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The vital-immaterial-mediocre multi-criteria decision-making method

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Abstract

Purpose – This paper proposes a new MCDM method, called the vital-immaterial-mediocre method (VIMM), to determine the weight of multiple conflicting and subjective criteria in a decision-making problem.

Design/methodology/approach – The novel method utilizes pairwise comparisons, vector-based procedures, and a scoring approach to determine weights of criteria. The VIMM compares alternatives by the three crucial components including the vital, immaterial, and mediocre criteria. The vital criterion has the largest effect on the final results, followed by the mediocre criterion and then the immaterial criterion, which is the least impactful on the prioritization of alternatives. VIMM is developed in two forms where the first scenario is designed to solve one-goal decision-making problems, while the second scenario embraces multiple goals.

Findings – To validate the method's performance and applicability, VIMM is applied to two real-world problems. Comparisons between VIMM, AHP, and BWM reveal that VIMM significantly requires fewer comparisons. Moreover, VIMM works well with both fractional and integer numbers in its comparison procedures.

Originality/value – The new weighting method is presented for the first time in this paper.

Keywords: Multi-criteria decision-making; subjective weighting method; Pairwise comparison; BWM; AHP

1. Introduction

Multi-criteria decision-making (MCDM) problems are constructed on a number of evaluation criteria and several alternative decision possibilities. The MCDM approach begins with the identification of the available alternatives, or options, evaluated against the criteria in order to find the best alternative. According to Guo and Zhao., (2017), The essence of MCDM is the ranking of all the alternatives and then the selection of the optimal one by employing certain approach and existing decision information by considering different criteria. MCDM approaches are powerful tools when we need to define preferences, to achieve desired outcomes based on the opinion of multiple decision-makers or criteria (Hashemi *et al*., 2020). Some the most popular MCDM methods include the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang and Yoon (1981), the analytic hierarchy process (AHP) by Saaty (1971, 1988), Analytical network process (ANP) proposed by Saaty (1996), simple additive weighted (SAW) (MacCrimmon and Rand., 1968), data envelopment analysis (DEA) proposed by Charnes *et al* (1978), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic, 1998 ; Opricovic & Tzeng., 2002), decision making trial and evaluation laboratory (DEMATEL) developed by Fontela and Gabus (1972), preference ranking organization method for enrichment evaluations (PROMETHEE) (Mareschal *et al.*,1984), and ELimination Et Choix Traduisant la REalité or ELimination and Choice expressing reality (ELECTRE) first proposed by (Roy.,1971,1978; Roy & Bertier., 1972). Moreover, some of the recent development of the MCDM method are the Step-wise weight assessment ratio analysis (SWARA) first developed by Keršulienė and Turskis (2011), Multi-attribute evaluation using imprecise weight estimates (IMP) method proposed by Jessop (2014), best-worst method (BWM) introduced by Rezaei (2015), Ranking based on optimal points multi-criteria decision-making method "RBOP" developed by Zakeri (2019), The stratified multi-criteria decision-making method "SMCDM" by (Asadabadi., 2018), and A Combined Compromise Solution (CoCoSo) method by (Yazdani *et al*., 2019).

According to Csiszár *et al*., (2020), classical MCDM procedures are performed in two steps: 'aggregation' which defines an outranking relation that indicates the global preference between any ordered pair of alternatives, and 'exploitation' which transforms the information into a global ranking. MCDM algorithms initiate with "the problem definition". One of the generally accepted definitions of decision-making processes is presented by (Yoe., 2002). According to his work, the multi-criteria decision-making process has eight-steps starting with the problem definition. The proposed concept by Yoe includes the following steps (Zardari et al., 2015): 1. Explicitly define the multi-criteria problem and objectives; 2. List and describe the alternatives to meet the objectives; 3. Define criteria/attributes/performance indicators to measure the performance of alternatives; 4. Gather data to evaluate alternative based on the criteria; 5. Prepare a decision matrix by arranging alternatives against criteria; 6. Elicit subjective or objective weights for criteria; 7. Rank alternatives and communicate results with interest groups; 8. Decision-makers select best alternative based on the input of interest groups and the obtained MCDM results.

MCDM methods are classified regarding the characteristics of the criteria, alternatives, or solution sets in the structure of the decision problem (Arslan., 2018). There are different classifications for MCDM methods; in general, MCDM methods can be classified into Outranking methods (ELECTRE, PROMETHEE), Compromise ranking (GRA), Distance-based (VIKOR, TOPSIS), and Pairwise comparison (AHP, ANP) (Akkucuk., 2016; Elhassouny & Smarandache., 2016; Felix & Karl., 2014; Gupta & Ilgin., 2017; Mosadeghi., 2013; Ricci et al., 2011; Smarandache., 2016; Velasquez & Hester., 2013). Gupta and Ilgin (2017) suggest that MCDM methods are categorized into five categories: 1. Quantitative techniques; 2. Qualitative techniques; 3. Mixed techniques; 4. Heuristics and metaheuristics; and 5. Simulation. In addition, MCDM methods can be classified into three groups (Chen & Hwang., 1992; Kahraman *et al*., 2015; Liao *et al*., 2018; Wu & Liao., 2019) including 1. The utility value-based methods, such as the TOPSIS, VIKOR, MULTIMOORA (Zhang & Chen *et al*., 2019; Lin *et al*., 2020), or DNMA (Liao *et al*., 2018); 2. The outranking methods, such as the PROMETHEE, ELECTRE, GLDS (Liao *et al*., 2018); and 3. The preference ordering-based methods, such as the AHP and BWM. Nemery and Ishizaka (2013) have classified MCDM methods based on their performance into the following four groups: 1. Alternatives selection through their analysis (e.g.

AHP and ANP); 2. the alternative rating (*e.g*., ELECTRE, TOPSIS, or PROMETHEE); 3. The classification of alternatives, *e.g*., the proposed method is expanding the UTilites Additives DIScriminantes (UTADIS) method (see Esmaelian *et al*., 2016); 4. The alternative identification, *e.g.,* Geometrical Analysis for Interactive Aid (GAIA) method (see Elevli & Ozturk., 2019 and Zindani & Kumar., 2018). Another classification proposed by (Roy; 1996) includes three groups: 1. the unique synthesis criterion approach; 2. the outranking synthesis approach; and 3. the interactive local judgment approach (*also see* Schramm & Morais; 2012). Zardari *et al*., (2015) proposed a classification with three classes: 1. Elementary methods such as Weighted product (Boltürk *et al*., 2019; Mateo., 2012), simple additive weighting method (Piasecki *et al*., 2019; Sivaram *et al*., 2020), and Linear assignment (Gou *et al*., 2019; Haghighi *et al*., 2019); 2. Unique synthesis criterion such as simple multi attribute rating technique abbreviated (Alinezhad & Khalili., 2019; Sari *et al*., 2018), AHP, and TOPSIS; 3. Outranking methods such as ELECTRE family and PROMETHEE. MCDM methods are vastly applied in various fields such as the supplier evaluation (Agrawal & Kant., 2020, Rouyendegh *et al*., 2020, Lei *et al*., 2020, Kumari & Mishra., 2020, Gan *et al*., 2019), Energy Policy (Homaei & Hamdy., 2020, Wu & Wang *et al*., 2020, Zheng & Wang., 2020, Kheybari *et al*., 2019), Transportation (Seker & Aydin., 2020, Huang *et al*., 2020, Mahdi Rezaie *et al*., 2020, Moslem *et al*., 2020, Moslem & Gul *et al*., 2020), and Sustainability (Ren & Ren., 2020, Shete *et al*., 2020, Liu, Lo, & Liou., 2020, Garg & Sharma., 2020, Ecer & Pamucar., 2020).

