribute of the jth criterion, and p_j is the number of the j^{th} criterion sub-criteria.

The local values of alternatives with respect to each criterion on the lowest level (attribute) can be measured by value functions, pair-wise comparisons (Saaty, 1994) or directly (Belton and Stewart, 2001). During synthesis, the additive model is usually used (Belton and Stewart, 2001). When the criteria are structured in one level only, the aggregate alternatives' values are obtained by:

$$v(X_i) = \sum_{j=1}^{m} w_j v_j(X_i) \qquad \text{for each i = 1, 2, ..., n,} \tag{3}$$

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

When the criteria are structured in two levels, the aggregate alternatives' values are obtained by (Čančer, 2009):

$$v(X_i) = \sum_{j=1}^{m} w_j \left(\sum_{s=1}^{p_j} w_{js} v_{js}(X_i) \right) \qquad \text{for each i = 1, 2, ..., n,} \tag{4}$$

where $vjs(X_i)$ is the local value of the i^{th} alternative with respect to the s^{th} attribute of the j^{th} criterion.

If there is interaction among the criteria, decision makers usually return to the hierarchy and redefine the criteria (Belton and Stewart, 2001; Bouyssou et al., 2000). They can also use other models to obtain the aggregated alternatives' values, e.g. the multiplicative and the fuzzy ones. It has already been delineated how to complete the additive model into the multiplicative one (Čančer, 2009; Čančer, 2010). Further, the concept of fuzzy measure has been introduced (Marichal, 2000): 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. A suitable aggregation operator, which generalizes the weighted arithmetic mean, is the discrete Choquet integral. Following Grabisch (1995) and Marichal (2000), 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 by $v = (v_1, ..., v_m) \in R^n$. The (discrete) Choquet integral of $v \in R^n$ with respect to w is defined by:

$$C_w(v) = \sum_{j=1}^{m} v_{(j)} \left[w(K_{(j)}) - w(K_{(j+1)}) \right] \tag{5}$$

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

The Criteria Weighting Based on Questions

In MCDM, by using the groups of methods based on assigning weights, it is assumed that decision makers are able to express their judgments about the criteria's importance. However, very often decision makers are not aware of the relationships among different criteria. Marichal and Roubens (2000) have already emphasized that it is important to ask the decision maker the kind of good questions to determine the weights of interacting criteria from a reference set; since questions are not evident from (Marichal and Roubens, 2000), we propose the use of the problem definition method based on questions to determine

the weights of criteria.

According to Cook (1998), the 5Ws & H technique is a structured method that examines a problem from multiple viewpoints. It is based on who, what, when, where, why and how questions. When the technique is used for problem definition, the process may be summarized as follows (Cook, 1998). We state the problem starting with 'In what ways might ... ?' and write down the questions that are relevant to the problem. Participants answer the questions, examine responses to each question and use them to stimulate new problem definition. Any redefinitions suggested are written down so that one redefinition that best captures the problem we are trying to resolve is selected.

In this paper, we propose the following process of establishing the judgments about the criteria's importance by the 5Ws & H technique:

1. In what ways might the criteria weights be determined?
2. The questions regarding the criteria's importance are put and written down.
3. The questions are answered and the weights are determined and re-determined.

When there are synergies and redundancies among different criteria, the re-determination of the criteria weights comes into forefront.

