A Methodology for Alternatives Ranking by Estimations Forming based on Values from Criteria Decomposition into Options

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Abstract - Decision-making problems are a daily part of the activity not only of companies and organizations but also of the individual. Broadly, they can be divided into group decision-making problems and those with a single decision-maker. In both decision-making situations, the alternatives from which a choice must be made are characterized by multiple attributes. Given that the number of attributes and alternatives increases, the decision-maker's ability to deal with the problem decreases, and an appropriate process is needed to handle the available information. In this regard, this article proposes a methodology for group decision-making to support the experts in expressing preferences. This approach is suitable for group decision-making problems where all criteria can be chosen in such a way as to be objectively measurable. These criteria are grouped based on experts' areas of expertise and at the same time decomposed with clearly defined options. The option reflects the availability and the value of a feature in each of the alternatives. By decomposing the criteria, the procedure for the decision-makers is shortened, taking the form of a survey in which they express the importance of the criteria and the options together with the criteria orientation . This allows decision-makers to skip the process of estimating the alternatives themselves. In this way, the decision-makers do not need to know in depth the alternatives among which they are choosing. The applied model is tested for a specific real case of choice, and the obtained results show its applicability.

Key-Words: - Group decision-making, Alternatives ranking, Criteria grouping, Criteria decomposition, Objective criteria, Criteria orientation , Office Monitors.

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1 Introduction

One of the most important and fundamental tasks in management is decision-making. This type of task involves several main stages related to the correct expression of objectives, the determination of various and possible solutions, the assessment of their feasibility, the assessment of the consequences and results of the implementation of each decision, and finally the selection and implementation of the decision. An overview of the concept of decision-making, including the main stages of the decision-making process itself, and models for decision-making is presented in [1]. Based on reviewed articles authors propose some guidelines for selecting the most appropriate decision-support tools for particular community needs, [2]. The applications of Multiple-Attribute Decision-Making (MADM) are dominant compared to multi-objective decision-making (MODM) and therefore various MADM techniques are developed and some of the MADM methods are presented, [3]. Research demonstrates how tools can support managerial decisions by building competencies in data-driven decision-making [4], while other studies highlight how knowledge can manage decision-making style and organizational performance, [5].

There are many decision-making situations in which the alternatives from which a choice must be made are characterized by multiple attributes and are predefined in advance. These kinds of problems are solved by MADM methods. The methods of MADM can be divided into two groups – non-compensatory and compensatory. Among the non-compensatory methods are maxmin, maximax, dominance, conjunctive constraint method, and lexicographic method, [6]. The variables aggregation is one of the most critical stages in the forming of composite indicators, and most questions concern the issue of compensation between poor and above-average performing variables, [7]. The compensatory models are very popular and can be distinguished into three categories relating to: (1) scoring methods (2) compromising methods and (3) concordance methods, [8]. The compromising methods seek expedient and mutually acceptable solutions obtained from the available alternatives and some representatives are TOPSIS [9] and VIKOR [10].

Some of the scoring methods rely on multi-attribute utility theory (MAUT) [11] where the preferred alternative has the highest score. Other very popular and easy-to-understand methods are Simple Additive Weighting (SAW) and Analytical Hierarchy Process, [12]. In a recent paper, the authors propose cluster models for classification based on appropriate techniques for building scoring models in different domains, [13].

MADM has been applied in a variety of contexts to deal with the problems of an individual Decision Maker (DM) or a group of DMs, [14]. The tricky in applying this type of method is the evaluation of DMs' preferences and the definition of the evaluation parameters. The critical step is determining the criteria orientation, to ensure the proper ranking of alternatives, as this affects the normalization process, [15]. In addition, when forming the final group decision, it is important to take into account the experts' competencies toward evaluation criteria, [16]. With increases in the number of attributes of the alternatives, the DM's ability to deal with the problem decreases, necessitating the use of information preprocessing. On the other hand, psychologists have long argued that making a choice changes a DM's preferences, and choices simply reveal preexisting preferences, [17].

Taking into account all of these circumstances, the goal of the article is to propose an easy-to-use and easy-to-understand approach for ranking alternatives based on a modification of the SAW approach. This approach needs to be capable of handling group decision-making problems where the problem for solving is characterized by multiple criteria and sub-criteria expressed by some kind of measure.