MCDM methods could be divided into the three main categories in terms of their performance: 1. the rating methods with ranking of alternatives, such as TOPSIS and SAW; 2. the weighting methods with weight allocation to the problem's criteria such as Shannon's Entropy (Zakeri *et al*., 2019), and 3. the dual methods that combine ranking and weight allocation.

The MCDM weighting methods are divided into two categories: subjective methods and objective methods. Subjective methods rely completely on the DM's judgement, level of knowledge, and deliberation. On the other hand, the objective methods derive weights through computation operations or mathematical algorithms and models from the decision matrix without taking the human judgments interference into consideration. There are also hybrid approaches, which are designed to take the advantages of both subjective and objective approaches (Yang *et al*., 2017), such as the integrated subjective and objective approach developed by Ma *et al.,* (2019). Wang *et al* (2009) propose a third type called combination weighting method which embraces hybrid methods of the multiplication and additive synthesis. Some of the most important subjective methods are Digital Logic and Modified Digital Logic methods (Dehghan-Manshadi *et al*., 2007), Pairwise Comparison, BWM, Ratio Method (Peng *et al*., 2017), Swing Method (Mustajoki *et al*., 2005), SMART, and SIMOS Method (see Siskos & Tsotsolas., 2015). The examples of the objective method are the Shannon's Entropy (Zakeri & Keramati., 2015) and the CRiteria Importance Through Intercriteria Correlation (CRITIC) method (Wang & Zhao., 2016).

Determining the weights of criteria is a key issue for the validity of the evaluation results (Krylovas *et al*., 2014). The impact of the criteria on the ranking process of alternatives and their importance differ to some extent, yet the main idea of the criterion weight evaluation is that, in fact, the most important criterion is assigned the largest weight in any method used for criterion weight evaluation (Vinogradova *et al*., 2018). Within the subjective and integrated approaches, DM is assumed to be honest, and aims to obtain "best" attribute weights to get a ranking of alternatives (see Dong *et al*., 2018).

There are several methods and approaches to determine criteria weights, ranging from direct criteria rating and point allocation, to more elaborate methods using trade-offs in a structured manner, with significant effects for actual decision-making (Danielson & Ekenberg., 2019). AHP is one of the most popular MCDM subjective weighting methods. As a measurement theory of intangible criteria, AHP assumes that the inherent complexity of a multiple criteria decision-making problem can be solved through the construction of hierarchic structures consisting of a goal, criteria and alternatives (León *et al*., 2019). In the classic form, AHP shows some shortcomings in its processes: 1. Working only with the crisp decisions: the traditional analytical hierarchy process (AHP) is limited by its sole use of exact values when making pairwise comparisons (Ecer., 2020); 2. it relies on the DM's level of knowledge thus dealing with an unbalanced scale of judgment; 3. its inadequacy for ranking the alternatives; and 4. the AHP results are highly impacted by the DM's ambiguity and multiplicity of their preferences and selections in the decision-making process (Gnanavelbabu & Arunagiri., 2018). Rezaei (2015) explains that very significant challenge to the AHP method comes from the lack of consistency in the pairwise comparison matrices, usually occurring in practice due to the unstructured way the comparisons are performed (see Forman & Selly., 2001; Karapetrovic & Rosenbloom., 1999). In addition, the AHP method overlooks the ultimate objectives, which is the starting point of any MCDM method, incorporating inaccuracy due to misalignment of the analytic processes with the DMs objectives. Another popular subjective weighting method is BWM. BWM executes assessments of all criteria with respect to the most critical criterion, as predefined by DMs or experts. This approach allows to overcome the pairwise assessment limitations with regards to perceived criterion performances, thus mitigating eventual discrepancies that may arise at the decision-making matrix level (Muneeb *et al*., 2020). Considering that the existing subjective methods ignore the initial objectives in their approaches, their output carries inaccuracy and imprecision. For example, in both the AHP and BWM methods, the criteria are compared to each other ignoring the initial objectives of the decision-makers (Rezaei., 2015).

In this paper, a new goal-oriented MCDM subjective method called the vital-immaterial-mediocre multi-criteria decision-making method (VIMM) is introduced to solve these shortcomings. Using three main concepts consisting of the vital, immaterial, and mediocre criteria, this novel method is designed to enable obtention of criteria weights based on DMs opinions with an integrated approach to pairwise comparisons, distance measuring, and the scoring method. The main contribution of this paper is introducing a new subjective weighting method that benefits from fewer comparisons compared with BWM and AHP. In addition, it is not dependent on the number of criteria to generate accurate outputs.

VIMM is a goal-oriented subjective weighting method. Also, it employs the pairwise comparison matrices, distance measuring, and scoring method to offer more reliable results compared with other subjective methods.

The remainder of this paper is outlined as follows. In Section 2, the VIMM is proposed. Section 3 presents the application of the VIMM to two real-world problems, including a sustainable supplier evaluation problem and the smartphone selection problem, where the VIMM process is compared to the BWM and AHP approaches considering several evaluation criteria. Conclusions and suggestions for future work are presented in Section 4.

2. The vital-immaterial-mediocre method

The vital-immaterial-mediocre method (VIMM) is a subjective weighting method that principally deals with human judgment. VIMM is designed around the decision-makers' objectives and goals. Goal setting is a distinctive step that needs to be defined separately from the problem characterization. The decision-makers' goals are transformed into the problem structure which shape the remaining steps. The pattern of a decision-making process and the steps where VIMM performs is displayed in Fig. 1.