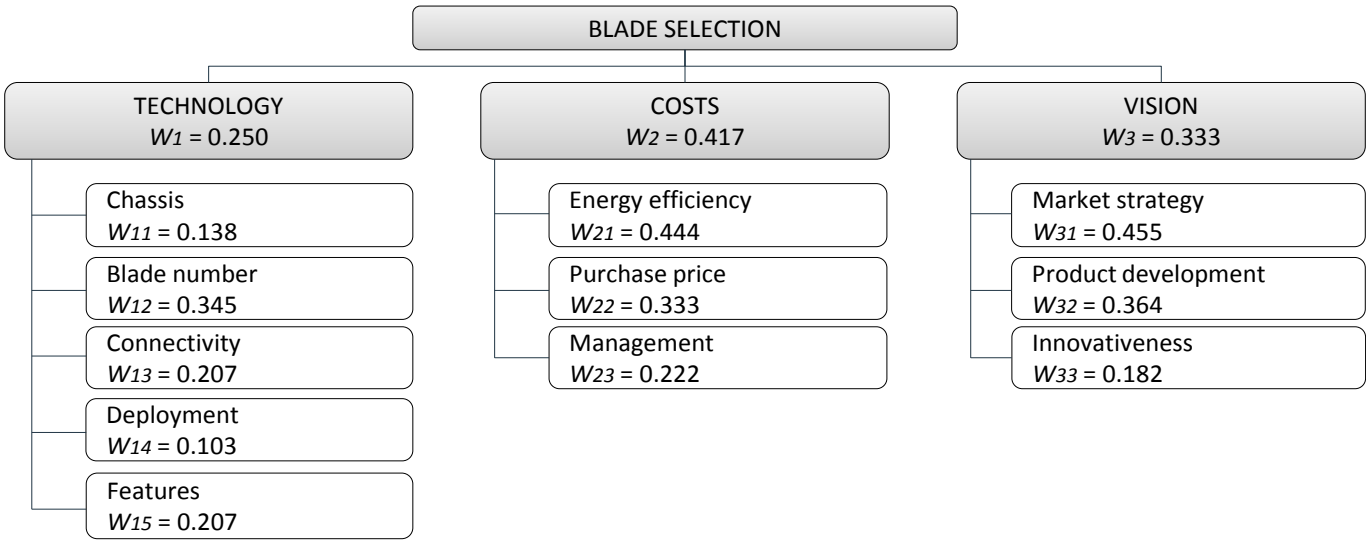
To determine the criteria's importance by using the SWING method, the frame questions can be written as follows: (1) Q-SWING-1: Which criterion change from the worst to the best level is considered the most important? and (2) Q-SWING-2: With respect ot this change importance, how many points less and how many points are given to other criteria changes?

To determine the criteria's importance by using the SMART method, the following frame questions can be used: (1) Q-SMART-1: Which criterion change from the worst to the best level is considered the least important? and (2) Q-SMART-2: With respect to this change importance, how many points more and how many points are given to other criteria changes?

A Practical Case: Blade Selection

This section describes the process of establishing judgments about the criteria's importance by using the 5Ws & H technique in decision-making about blade selection. The MCDM model for the selection of the most suitable blade was built together with an IT company with the aim of presenting possible solutions to their current and potential customers: medium-sized and large companies. The blades that can be offered are described as alternatives in Table 1: IBM BladeCenter (IBM Systems and Technology, 2011) – Alternative 1, HP BladeSystem c7000 Enclosure (Hewlett-Packard Development Company, 2011) – Alternative 2, Oracle's Sun Blade 6000 (Oracle, 2010) – Alternative 3, whereas blades that are not suitable to medium-sized and large companies were eliminated. The criteria hierarchy includes the 'technology' (Chassis, Blade number, Connectivity, Deployment, Features), 'costs' (Energy efficiency, Purchase price, Management) and 'vision' attributes (Market strategy, Product development, Innovativeness). The criteria structure is presented in Figure 1.

Figure 1
The Criteria Structure and the Weights for the Blade Selection



Source: Author's illustration

The decision maker with appropriate knowledge for the problem definition techniques and for MCDM (in this case, the co-ordinator) asks (Q) and answers (A) the typical question of the first step of the 5Ws & H technique process:

Q: In what ways might the criteria weights be determined?

A: Directly, by using several methods based on the interval scale (e.g. SWING, SMART), ordinal (SMARTER) and ratio scale (AHP); individually, in groups; by assuming independence between two criteria, by considering interactions among multiple criteria.

In the second step, the co-ordinator asked, and in the third step, answered the questions about the responsibility and competency regarding expressing judgments about the criteria's importance. After the participants of the group for solving the problem were defined (project manager, seller, engineers in the considered IT company, responsible for pre-sales support, customers), they answered the questions, successively put by the co-ordinator. To determine the first level criteria's importance, the SWING method was used:

Q: Which criterion change from the worst to the best level is considered the most important?

A: The change from worst to best costs.

Q: With respect to this change importance, how many points less and how many points are given to other first-level criteria changes?

A: 20 points less, i.e. 80 points are given to the change from the worst to the best vision, and 40 points less (i.e. 60 points) are given to the change from the worst to the best technology.