With advances in digitization, computer vision syndrome has been identified, which is related to eye discomfort that comes from looking at screens and includes eye strain, headaches, and neck or back pain, among others. Techniques to reduce leg syndrome include everything from using the right hardware to good workspace design. Some authors have investigated the work with visual display units [18] and work with multiple monitors [19] and this motivates us to illustrate the proposed model in the selection of monitors.

The rest of the article is organized as follows: Section 2 provides a problem description. Section 3 describes the proposed methodology for alternatives ranking by estimations forming based on values from criteria decomposition into options. Section 4 presents the mathematical model for group decision-making and the approach for decomposing the criteria into options. In Section 5 the proposed methodology is applied to a real-life problem. Section 6 discusses the obtained results and Section 7 presents the conclusions of authors and the areas of feature development.

2 Problem Description

Digital transformation sustainably replaces conventional resources, but the fact that hardware resources directly affect the health of workers is to be taken also into account. Therefore, the specific problem under consideration is related to the determination of the appropriate type of monitors for updating the office equipment of a medium-sized company. When selecting office equipment, the focus of the company's financial department is on cost optimization, designers are interested in sizes, shapes, and color gamuts, while the employees seek comfort and a pleasant experience rather than the cost of their office resources. It is needed to take different points of view in forming the final choice, which transforms the problem into a problem for a group decision. The selection process should be simple and intuitive enough to allow all experts to express their point of view about the devices' parameters without the need for extensive study.

3 Methodology for Alternatives Ranking by Forming Estimations Based on Values from Criteria Decomposition into Options

In order to solve the formulated problem, it is proposed the following methodology for alternatives ranking by estimations is proposed based on values from criteria decomposition into options, as shown in Figure 1.

The first step of the methodology concerns determining the ranking problem parameters as a whole. For example, it is necessary to determine parameters such as the number of alternatives, the number of criteria, and the number of DMs.

In Step 2, criteria should be grouped by appropriate subject areas and required expertise. This information is the basis on which the importance weights of the expert DMs are determined, which happens in Step 3. It is through these weights that it is possible to manage the importance of each DM by assigning the highest importance weight to the area where is the competence of the individual DM.

Step 4 refers to determining the type of criteria. It is proposed to define two types of criteria non-decomposable and decomposable. The decision of whether to decompose the criterion is subjective. For example, financial criteria such as price and operating costs, which have mostly numerical values do not sense to be decomposed. In this case, the non-decomposable criterion numerical value could be directly used as an estimation of the alternatives for each DM. In the case that it is appropriate for the criterion to be decomposed the algorithm goes to Step 5.

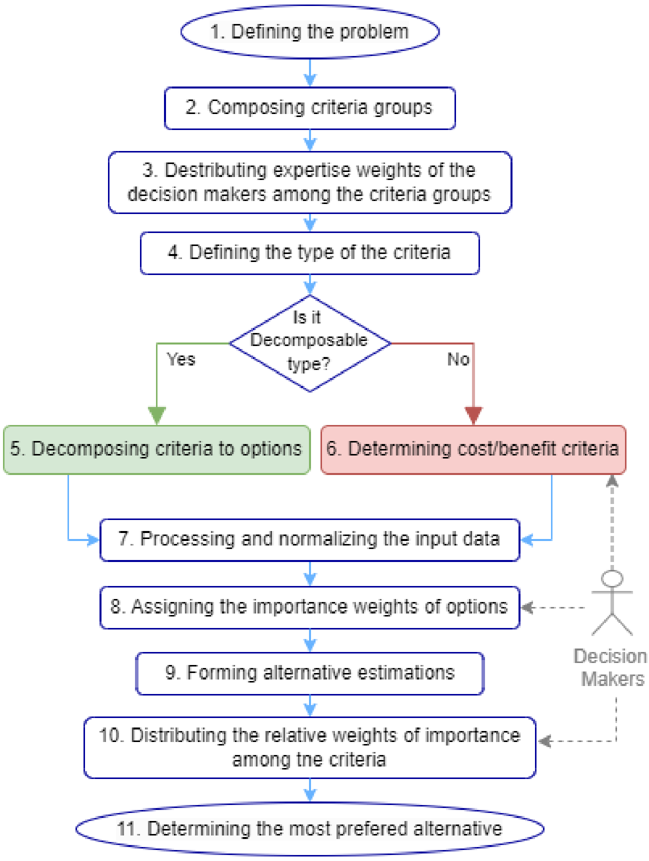

Fig. 1: Methodology for alternatives ranking by forming estimations based on values from criteria decomposition into options

In Step 5, the criterion can be represented by a tree structure, where the end nodes reflect the presence and value of the options in each of the alternatives. Options can accept boolean values, numeric values, or a combination of both data types.