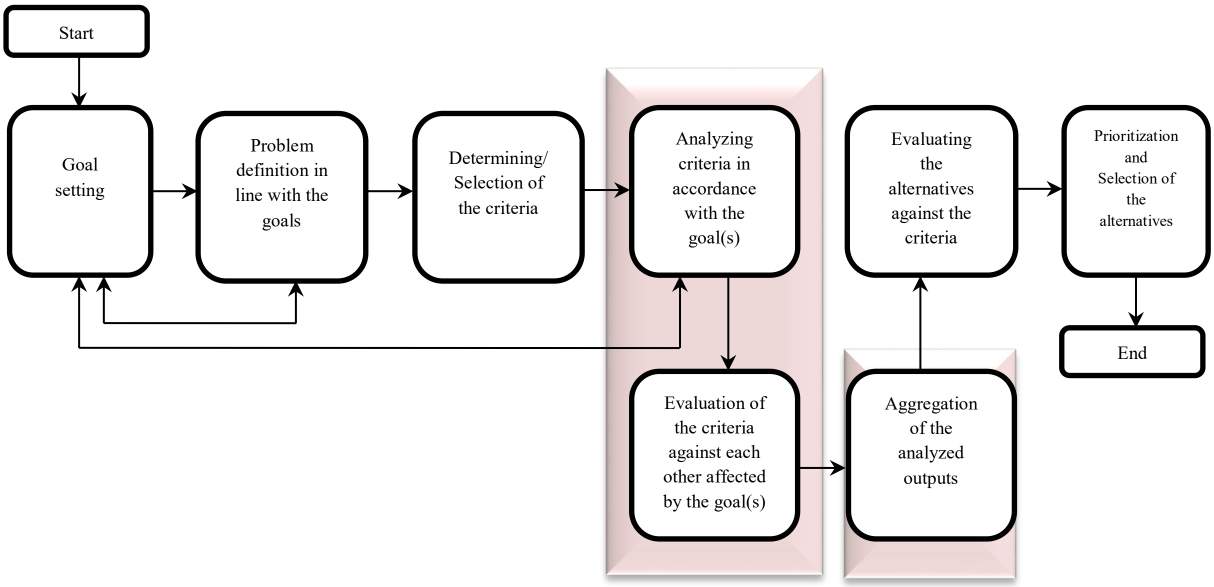

Fig 1

The decision-making process, and the steps that VIMM operates

The three steps of decision-making of the VIMM process are as follows:

Step 1. Goal setting

Clearly defining the decision-making goals helps to assess available criteria or to add new criteria to evaluate the alternatives. In addition, the definition of the goals allows the criteria to be evaluated against each goal, rather than a general concept of goals. Most of the MCDM methods ignore this step and initiate the decision-making process with the problem definition. However, the decision-making problems are the questions that shape the whole decision-making process and conduct it to achieve the goals.

Step 2. Problem definition

The problem needs to be defined with respect to the goals. As the final objective of the decision-making process is to meet the needs that characterize the decision-making goals, the problem must be structured in a way that specifically characterizes each goal and facilitates the algorithm to design the process, which eventually leads to generating the solution. Ultimately, the problem solutions conduct the DM(s) to the goal(s).

Step 3. Determining/ selection of the criteria

In order to analyze the available alternatives, the DM determines and selects the appropriate criteria in three ways (Fig 2):

1. Determining criteria by which to evaluate the alternatives by searching through available resources and databases.
2. Selecting the criteria based on the information the DMs possess in their previous experiences of decision-making.
3. Selecting classically used criteria to evaluate the alternatives such as "cost".

The criteria are initially refined in this step in which some criteria are eliminated and then evaluated in the next two steps according to with their weights of importance.

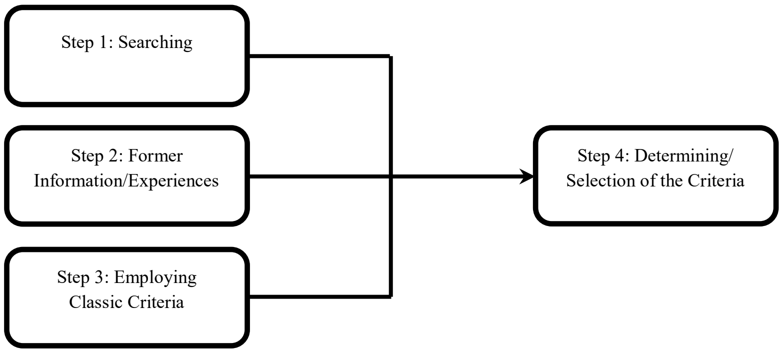

Fig 2

The procedures that fashion the selection of appropriate criteria

The following three steps are the stages where VIMM plays its role in the decision-making process (Fig 1):

1. Analyzing criteria in accordance with the goals.
2. Comparison of the criteria against each other affected by the goals.
3. Aggregation of the analyzed outputs.

Steps 2 and 3 utilize MCDM rating methods. The VIMM approach categorizes the criteria into the vital, mediocre, and immaterial classes of criteria selected by DM. The vital criteria include the criteria that the DM believes has the most impact on the final results, accordingly, having the highest weights amongst other criteria. The immaterial criteria are those which can be possibly ignored in some circumstances based on the decision-making goals. The mediocre criteria refer to the criteria which affect the results to a lesser extent than the vital criteria. Hence, based on the decision-making goals and the DM's judgment, every criterion could be placed in the three VIMM categories (spectrums) (shown in Fig 3. where c_y denotes the yth criterion $y \in \{1,2, \dots, m\}$).

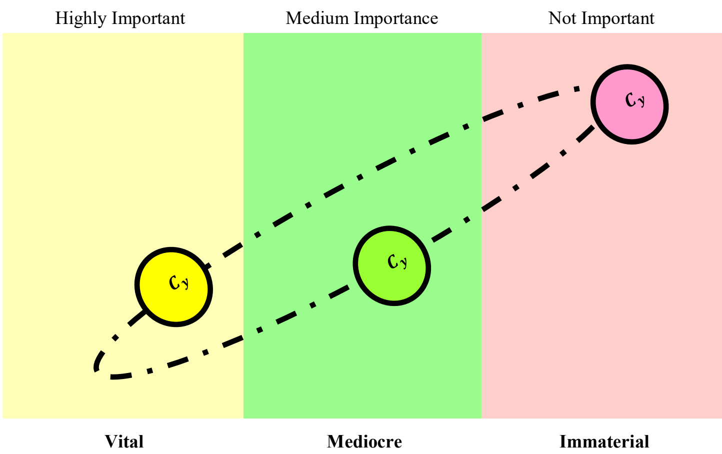

Fig 3

The three spectrums of VIMM

The fourth step of the approach in Fig 2. is the analysis of the criteria according to the decision-making goals. The VIMM proposes two approaches to compute the weights of each criterion: either to achieve 1) only one goal or 2) two or more goals in the decision-making process.

The classic one-goal VIMM algorithm consists of five phases shown in the first scenario. The second scenario has been formulated for two or more goals. To illustrate the VIMM algorithm, the phases have been displayed alongside a numerical example of a typical supplier selection.

2.1. The VIMM: the first scenario

The following phases shows the VIMM for the one-goal decision-making process:

Phase 1. Determine the vital, immaterial and mediocre criteria by the DM.