Similar questions were asked to determine the importance of the attributes of technology. To determine the weights of the vision attributes, the SMART method was used:

Q: Which criterion change from the worst to the best level is considered the least important?

A: The change from worst to best innovativeness.

Q: With respect to this change importance, how many points more and how many points are given to other vision attributes changes?

A: 10 points more, i.e. 20 points are given to the change from the worst to the best product development, and 15 points more (i.e. 25 points) are given to the change from the worst to the best market strategy.

Similar questions were asked to determine the importance of the attributes of the costs. The weights in Figure 1 were determined by considering the above-written answers, (1) for the weights of the first level criteria and (2) for the weights of the second level criteria.

Table 1
Alternatives' Data with Respect to the Attributes

	Data Type	Alternative 1	Alternative 2	Alternative 3	Measuring Local Alternatives' Values
Chassis	Quantitative: number of choices	5	3	2	Value function, LB: 1, UB: 5
Blade Number	Quantitative: number	14	16	10	Value function, LB: 6, UB: 16
Connectivity	Qualitative, verbal evaluation	Flexible	Limited	Flexible	Pair-wise comparisons
Deployment	Quantitative, MU: h	12	8	8	Value function, LB: 4, UB: 16
Features	Quantitative: number	3	3	1	Value function, LB: 1, UB: 4
Energy Efficiency	Quantitative: 1000 kWH	190	240	165	Value function, LB: 60, UB: 240
Purchase Price	Quantitative, MU: 1000 €	100	140	130	Value function, LB: 60, UB: 140
Management	Quantitative, MU: 1000 €	400	400	600	Value function, LB: 400, UB: 600
Market Strategy	Qualitative, verbal evaluation	Good	Very good	Not enough	Pair-wise comparisons
Product Development	Qualitative, verbal evaluation	Good	Very good	Good	Pair-wise comparisons
Innovativeness	Qualitative, verbal evaluation	Medium	Medium	Low	Pair-wise comparisons

Note: MU – measurement unit, € – Euro, h – hour, kwH – kilo watt hour, LB – lower bound, UB – upper bound, Alternative 1 – IBM BladeCenter (IBM Systems and Technology, 2011), Alternative 2 – HP BladeSystem c7000 Enclosure (Hewlett-Packard Development Company, 2011), Alternative 3 – Oracle's Sun Blade 6000 (Oracle, 2010)

Source: Hewlett-Packard Development Company, 2011; IBM Systems and Technology, 2011; Oracle, 2010; own experience of the observed company's pre-sales support engineers

Table 1 shows the alternatives' data with respect to the criteria of the lowest hierarchy level, together with the methods that are used to measure the local alternatives' values. To evaluate alternatives with respect to the 'vision' attributes (Figure 1) and to 'connectivity', engineers in the considered IT company compared preferences to alternatives by pairs. They evaluated the considered blades with respect to the 'costs' attributes (Figure 1) and to 'deployment' by using decreasing value functions, and with respect to 'chassis', 'blade number' and 'features' by using increasing value functions (Table 1). The alternatives' values with respect to the higher level criteria and the aggregate alternatives' values obtained by the additive model (4) are presented in Table 2. They allow us to report that Alternative 1 is the most appropriate alternative.

Table 2
The Alternatives' Values, Obtained with the Additive Model

	Alternative 1	**Alternative 2**	**Alternative 3**
Value with respect to 'technology' v_1	0.675	0.650	0.330
Value with respect to 'costs' v_2	0.512	0.222	0.227
Value with respect to 'vision' v_3	0.244	0.601	0.156
Aggregate alternative's value v	0.463	0.455	0.229
Rank	1.	2.	3.