Step 6 is critical to determine the direction chosen for normalization. That means each DM should select if the non-decomposable criteria will be considered a profitable/beneficial category or part of a cost category. Based on this information, DMs need to express their preferences regarding the non-decomposable type of criteria.

Step 7 refers to the processing and normalization of the raw data of the two types of criteria (non-decomposable and decomposable). The units and values are to be converted to a form convenient for comparison, this is done in order to preserve the proportions. Also, the administrative expert needs to select and apply the most appropriate normalization technique to make the processing data dimensionless and comparable.

In Step 8, each DM needs to determine weighting coefficients for importance to each of the decomposed options. This is the way DMs' preferences are expressed for this type of criteria.

In Step 9, already processed input data of the options from the decomposed criteria and the expressed preferences are calculated to get estimations of the alternatives for each DM.

In Step 10, the DMs have to determine the relative importance weights among the criteria.

In the final Step 11, a matrix of alternatives is assembled and filled with as many extracted preferences and objective data as possible. By applying a suitable model, the most preferred alternative can be determined, taking into account the opinions of the group of experts.

4 Mathematical Model

The well-known SAW model seems to be appropriate to be integrated with the proposed methodology for alternatives ranking by forming estimations based on values from criteria decomposition into options, as follows:

$$A_{SAW}^{*} = max \sum_{j=1}^{N} w_j a_{ij},\ i = 1,2,\ldots,M \quad (1)$$

$$\sum_{j=1}^{N} w_j = 1 \quad (2)$$

where a DM estimates the alternatives a_{ij} according to the number of extracted criteria N, and expresses their opinion on the importance of the criteria with relative weighting coefficients w_j for which there is a constraint (2).

To take into account the expertise of different DMs in group decision-making at the same time in the various areas of competence, the following modification can be used, [16]:

$$A_{SAW}^{GDM} = max(\Lambda) \sum_{j=1}^{N} w_j^k a_{ij}^k,\ i = 1,2,\ldots,M \quad (3)$$

$$\Lambda = \begin{matrix} \\ CG_1 \\ \ldots \\ CG_R \end{matrix} \begin{matrix} DM^1 & \ldots DM^k & \ldots DM^Q \\ \begin{bmatrix} \lambda_1^1 & \ldots & \lambda_1^k & \ldots & \lambda_1^Q \\ \ldots & & \ldots\ \lambda_p^k & \ldots & \\ \lambda_R^1 & \ldots & \lambda_R^k & \ldots & \lambda_R^Q \end{bmatrix} \end{matrix} \quad (4)$$

where λ_p^k is the weighted coefficient for the expertise of k-th DM ($k = 1,2,..,Q$) in accordance with the p-th criteria group CG_p ($p = 1,2,..,R$), composed in the matrix $\Lambda = \{\lambda_p^k\}$. The following constraint $\sum_{k=1}^{Q} \lambda^k = 1$ is applied to the distribution of expert weights.

The proposed approach for forming the evaluations of the alternatives against a criterion of a decomposable type is expressed as follows:

$$a_{ij}^k = \frac{\sum_{l=1}^{L} s_l^k v_l}{L\ S_{max}} \qquad (5)$$

where the number of the options for the decomposable criteria is denoted by L, and $l = 1,2,..,L$ is the index of the current option. The option's value is indicated with v_l and s_l^k is the importance coefficient set by the k-th DM in accordance with the l-th option. The maximal estimation that can be set in accordance with the scale that is chosen is denoted by S_{max}.

In case the criterion is of non-decomposable type its evaluation is formed from the normalized objective numerical values. These values directly can be used as a_{ij}^k in the modified SAW (3).