- Each decision-making problem always consists of vital criteria, and either an immaterial or a mediocre criterion or both.
- The initial vital, immaterial and/or mediocre criteria is selected by the DM.
- The first assortment procedure, which determines the vital, immaterial, and mediocre criteria, is the second refinement (see *step 3* of the VIMM decision-making pattern).

Phase 2. Allocate values of 5 and 1 to the vital and immaterial criteria, respectively.

Phase 3. Compare the remaining criteria with the vital and immaterial criteria following the numerical-linguistic scale, where the j stands for the number of criteria. This step is based on two main comparisons; first, compare all remaining criteria with the vital criteria and secondly, compare them with the immaterial criteria. As demonstrated in Fig 4, three variables have been defined on a comparison scale, with an interval of $[2,9]$, that denotes the importance of a criteria when compared to another. The DM is able to designate the pairwise comparison level of importance per criterion (even fractions).

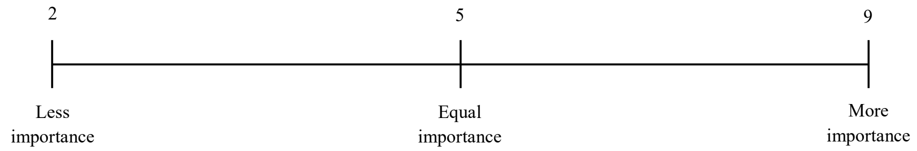

Fig 4

The linguistic/numerical variables scale

For example, if α_x is 10, then, c_j would be …, and if $\beta_1$is 1, then, c_j would be …; In the subjective decision-making process, one of the emerging sources of uncertainty is the DMs' lack of knowledge regarding transforming their opinions into numbers. This also generates deep levels of uncertainty and deviation from actual results if we are working with a large number of DMs. Furthermore, DMs do not need to know how to create a pattern of numbers to translate their feelings, opinions, and interpretations into numbers. In fact, they may establish a wrong pattern of numbers which finally generate uncertainty. This is the reason why the existing scales for transforming the linguistic variables into numeric variables are constantly altering to include more linguistic variables and corresponding numbers, which eventually results in more complexity. To solve this problem, it is necessary to represent the DMs simple linguistic variables which are used to express their feelings, such as very good, very high, medium, etc. There is also the possibility of providing the DMs with a simple numeric scale structure to represent their opinions. In VIMM, we have given DMs three linguistic variables and three numbers so that the DMs are able to design their numeric pattern and select any number between these three numbers to express their opinions. Moreover, VIMM accepts also fractions.

Phase 4. Calculate the distance between each criterion and the vital and immaterial criteria according to the linguistic/numeric scale in Fig 4, where d_{xy}^{+} and d_{xy}^{-} express distances between the yth criterion in the xth comparison, and the immaterial and vital criteria respectively, where x is the number of the comparison, and y states the number of criteria, where $y \in j$.

Phase 4.1. Normalize the distance matrix in accordance with equations (1) and (2).

$$d_{xy}^{+}{}' = {c_y}\Big/{\max_{y \in j} d_{xy}^{+}} \qquad (1)$$

$$d_{xy}^{-}{}' = {\min_{y \in j} d_{xy}^{-}}\Big/{d_{xy}^{-}} \qquad (2)$$

Phase 4.2. Compute the first score based on equation (3) where S_{xy} denotes the score of the yth criterion in the xth comparison.

$$S_{xy} = d_{xy}^{+}{}' + d_{xy}^{-}{}' \qquad (3)$$

Phase 5. Re-iterate Phases 3 and 4 for all other criteria comparisons until the number of remaining criteria reaches 2 for an even number of criteria or 1 for an odd number of criteria.

Phase 6. Finally, compute the criteria weights computes in accordance with equations (4) and (5).

$$\mathbb{S}_j = \sum_{y \in j}^{x} S_{xy} \qquad (4)$$

$$W_j = \sum_{j=1}^{y} \mathbb{S}_j \quad y \in j; \qquad (5)$$

And the obtained weights are ($\sum_{j=1}^{n} W_j = 1$).

Example 1. In a supplier evaluation problem, the problem is simply defined as the selection of the best supplier based on some criteria, whilst the concept of "the best supplier" is the product of the aggregation of the goals. Yet, most MCDM methods ignore it. To select the best supplier as the decision-making goal, the decision-making matrix is shown in Table 1, where five alternative suppliers $\{A_1, \dots, A_5\}$ are being considered. These suppliers are evaluated against seven criteria which are the cost, quality, delivery, service, social responsibility, risk, and agility.

Table 1
The supplier evaluation decision making matrix where $p_{i^* j^*}$ stands for the value of i^*th alternative via j^*th criterion

	Cost	Quality	Delivery	Service	Social Responsibility	Risk	Agility
A_1	p_{11}			$\cdots$			p_{17}
A_2							
A_3	$\vdots$			$\ddots$			$\vdots$
A_4							
A_5	p_{51}			$\cdots$			p_{57}

According to the VIMM: the first scenario, the following phases are employed to derive the importance weights of criteria:

Phase 1. Determination of the vital, immaterial or mediocre criteria by the DM. In this example, the vital criterion is the cost, and the immaterial criterion is the social responsibility, where α_x and β_x denote the vital and immaterial criterion respectively, and x stands for the number of the comparison. In this case, there is no mediocre criteria.

Phase 2. The values of 5 and 1 must be assigned to the vital and immaterial criterion respectively, then:

$\alpha_1 = 5$

$\beta_1 = 1$

Phase 3. The first two comparisons are as shown in the following tables.

Table 2
The comparison of the cost (vital criterion) with other criteria

	Quality	Delivery	Service	Risk	Agility
Cost	9	7.5	8	6.5	7

Table 3
The comparison of the Social Responsibility (immaterial criterion) against other criteria

	Quality	Delivery	Service	Risk	Agility
Social Responsibility	9	8	8.5	6	7.5

Phase 4. The distances between all criteria and the vital and immaterial criteria are shown in Table 5.

Table 4

The distances between the criteria and first vital and immaterial criterion

	d^+	d^-
Quality	8	1
Delivery	7	2.5
Service	7.5	2
Risk	5	3.5
Agility	6.5	3

Phase 4.1. Normalization of the distance matrix in accordance with equations (1) and (2), where the normalized distance matrix is illustrated in Table 5.

Table 5
The normalized distance matrix

	$d^{+'}$	$d^{-'}$
Quality	1.000	1.000
Delivery	0.875	0.400
Service	0.938	0.500
Risk	0.625	0.286
Agility	0.813	0.333

Phase 4.2. Computing the first score with respect to Equation (3) and shown in Table 6 to determine the second vital and immaterial criteria. The yellow cell highlights the vital criterion, and blue highlights the immaterial criterion.