This is a complex MCDM process, where interactions among criteria should be considered; the co-ordinator found that the Choquet integral as an aggregation function has proven quite useful and convenient in this direction. Since engineers in the considered IT company, who are responsible for pre-sales support, can evaluate the synergies and redundancies between factors on the bases of their professional experience, detailed data from the principal, and the project goals directly, he asked them the following questions:

Q: Which synergies should be taken into consideration?
A: The customers' (especially top) managers that make the blade purchase decisions are interested in the interactions among higher level criteria, in this case among 'technology', 'costs' and 'vision'.
Q: Where are the synergies/redundancies in this model?
A: Synergy: between 'costs' and 'vision,' redundancy: between 'technology' and 'vision'.
Q: Why is there synergy between 'costs' and 'vision' and what does it mean?
A: Appropriate vision enables better cost controlling. In the concept of the Choquet integral this means: w2,3 > w2 + w3; w2 + w3 = 0.75 (Figure 1), w2,3 = 0.85.
Q: Why is there redundancy between 'technology' and 'vision' and what does it mean?
A: Because the vision determines the technology. For the concept of the Choquet integral, this means that w1,3 < w1 + w3; note that w1 + w3 = 0.583 (see Figure 1), w1,3 = 0.45.

Considering the above-written answers, the weights were re-determined. Table 3 presents the Choquet integrals for the selection of the most suitable blade, obtained by (5).

Table 3
The Alternatives' Values, Obtained by Considering Interactions among Criteria with the Choquet Integral

	Alternative 1	**Alternative 2**	**Alternative 3**
Choquet integral C	0.463	0.405	0.229
Rank	1.	2.	3.

Studying the results in Table 3, which were obtained by considering the synergic and redundancy elements with the Choquet integral, we can report that considering interactions among criteria did not change the final rank of alternatives. However, when comparing it with the values obtained by the additive model (Table 2), it can be concluded that redundancy between 'technology' and 'vision' decreased the value of the Choquet integral C of Alternative 2 (note that $v_2 < v_3 < v_1$). Because $v_3 < v_2 < v_1$ for alternatives 1 and 3, the above mentioned redundancy did not influence C of alternatives 1 and 3, and the synergy between 'costs' and 'vision' did not come into forefront. Although the aggregate values of alternatives 1 and 2, obtained by the additive model (4) (Table 2), are extremely sensitive to the changes of the weights of 'costs' and 'vision', the redundancy between 'technology' and 'vision' considerably decreases C of Alternative 2 and thus strengthen the decision-making basis.

Discussion and Conclusion

The problem definition techniques based on questions (W, 5Ws & H, Why, the 5 Whys) and visualisation (cognitive mapping, fishbone diagrams, mind mapping) are usually applied in problem definition – the first step of the frame procedure for MCDM, based on assigning weights, in order to find and describe a problem, relevant criteria and alternatives. However, we illustrated that in this paper adapted and completed steps of the 5Ws & H technique enable decision makers to consider several aspects regarding establishing the criteria weights. The described approach requires the co-ordinator that can be a member of the decision-making group, but has knowledge on both the considered problem definition technique (5Ws & H) and the computer supported MCDM methods based on assigning weights (SMART and SWING). It enables other participants to focus on professional aspects of the considered problem without knowing the particularities of weighting and aggregation procedures for interacting criteria.

Answering the research questions written in the introduction part of this paper, the results of our research work can let us draw the following conclusions. The first result is a theoretical statement of the weighting scheme, based on the interval scale, for a new decision mechanism. Considering the main features of the 5Ws & H technique, we answered the first research question. The process of establishing the judgments about the criteria's importance includes three steps: from finding the ways for the criteria weights determination, through putting and writing down the questions regarding the criteria's importance, to answering the questions and the weights determination and re-determination. Following the main characteristics of the methods for criteria weighting based on the interval scale, we wrote the frame questions for the SWING and the SMART method to contribute to the second step of the above mentioned process for establishing the judgments about the criteria's importance. The quantitative weighting and aggregation tools, selected in this paper, can let us consider interactions among criteria. The second result is the application of the presented weighting scheme in a real-world case-study: the selection of the most appropriate blade. The MCDM results obtained in the real-life application can let us answer the second research question: considering interactions among criteria strengthened the decision-making basis in the selection of the most appropriate blade.

The paper shows that creative approaches are not limited to merely problem definitions and problem structuring. They can be also used in typically analytical steps in the framework procedure. The adapted and completed steps of the problem definition 5Ws & H technique, the frame questions for the SMART and the SWING methods and their inclusion in the frame procedure for MCDM allow the mutual assistance of creative and decision-making methods.

We recognize further application possibilities of the methods based on questions in measuring the local alternatives' values. The proposed procedure can be applied in the selection of the IT structure where synergies and redundancies appear among criteria.

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