5 Case Study for Selecting the Type of Office Monitors

In order to verify the correctness of the proposed methodology, it was applied to the office monitor type selection case of a medium-sized IT company. The selection of a monitor has to be done from a predefined set of five alternatives, three DMs, and three groups of criteria, containing a total of 21 sub-criteria that are broken down into 33 options. The set of monitors (alternatives) that need to be ranked are as follows:

- Dell U2724DE (A1);
- HANNSpree HT248PPB (A2);
- Samsung U32J590 (A3);
- LG 32QP88NP-B (A4); and
- MSI MEG 342C (A5).

All of the evaluation criteria are divided into three groups: Financial criteria (Group 1), Healthcare and Ergonomic criteria (Group 2) and Technical criteria (Group 3). Among the selected DMs are:

- technical person or software engineer (DM1);
- human resources specialist who cares about the health and comfort of the employees (DM2);
- representative of the financial department (DM3).

The selected DMs are with competencies that meet all groups of criteria. Taking into account the competencies of the experts and the formed three groups of criteria, the weighted coefficients for the expertise of DMs regarding the criteria groups are shown in Table 1.

Table 1. Expert weights for DMs competencies according to criteria groups

Criteria Groups	DM1	DM2	DM3
Group 1: Financial criteria	0.17	0.31	0.52
Group 2: Healthcare and Ergonomic	0.34	0.46	0.20
Group 3: Technical criteria	0.60	0.20	0.20

The criteria distributed into groups are presented in Table 2.

Table 2. Distribution of criteria in groups and their measurement unit

Criteria Groups	Criteria	Measure
Group 1: Financial criteria	C1: Price	EUR
	C2: Warranty	Months
	C3: Power Consumption	kW/h
	C4: Power Consumption on Standby	kW/h
	C5: Cables Included	Yes/No
Group 2: Healthcare & Ergonomic	C6: Eye care technologies	Options
	C7: Tilt Angle	Degrees
	C8: VESA wall-mount	Yes/No
	C9: Adjustable High	Yes/No
	C10: Portrait Mode	Yes/No
Group 3: Technical criteria	C11: Screen Size	Options
	C12: Panel Type	Options
	C13: Backlight Technology	Options
	C14: Resolution	Options
	C15: Refresh Rate	Hz
	C16: Response Time	ms
	C17: Connectivity options	Options
	C18: Brightness	cd/m²
	C19: Colour Support	bits
	C20: Colour Gamut	% sRGB
	C21: Additional Options	Options

The measurement units that are used for the Financial criteria are respectively for C1 – "*price in euros*", for C2 – "*number of months*", C3 and C4 – "*kilowatts per hour*", and for C5 – available or not.

Very important features that integrate vision protection technologies and the musculoskeletal system through the ergonomics of monitor use are composed in Group 2. Criterion C6 contains the vision protection technologies broken down as options. The rest of the criteria in the group aid the correct body position and employee productivity. Although a numerical value can be extracted for each of these criteria, only the "*Tilt Angle*" will be evaluated with it. Since the values of C8, C9, and C10 are a norm for the selected alternatives, it was decided that they should participate with values – available or not.

Six criteria of a technical character in Group 3, are decomposed into options C11, C12, C13, C14, C17, C21, and the rest are represented with their numerical value measure. It is specific to the C11 that it can be expressed directly by the size in inches, but it is chosen to be decomposed to allow the DMs the possibility to express their preference for a specific screen size. For the C19, the color gamut has been chosen to be measured according to the industry standard "*sRGB*". Since the number of colors of different monitors in C20 criteria differs by two numerical orders, in order not to distort the results, it was chosen to use as a measure the number of bits with which one color is represented.

The data of the options from the decomposed criteria is collected from the official specifications of the alternatives. This data together with the importance weights assigned to the options by the DMs corresponding with s_l^k according to (5) are presented in Table 3.

The options take a boolean value that reflects the presence or absence of the corresponding characteristic in each of the alternatives. The exception is the options for C17. It is broken down into options, but they do not only indicate the presence but also the number of connecting ports supported by the respective monitor.

Criterion C6 is divided into four main features and technologies to reduce digital eye strain from wide pulse modulation and minimize visual and physical discomfort from blue light.