Table 6
The second vital and immaterial criteria in accordance with the scores

	$d^{+'}$	$d^{-'}$	S_x	Vital	Immaterial
Quality	1.000	1.000	2.000		
Delivery	0.875	0.400	1.275		
Service	0.938	0.500	1.438		
Risk	0.625	0.286	0.911		
Agility	0.813	0.333	1.146		

Based on the calculated scores, the second vital and the immaterial criteria are quality and risk as they have the highest and lowest scores, respectively. Following the first selection of the vital and immaterial (or mediocre criterion in other cases), the next vital and immaterial criteria are derived from the comparison tables, whilst the mediocre criterion is selected by the DM.

Phase 5. The comparison steps continued until the number of remaining criteria reaches 2 for an even number of criteria and 1 for an odd number of criteria. Therefore:

$\alpha_2 =$ Quality

$\beta_2 = \text{Risk}$

Phase 5.1. The value of 5 and 1 are added to the initially calculated scores for the second vital and immaterial criteria:

$S_{2Quality} = 5 + 2 = 7$

$S_{2Risk} = 1 + 0.911 = 1.911$

For each comparison, the value of 5 and 1 are added to each vital criterion and immaterial criterion scores respectively, except for the first immaterial criterion, which in this case is the social responsibility; therefore, in the second comparison the cost's score is 10 (5+5) and the Social Responsibility's score remains as 1. However, if the decision-maker selects the mediocre criterion, in contrast to the immaterial criterion, it gains 1 value for each comparison number.

The results of comparison between the second vital and immaterial criteria with the delivery, service, and agility are shown in Table 7 and 8, respectively.

Table 7
The comparison results of the remaining criteria with the quality as the second vital criterion

	Delivery	Service	Agility
Quality	8	8.5	7

Table 8
The comparison results of the remaining criteria with the risk as the second immaterial criterion

	Delivery	Service	Agility
Risk	8.5	9	8

With respecting Table 7 and Table 8, the scores are demonstrated in Table 9.

Table 9
The scores of the delivery, service and agility

	d^+	d^-	$d^{+'}$	$d^{-'}$	S_x	Vital	Immaterial
Delivery	7.5	2	0.938	0.750	1.688		
Service	8	1.5	1.000	1.000	2.000		
Agility	7	3	0.875	0.500	1.375		

When there is an odd number of criteria, the comparison will continue until there is one remaining criterion. The last criterion attains a value of 5 (see Table 10).

Table 10
The final comparison process with "delivery" as the last criterion

	S_1	S_2	S_3	S_4	Vital	Immaterial
Cost	5	5	5	5		
Quality	2.000	5	5	5		
Delivery	1.275	1.688	5	5		
Service	1.438	2	5	5		
Risk	0.911	1	0	0		
Agility	1.146	1.375	1	0		
Social Responsibility	1	0	0	0		

The final result of comparison would be Delivery in which the value of 10 adds to its final score of the previous step.

Phase 6. According to equations (4) and (5), the weights of criteria are exhibited in Table 11.

Table 11

The criteria weight importance

	S_1	S_2	S_3	S_4	$\mathbb{S}_j$	W_j
Cost	5	5	5	5	20	0.286
Quality	2	5	5	5	17	0.243
Delivery	1.275	1.688	5	5	12.963	0.186
Service	1.438	2	5	5	13.438	0.192
Risk	0.911	1	0	0	1.911	0.027
Agility	1.146	1.375	1	0	3.521	0.050
Social Responsibility	1	0	0	0	1	0.014

2.2. The VIMM: the second scenario

As mentioned heretofore, VIMM: the first scenario is used for those decision-making problems that aim to achieve merely one goal, therefore, the problem's criteria are evaluated versus the set goal. Yet, The VIMM: the second scenario operates when there several goals that have been set by DM(s). The second scenario algorithm runs by merely one phase more than the first scenario to find the vital and immaterial criteria where the mediocre criterion selects by DM, and the remaining steps are utterly similar. For a better understanding, the evaluation process is demonstrated alongside with an illustrative example of a smartphone selection problem.

Example 2. In this example, a smartphone[1] selection problem has been provided with twelve criteria including 1. Price; 2. Brand; 3. Display design; 4. Security system; 5. Processor; 6. RAM; 7. Camera; 8. Battery; 9. Screen size; 10. Storage; 11. Audio quality; 12. Network technology. At the most reasonable price, DM tends to buy a smartphone amongst eight top brands flagship smartphones which is suitable for the photography that needs a high-resolution camera and enough storage to store the media. The smartphone selection decision matrix has been provided in Table 12.

Table 12

The smartphone selection decision matrix

	Price	Brand	Display design	Security system	Processor	RAM	Camera	Screen size	Storage	Audio quality	Network technology
Smartphone 1	p_{11}					$\cdots$					p_{112}
Smartphone 2											
Smartphone 3											
Smartphone 4	$\vdots$										
Smartphone 5						$\ddots$					$\vdots$
Smartphone 6											
Smartphone 7											
Smartphone 8	p_{81}					$\cdots$					p_{812}

As expressed before, DM's judgment for criteria importance weights would be according to the three objectives consisting of the reasonable price, high-resolution camera, and the high internal storage/

[1] In this case, the smartphones operating system is Android.

expandable storage. The twelve criteria are evaluated in line with the mentioned three objectives. In order to evaluate the criteria in accordance with the objectives, a relation matrix needs to be established which is displayed in Table 13.

Table 13

Smartphone selection objectives and criteria relation matrix

	Price	Brand	Display design	Security system	Processor	RAM	Camera	Screen size	Storage	Audio quality	Network technology
Reasonable price	a_{11}					$\cdots$					a_{112}
high-resolution camera	$\vdots$					$\ddots$					$\vdots$
high internal storage	a_{31}					$\cdots$					a_{312}

In order to find the vital and immaterial criteria, the relation matrix ought to be analyzed. The relation matrix analysis process functions by the following equation, where the j stands for the number of criteria, i denotes the number of goals, and w_i demonstrates the weight of ith goal.

$$S_j' = \sum_{i=1}^{m}\sum_{j=1}^{n} w_i a_{ij} \left(\sum_{i=1}^{m} w_i a_{ij}\right)^{-1} \left(\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{j=1}^{n} w_i a_{ij} \left(\sum_{i=1}^{m} w_i a_{ij}\right)^{-1}\right)^{-1} \times 10 \qquad (6)$$

To find the vital and immaterial criteria, the outputs of (Eqn. 6) require to be corresponded with the following scale.

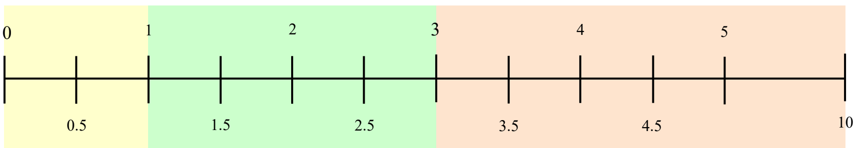

Fig 5

The three spectrums scale

As illustrated in (Fig 5), three spectrums have been defined to match with S_j' value to find vital and immaterial criteria, where yellow and pink show the immaterial and vital numerical interval and the green displays the “possible mediocre” numerical interval. Therefore:

- if $0 < S_j' < 1$, then it is an immaterial criterion.
- if $1 \leq S_j' < 3$, then it is a possible mediocre criterion; if it is close to 1 it tends to be immaterial criterion, and vice versa, if it was close to 3, it tends to be vital criterion.
- if $S_j' \geq 3$, then it is the vital criterion ($S_j' < 10$).