Table 3. Input data of the options extracted from the alternatives' official specifications

Decomposed Criteria		**Input Data of Options**					**Determined Weights for Importance by DMs**		
Options		***A1***	***A2***	***A3***	***A4***	***A5***	***DM1***	***DM2***	***DM3***
C6	O1: Blue Light Filter	yes	yes	no	no	yes	6	7	3
	O2: Flicker Reduction	no	yes	yes	yes	yes	6	7	3
	O3: Ambient Light Sens	yes	no	no	yes	yes	3	6	2
	O4: Anti-glare Coating	yes	yes	yes	yes	yes	5	6	3
C11	O5: Size 23.8"	no	yes	no	no	no	1	2	5
	O6: Size 27"	yes	no	no	no	no	6	3	5
	O7: Size 31.5"	no	no	yes	yes	no	4	5	4
	O8: Size 34.2"	no	no	no	no	yes	7	7	3
C12	O9: IPS	yes	no	no	yes	no	5	7	4
	O10: VA	no	yes	yes	no	no	4	3	4
	O11: OLED	no	no	no	no	yes	6	5	3
C13	O12: LED	yes	yes	yes	yes	no	5	4	5
	O13: QD-OLED	no	no	no	no	yes	6	4	4
C14	O14: UW-QHD	no	no	no	no	yes	7	4	3
	O15: UHD	no	no	yes	no	no	6	6	3
	O16: QHD	yes	no	yes	yes	no	4	5	5
	O17: FHD	yes	yes	yes	yes	no	2	2	5
C17	O18: HDMI	1	1	2	2	2	7	6	5
	O19: DisplayPort	2	1	1	1	1	7	5	5
	O20: USB-Type C	2	0	0	1	1	4	4	3
	O21: USB C (DP alt)	1	0	0	1	1	7	4	3
	O22: Thunderbolt 4	2	0	0	0	0	4	4	3
	O23: USB Type A	4	2	0	2	4	3	5	5
	O24: USB Type B	0	0	0	0	1	1	3	2
	O25: D-Sub	0	1	0	0	0	1	3	3
	O26: RJ-45	1	0	0	0	0	2	3	5
	O27: Audio line out	1	1	1	1	2	2	6	5
C21	O28: Curved	no	no	no	no	yes	5	6	2
	O29: G-Sync	no	no	yes	yes	yes	5	2	1
	O30: PiP/PbP	yes	no	yes	no	yes	6	5	5
	O31: KVM Switch	yes	no	no	no	yes	6	5	4
	O32: Touch Screen	no	yes	no	no	no	4	6	2
	O33: Speakers	no	yes	no	yes	yes	3	3	1

The options of C14 are formulated in such a way that if one monitor supports high resolution, it also supports all lower ones with the same proportions (16:9). This condition excludes option O14 which has an aspect ratio of 21:9. In this regard, it can be noticed that the options of C11, C12 and C13 have mutually exclusive relationship, and options of C6, C17 and C21 can be present together at the same alternative.

To express preferences for options, DMs used a scale from 1 to 7, where a value of 1 represents the lowest degree of appropriateness and 7 represents the highest degree of appropriateness. That means when using these data in the proposed model they need to be normalized in the range between 0 and 1 to be compatible with the ranges of the evaluation score.

6 Results and Discussions

All of these data for the described problem as a result of the applying proposed methodology were used under three different cases – Case 1, Case 2, and Case 3. Case 1 is a generalized case, where the criteria orientation determination is done by an administrative expert rather than DMs. Case 2 illustrates the situation where a DM changes the orientation of a criterion which is from his area of expertise. Case 3 considers the situation when the DM changes his preferences to the options of a decomposable criterion.

The aggregated group decision matrix for Case 1 is shown in Table 4.

For the decomposable criteria, estimations of the alternatives are formed for each DM separately. This is achieved by applying the expression (5) to the objective data and the assigned importance weights to the options filled in Table 3. For the non-decomposable criteria, the calculated estimation is produced by applying a linear normalization on the objective values and this estimation is used for all three DMs.

The additional column "*Category of criteria*" in the aggregated group decision matrix indicates the chosen criteria orientation (benefit/cost) for the non-decomposable criteria. In Case 1 it is set by the administrative expert and is the same for all the DMs. The administrator expert has determined that in the general case C1, C3, C4, and C16 are not in favor of the users of monitors. Therefore, these non-decomposable criteria participate as a cost in the process of normalization. The ranking of the alternatives in the Case 1 is represented in Figure 2.

Table 4. Aggregated group decision matrix and types of category for criteria under Case-1

Criteria	**Relative importance weights of criteria**			**A1**			**A2**			**A3**			**A4**			**A5**			**Category of criteria**
	DM1	***DM2***	***DM3***	***DM1***	***DM2***	***DM3***	***DM1***	***DM2***	***DM3***	***DM1***	***DM2***	***DM3***	***DM1***	***DM2***	***DM3***	***DM1***	***DM2***	***DM3***	
C1	0.02	0.04	0.11	0.57			0.82			1.00			0.69			0.23			cost
C2	0.04	0.09	0.09	1.00			0.67			0.67			1.00			1.00			benefit
C3	0.02	0.02	0.08	0.57			1.00			0.24			0.33			0.33			cost
C4	0.01	0.02	0.07	0.60			1.00			1.00			0.60			1.00			cost
C5	0.06	0.08	0.07	1.00			1.00			1.00			0.00			1.00			benefit
C6	0.09	0.09	0.06	0.50	0.68	0.29	0.61	0.71	0.32	0.39	0.46	0.21	0.50	0.68	0.29	0.71	0.93	0.39	-
C7	0.07	0.08	0.04	0.47			1.00			0.31			0.91			0.45			benefit
C8	0.01	0.07	0.02	1.00			1.00			1.00			1.00			1.00			benefit
C9	0.03	0.06	0.04	1.00			0.00			0.00			1.00			1.00			benefit
C10	0.09	0.08	0.03	1.00			0.00			0.00			1.00			0.00			benefit
C11	0.08	0.06	0.07	0.21	0.11	0.18	0.04	0.07	0.18	0.14	0.18	0.14	0.14	0.18	0.14	0.25	0.25	0.11	-
C12	0.09	0.02	0.02	0.24	0.33	0.19	0.19	0.14	0.19	0.19	0.14	0.19	0.24	0.33	0.19	0.29	0.24	0.14	-
C13	0.06	0.02	0.03	0.36	0.29	0.36	0.36	0.29	0.36	0.36	0.29	0.36	0.36	0.29	0.36	0.43	0.29	0.29	-
C14	0.07	0.04	0.03	0.21	0.25	0.36	0.07	0.07	0.46	0.43	0.46	0.46	0.21	0.25	0.36	0.25	0.14	0.11	-
C15	0.03	0.02	0.01	0.69			0.34			0.34			0.43			1.00			benefit
C16	0.02	0.01	0.02	0.01			0.01			0.01			0.01			1.00			cost
C17	0.08	0.07	0.06	0.86	0.93	0.86	0.33	0.43	0.40	0.33	0.33	0.29	0.57	0.59	0.51	0.70	0.86	0.76	-
C18	0.05	0.03	0.02	1.00			0.71			0.77			1.00			0.71			benefit
C19	0.02	0.04	0.03	1.00			0.80			1.00			1.00			1.00			benefit
C20	0.03	0.04	0.02	0.72			0.72			0.71			0.71			1.00			benefit
C21	0.03	0.02	0.08	0.29	0.24	0.21	0.17	0.21	0.07	0.26	0.17	0.14	0.19	0.12	0.05	0.60	0.50	0.31	-

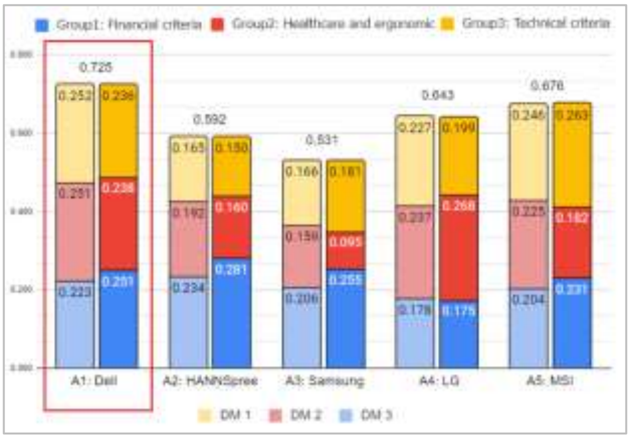
Fig. 2: Alternatives performance by groups of criteria and preferences of DMs in Case 1

With the highest score of 0.725, alternative A1 provides the best balance between the set criteria, although it is not leading in any criteria group. This result can be explained by a sample of the results generated against DM preferences, where A1 estimated with highest result among all alternatives by DM1 (0.252) and DM2 (0.251).