For the problems with more than five criteria, following scale needs to be employed to determine the vital, mediocre, and immaterial criterion (see Fig 6).

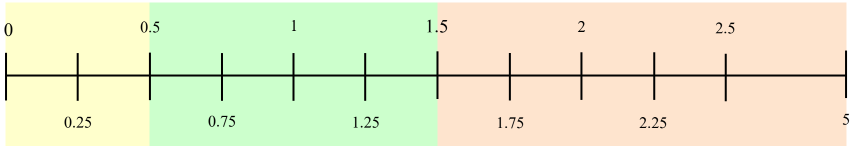

Fig 6

The three spectrums scale for the problems with more than 5 criteria

Therefore:

- if $0 < S'_j < 0.5$, the criterion is an immaterial criterion.

- if $0.5 \leq S'_j < 1.5$, then it is a possible mediocre criterion; if it is close to 0.5 it tends to be immaterial criterion, and vice versa, if it was close to 1.5, it tends to be vital criterion, therefore selecting them as the immaterial or vital criterion is based on the decision-maker's decision.

- if $S'_j \geq 1.5$, then the criterion is the vital criterion ($S'_j < 5$).

As can be observed, the vital criterion in *the Example 1*, is the immaterial criterion in fact. Having said that, DM decides the difference between the three classes, and the three spectrums scale could be possibly utilized as a pattern for DM.

3. Real-world application and results

In this section, the VIMM scenarios have been applied to real-world cases to show their processes in deriving criteria weights in different situations in terms of the decision's goals number.

3.1. The sustainable supplier selection

A sustainable supplier evaluation problem is considered one of the major decision-making problems that most companies are dealing with today. Adopted from Ecer & Pamucar (2020), VIMM is applied for supplier selection for a home appliances manufacturer in Serbia. For the purpose of comparison to VIMM, using fuzzy BWM (Guo & Zhao., 2017), the weights have been generated as in Table 14, where the importance weights of the criteria are shown to be close and do not indicate significant differences.

Table 14

The normalized weights of the criteria for the sustainable supplier selection

	Economic					Environmental					Social				
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Weight	0.053	0.034	0.029	0.104	0.100	0.059	0.063	0.077	0.025	0.027	0.040	0.140	0.043	0.121	0.086
	0.319					0.251					0.430				

On the other hand, the derived results represent the perspective of the relative importance of the criteria based on the three experts' decisions. Therefore, to determine the initial vital and immaterial criteria, the criteria are arranged in descending order based on their computed weights (see Table 15). As the weights of the main criteria and their sub-categories have been distinguished, the weights of the main criteria: the economic, environmental, and social criteria, have been converted to their corresponding sub-criteria importance weights in order to reduce complexity; then, the products have been normalized and ordered according to their values. The first vital and immaterial criteria are obtained by respecting the normalized weights.

Table 15

The first vital and immaterial

	Vital														Immaterial
Criterion	C_{12}	C_{14}	C_{15}	C_4	C_5	C_8	C_{13}	C_{11}	C_1	C_7	C_6	C_2	C_3	C_{10}	C_9
Weight	0.172	0.149	0.106	0.095	0.091	0.055	0.053	0.049	0.048	0.045	0.042	0.031	0.026	0.019	0.018

The vital and immaterial criteria of this problem are (C_{12}) and (C_9), respectively. Therefore, their scores are as follow:

$\alpha_1 = C_{12}$

$\beta_1 = C_9$

$S_{1C_{12}} = 5$

$S_{1C_9} = 1$

To initiate the process of calculating the criteria weights, the comparison procedure needs to be executed first. Thanks to the available weights computed by fuzzy BWM, which are established by the experts' opinions, the comparison of each of the criteria with the vital and immaterial criteria is not necessary. In the next process, in order to find the first scores of each criterion, the distance between each criterion and the first vital and immaterial criteria is calculated and shown in Table 16, where d_{1y}^{+} and d_{1y}^{-} depict the distances between yth criterion in the first comparison, and the vital and immaterial criterion respectively. The distances, the normalized distances, and the criteria scores are shown in Table 16. The second vital and immaterial criteria are then:

$\alpha_2 = C_{14}$

$\beta_2 = C_{10}$

Table 16

Distances between each criterion and first vital and immaterial criteria and the criteria first scores

	C_{14}	C_{15}	C_4	C_5	C_8	C_{13}	C_{11}	C_1	C_7	C_6	C_2	C_3	C_{10}
d^{+}	0.023	0.066	0.077	0.081	0.117	0.119	0.123	0.124	0.127	0.130	0.141	0.146	0.153
d^{-}	0.131	0.088	0.077	0.073	0.037	0.035	0.031	0.030	0.027	0.024	0.013	0.008	0.001
$d^{+'}$	1.000	0.348	0.299	0.284	0.197	0.193	0.187	0.185	0.181	0.177	0.163	0.158	0.150
$d^{-'}$	1.000	0.672	0.588	0.557	0.282	0.267	0.237	0.229	0.206	0.183	0.099	0.061	0.008
S_1	2.000	1.020	0.886	0.841	0.479	0.460	0.424	0.414	0.387	0.360	0.262	0.219	0.158
Vital													
Immaterial													

The other steps' results and the final weights are presented in Table 17. The criterion C_{12}, as the vital criterion, possesses the largest importance weight value, while the immaterial criterion C_9 receives the smallest importance weight value.

Table 17

VIMM's steps numerical results and the final weights

	C_{12}	C_{14}	C_{15}	C_4	C_5	C_8	C_{13}	C_{11}	C_1	C_7	C_6	C_2	C_3	C_{10}	C_9
S_1	5	2	1.02	0.886	0.841	0.479	0.46	0.424	0.414	0.387	0.36	0.262	0.219	0.158	1
S_2	5	5	2	1.67	1.569	0.871	0.839	0.775	0.759	0.712	0.666	0.502	0.43	1	0
S_3	5	5	5	2	1.675	0.636	0.599	0.526	0.508	0.456	0.404	0.219	1	0	0
S_4	5	5	5	5	2	0.5	0.462	0.387	0.368	0.313	0.259	1	0	0	0
S_5	5	5	5	5	5	2	1.794	1.396	1.299	1.013	1	0	0	0	0
S_6	5	5	5	5	5	5	2	0.833	0.661	1	0	0	0	0	0
S_7	5	5	5	5	5	5	5	2	1	0	0	0	0	0	0
S_8	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0
$\mathbb{S}_j$	40	37	33.02	29.556	26.085	19.486	16.154	11.341	5.009	3.881	2.689	1.983	1.649	1.158	1
W_j	0.174	0.161	0.144	0.128	0.113	0.085	0.070	0.049	0.022	0.017	0.012	0.009	0.007	0.005	0.004

As a subjective weighting method, VIMM operates with DMs' decisions, however, the results of another subjective weighting method, fuzzy BWM, are utilized to show its performance. In addition, by looking at the final products, both methods generated almost identical outputs. Rezaei (2015) strived to prove that BWM is a more interesting method to employ instead of AHP to derive weights of criteria from the experts/DMs' opinions. The next section is dedicated to the comparison between the two methods.

3.2. The smartphone selection

For decision-making problems with multiple goals, a critical phase of the VIMM method is to find the vital, immaterial, and mediocre criteria. Once the criteria spectrums are identified (see Fig. 5 and Fig. 6), the computation of their weights is based on the "VIMM: the first scenario" methodology. The following real-world case[2] demonstrates how the vital, the immaterial and the mediocre criteria are identified, the VIMM second scenario evaluation process and how the algorithm deals with multiple goals in decision-making problems.

Smartphone selection is a prevalent decision-making problem that people encounter in a frequent manner. In this real-world case, the DM's judgments for the evaluation of the importance weights of criteria to buy a smartphone have been made in accordance with the following three objectives: 1) a reasonable price smartphone that has 2) a high-resolution camera and 3) a large internal or expandable storage. The seven alternative smartphones include the Apple iPhone 12 Mini, Asus Zenfone 8, BlackBerry Key2, Huawei P40 Pro, Samsung Galaxy S20 5G (Qualcomm Snapdragon 865), Sony

[2]The information has been adopted from https://versus.com/en/apple-iphone-12-mini-vs-asus-zenfone-8-vs-blackberry-key2-vs-huawei-p40-pro-vs-samsung-galaxy-s20-5g-qualcomm-snapdragon-865-vs-sony-xperia-5-ii-vs-xiaomi-black-shark-3

Xperia 5 II, and Xiaomi Black Shark 3. The seven criteria include Price, Design, Display, Performance, Storage (GB), Camera, Battery power (mAh) and ten sub-criteria including the Weight/gr (W), Volume/cm^2 (V), Pixel density/ppi (PD), Resolution/px (R), Screen size/inches (SZ), RAM/GB (RAM), CPU Speed/GHz (CPU), Main camera/Megapixels (MC), Front camera/Megapixels (FC), and the Video recording/fps (VR). The smartphone selection decision matrix data is provided in (Table 18).

Table 18

The smartphone selection decision matrix

	Price (€)	Design		Display			Performance		Storage (GB)	Camera			Battery power (mAh)
		W	V	PD	R	SZ	RAM	CPU		MC	FC	VR	
Apple iPhone 12 Mini	829.00	135	62.47	476	1080 x 2340	5.4	4	2 x 3.1GHz & 4 x 1.8GHz	256	12 & 12	12	2160 x 60	2227
Asus Zenfone 8	799.00	169	90.23	446	1080 x 2400	5.9	16	1 x 2.84GHz & 3 x 2.42GHz & 4 x 1.8GHz	256	64 & 12	12	4320 x 24	4000
BlackBerry Key2	797.00	168	92.4	434	1080 x 1620	4.5	6	4 x 2.2GHz & 4 x 1.84GHz	128	12 & 12	8	2160 x 30	3500
Huawei P40 Pro	791.23	209	102.79	441	1200 x 2640	6.58	8	2 x 2.86GHz & 2 x 2.36GHz & 4 x 1.95GHz	256	50 & 40 & 12	32	2160 x 60	4200
Samsung Galaxy S20 5G (Qualcomm Snapdragon 865)	706.99	163	82.81	566	1440 x 3200	6.2	12	1 x 2.84GHz & 3 x 2.42GHz & 4 x 1.8GHz	128	64 & 12 & 12	10	3240 x 30	4000
Sony Xperia 5 II	587.50	163	85.95	449	1080 x 2520	6.1	8	1 x 2.84GHz & 3 x 2.42GHz & 4 x 1.8GHz	256	12 & 12 & 12	8	2160 x 120	4000
Xiaomi Black Shark 3	699.00	222	135.62	395	1080 x 2400	6.67	12	1 x 2.84GHz & 3 x 2.42GHz & 4 x 1.8GHz	256	64 & 13 & 5	20	2160 x 60	4720

To find the vital, immaterial, and mediocre criteria, compute the spectrum of the main criteria, that have been evaluated against the mentioned three objectives. In order to evaluate the criteria according to the objectives, a relation matrix is established and displayed in Table 19.

Table 19

Smartphone selection objectives and criteria relation matrix

	Price	Design	Display	Performance	Storage (GB)	Camera	Battery power (mAh)
Reasonable price	9	7	7	7.5	7	7.5	7
High-resolution camera	5.5	3	2	7	7	9	7
High internal storage	5.5	2	2	7	9	2	5

According to (Eq. 6), the weight of each goal (w_i) needs to be calculated. To calculate w_i, the pairwise comparison matrix is employed as shown in Table 20. To compare the goals, the linguistic/numerical variables scale proposed in Fig 4 is used.

Table 20

The pairwise comparison matrix of the decision-making goals

	Reasonable price	High-resolution camera	High internal storage	w_i
Reasonable price	1	3	7	0.64
High-resolution camera	0.33	1	5	0.28
High internal storage	0.20	0.14	1	0.08

The next step is computing the weighted relation matrix which is affected by the weights of the decision-maker's objectives. The weighted relation matrix is shown in Table 21.

Table 21

The weighted relation matrix

w_i		Price	Design	Display	Performance	Storage (GB)	Camera	Battery power (mAh)
0.64	Reasonable price	9	7	7	7.5	7	7.5	7
0.28	High-resolution camera	5.5	3	2	7	7	9	7
0.08	High internal storage	5.5	2	2	7	9	2	5

Using Eq. 6, the calculations of S_j' for the different criteria are shown in Table 22. In addition, the weights are placed into the three spectrums scale provided in Fig.6.

Table 22

The weights of criteria

	Price	Design	Display	Performance	Storage (GB)	Camera	Battery power (mAh)
S_j'	1.9168	1.3571	1.2878	1.8128	1.7732	1.8524	1.6939
Vital							
Immaterial							
Mediocre							

Results show that Price, Performance, Storage, Camera and Battery power are the vital criteria to achieve the decision-making goals, which is to buy a smartphone that has a reasonable price, a high-resolution camera, and high internal storage. Moreover, there is no criterion located in the immaterial spectrum, yet Design and Display are considered as mediocre criteria.