Case 2 examines the same problem in a different context where the organization has gained external funding for equipment and the aim is to maximize its use. In this situation, the criteria orientation according to the price criterion for the financial expert changes from cost to benefit. After linear normalization, the estimations of DM3 get new scores on C1 as follows: A1 receives a score of 0.41; A2 – 0.28; A3 – 0.23; A4 – 0.34 and A5 – 1.00. The recalculated ranking is presented in Figure 3.

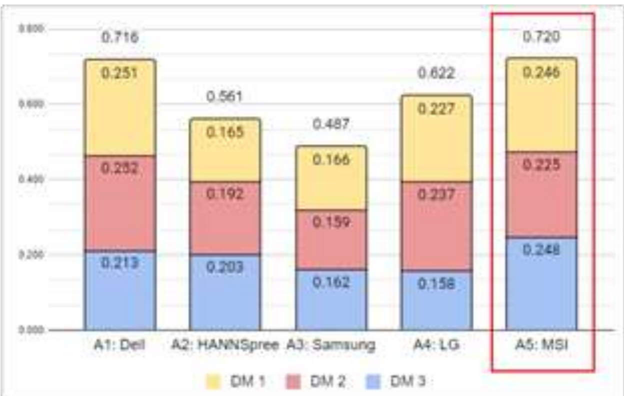
Fig. 3: Alternatives performance by DMs for Case 2

The combination of the highest expertise of DM3 in the financial criterion group and the highest relative importance of the Price criterion rewards A5 with a score of 0.720 to be the most preferred alternative. The ability provided to the DMs to choose the category of criteria normalization - cost or benefit, provides an additional mechanism for expressing their individual preferences.

In Case 3, despite the high quality of the OLED display, the software engineer changed his mind because this type of panel is not suitable for static images, which is the most common use of the office monitor. Therefore, DM 1 updates his preference degree from 6 (Table 3) and the OLED option receives the smallest weight of 1. It can be observed that changing the value of an option leads to a different final result and a slight increase in the evaluation of the alternative A5. This small change, however, does not rearrange the final ranking as it is not enough to have a significant effect. The property that a small change in the input leads to a small change in the output makes the method stable and predictable. The result of the experiment in Case 3 is illustrated in the comparative graphic in Figure 4.

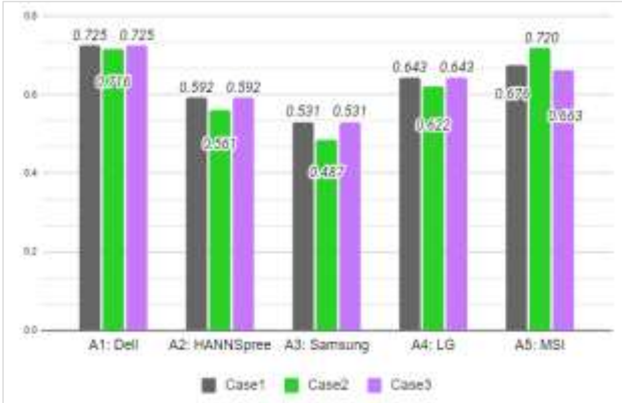
Fig. 4: Comparison of alternatives' overall performance in 3 cases with estimations changes in composable and non-decomposable criteria type

The methodology relies on objective data, but at the same time, it enables DMs to express their preferences through the three variables – the relative importance weights of the criteria and the newly introduced importance weights of the criteria options and criteria orientation preferences.

7 Conclusion

The article examines the problems of group decision-making in the presence of multiple criteria, some of which can be decomposed into several sub-criteria or options. For this purpose, a methodology is proposed, capable of forming an assessment of the alternatives in group decision-making where only objective criteria are used. The main idea of the proposed methodology is the decomposition of the criteria into options and gives the possibility for DMs to determine the category of criteria –

profitable or not. In this way, the DMs themselves are given the opportunity to revise the type of criterion, which would contribute to the control over the decision-making process. The additional advantage is that it cancels the need for the decision maker to know or to go into a detailed study of every single alternative. The requirement for a clear formulation of the criteria and their options has a subjective nature, and this makes it a critical point. The applicability of this approach is demonstrated in a case study of the selection of office monitors for a medium-sized company.

The future development of the methodology is related to its implementation in a software application that would improve the user experience of the decision-making process.

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