3.3. Comparison of VIMM with BWM and AHP

The VIMM algorithm considers three concepts: the vital, immaterial, and mediocre criteria, while the method mainly functions by using the first two criteria: the vital and immaterial criteria. Both vital and immaterial criteria are the elements that the DM assesses based on the VIMM framework by determining the relation ratio and distance between these two classes of criteria and the remaining criteria. Through pairwise comparison and calculating the distances, the criterion which is closer to the vital criterion has higher importance and conversely, the criterion with farthest distance from the vital criterion is denoted the immaterial criterion in the next comparison process. Each comparison uses the vital and immaterial criteria as a scale to gauge other criteria. VIMM endeavors to identify the semblance rate of each criterion with the vital and immaterial criteria. Each vital and immaterial criterion rewards the values of 5 and 1 as scores, respectively, in which the vital criterion continues to add the values until the last comparison step, while the immaterial criterion only receives its score in the first comparison step. The final weights are obtained by calculating the total scores.

In the real-world application in which the criteria weights resulted from BWM which are then used as the input to the VIMM algorithm, the comparison process does not include the calculation of the differences and similarities between the VIMM and BWM outputs and merely focuses on the structural advantages. In addition, we believe the reliability of the weights obtained by the subjective methods can only be examined by the DMs.

To extract weights from the DMs opinions, AHP uses one pairwise comparison matrix (n^2) where n is the number of criteria, BWM employs two pairwise comparison matrices ($1 \times n$) and ($n \times 1$) and VIMM deals with ${(n-1)}/{2}$ and ${n}/{2}$ number of pairwise comparison matrices for the even and odd numbers of criteria, respectively. The real-world demonstration case gives the number of pairwise comparison for AHP as (15×15), whereas BWM deals with one pair of comparison matrices (15×1 and 1×15), and VIMM exploits seven pairwise comparison matrices which are originated from more indices (vital, immaterial, mediocre criteria) to determine the criteria weights.

As Rezaei (2015) stated, more pairwise comparison matrices denote the more minimum violation, which gages the ordinal consistency of an MCDM method. However, as VIMM uses ($n-1$) and (n) vital and immaterial criteria for the even and odd numbers of criteria respectively, and identify the remaining criteria through pairwise comparison, it maintains a fixed framework for the DM's opinions to avoid any uncertainty or unreliability caused during the process. Furthermore, the DM can add a dynamic criterion called mediocre criterion, maximum (${(n-1)}/{2}$ or ${n}/{2}$), which has an independent existence. Indeed, the VIMM algorithm is designed to increase the accuracy of the decision-making process run by DMs which makes it more robust than BWM.

Fundamentally, the selection of the vital and immaterial criteria is based on decision-making goals. AHP and BWM do not exclusively consider the decision-making goals in their algorithm, whereas the VIMM approach is designed around the decision-making goals. The DM selects the criterion that has the highest effect on the criteria prioritization and the one that has the least effect. Then, he executes the first comparison and continues the process iteratively until the last two criteria/one criterion, while BWM stops after the first pairwise comparison. In fact, what makes BWM more reliable than AHP, VIMM executes it in a more developed form. Making use of the distance measuring approach and scoring method (including 1 and 5 as one of the most established numerical scales used in MCDM methods to transform linguistic variables to numeric variables) alongside the pairwise comparison makes it an interesting method amongst subjective methods.

4. Conclusion and future research

In this paper, a new multi-criteria decision-making (MCDM) method is proposed, called the vital-immaterial-mediocre method (VIMM). As a subjective MCDM weighting method, constituted on the three main elements consisting of the vital, immaterial, and mediocre criteria, VIMM derives weights of criteria from DMs opinions based on an approach combined with the pairwise comparisons of the vital and immaterial criteria with the other criteria, distance measuring, and scoring method. The new method is designed for two scenarios. The difference between the two scenarios is the consideration of the decision-making's goals in the second scenario's algorithm. Utilizing a five-step procedure, VIMM: the first scenario, extracts weights from the DMs' opinions, while the second scenario has an additional step. The method is applied to a real-world decision-making problem to determine criteria weights for the selection of sustainable suppliers to show its applicability and performance. The method was compared with the best-worst method (BWM) to show its advantages and notable features that make it a more reliable and robust method. The comparison results are as follows:

1. AHP and BWM need $n(n-1)/2$ and $2n-3$ comparisons respectively, while, VIMM requires fewer comparisons, only $(n-1)/2$ and $n/2$ number of comparisons for the even and odd numbers of criteria, respectively.
2. One of the limitations of AHP is the number of criteria it can process, which is restricted to seven criteria ($+/-2$). While Rezaei., (2015) did not reveal the levels of the dependence of the BWM to the number of criteria, in contrast to AHP, VIMM is not sensitive to the number of criteria.
3. VIMM exclusively takes the decision-making goals into account, and its procedure is naturally based on the goals (see VIMM second scenario) which has been ignored by the other methods such as BWM and AHP.
4. To generate reliable results, VIMM uses the following three approaches in its algorithm: pairwise comparison matrices, distance measuring, and scoring method. This approach is not only driven by the DMs opinions and the solid framework, but it also keeps the validity and reliability of the DMs' opinions in a framework runs by the algorithm.

5. AHP suffers from dealing with the use of the 9−point scale, which limits the DMs choices and makes the cognition process difficult. VIMM straightforwardly works with integer and fractional numbers by providing a platform limited between 1, 5, and 9 which allows the DM to select any number they think better represents their opinions which is an advantage for the new method over the existing methods. Moreover, this advantage makes VIMM simpler and more convenient to use (AHP works with fractional and integer numbers, and BWM deals with integer numbers.)
6. Benefiting from a resilient and adaptable algorithm, VIMM can be employed as an independent method to derive criteria weights and it also deals with the combination of subjective and objective methods very well.

As managerial implications, VIMM not only provides less complex process for the evaluation of the criteria in the managerial decision-making process, but it also generates consistent results, which make VIMM a reliable tool to apply to a large number of potential decision-making problems. In the VIMM process, the DM is assumed to be honest in giving their opinions regarding the importance of each criterion. Since the subjective weighting methods rely entirely on the DMs' opinions and their honesty during the process, we suggest considering the strategic weight manipulation of the MADM as discussed in (Dong *et al*., 2018; Liu *et al*., 2019) as future VIMM development. For future research, we also suggest employing VIMM as a ranking method for the evaluation and prioritization of the decision-making problems' alternatives. Due to the nature of VIMM, which comprises both vector-based h and pairwise comparison approaches, comparing its performance against other similar methods such as AHP, BWM, ANP, and SMART could be another interesting direction for future research. In addition, to optimize the VIMM method's process, we suggest to implement both scenarios in fuzzy environment (see Labella *et al*., 2021; Xu *et al*., 2019) to assess its output's accuracy and consistency. Finally, integrating the goal programming techniques with the VIMM: the second scenario could flourish other veiled behavioral aspects of the new method.

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