Subjective Equal Criteria Influence Approach (SECIA): A novel extended approach to weights determination

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Abstract. This study extends the Equal Criteria Influence Approach (ECIA) by developing its subjective counterpart, the Subjective Equal Criteria Influence Approach (SECIA), to enhance its applicability across a wider range of decision-making problems. The proposed method is evaluated using a case study focused on assessing healthcare sectors in Eastern Europe, with the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method employed to construct the decision model. SECIA's performance is compared with two widely used weighting methods: the Best-Worst Method (BWM) and the Level-Based Weight Assessment (LBWA). Additionally, a simulation study incorporating correlation coefficients and similarity metrics provides a detailed analysis of the differences in criteria weights and rankings derived from these methods. The results demonstrate SECIA's stability, flexibility, and alignment with established methods while highlighting its unique ability to directly adjust the influence of individual criteria on ranking outcomes. These findings underscore SECIA's value as a robust addition to the MCDM toolkit, particularly in scenarios requiring subjective input from decision-makers. Possible avenues for future research include extending SECIA's application to diverse decision-making contexts, formalizing its mathematical structure, and further exploring alternative approaches for determining the impact of criteria.

Keywords: multi-criteria decision analysis · criteria weights · subjective weighting · equal influence · MCDM · BWM · LBWA

1 Introduction

The advancement of civilization has given rise to increasingly complex problems, often requiring decision-making processes capable of delivering sufficiently effective solutions. Such challenges are frequently analyzed within the framework of multi-criteria decision-making (MCDM) and multi-criteria decision analysis (MCDA). The literature provides numerous examples of applying these methodologies to address diverse issues, including the evaluation of information and

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DOI: 10.1007/978-3-031-97567-7_28

communication technology (ICT) development in G7 countries [16], risk assessment in sustainable supply chains [6], assessment of hospital service quality [1], and performance-based university rankings [21].

There is a growing focus on enhancing decision support processes to improve the quality and efficiency of decision-making. Novel methodologies are being proposed, aiming either to simplify the decision-making process or to expand it in a way that provides decision-makers with comprehensive information about the problem under analysis and the derived solution. For instance, the RANking COMparison (RANCOM) approach [19] seeks to streamline the process of assessing the relative importance of criteria, offering an alternative to the widely utilized Analytic Hierarchy Process (AHP). Compared to AHP, RANCOM is characterized by a simpler implementation and greater result stability [19]. Another noteworthy method is the Exhaustive Objective Ranking Solution (EORS) [10], which enables the derivation of objective solutions complemented by additional indicators designed to comprehensively present the selected solution within the context of all possible scenarios. Additionally, sensitivity analysis techniques are increasingly gaining traction. A notable example is the Comprehensive Sensitivity Analysis Method (COMSAM) [20], which offers a more thorough and nuanced approach to sensitivity analysis compared to conventional methods.

In the context of decision-making, the determination of the relevance of criteria is a critical aspect that frequently arises. Within the framework of most multi-criteria decision-making methods (MCDMs), this relevance is quantified by assigning weights to individual criteria. However, this task introduces an additional challenge, as it is often the responsibility of the decision-maker to assess and specify the relative importance of each criterion. To address this issue, various methodologies are employed, ranging from statistical techniques designed to derive weights objectively to expert-based approaches. The latter involves leveraging the knowledge and judgment of domain experts, who can evaluate the significance of criteria either by ranking them or assigning numeric values that represent their importance in relation to the specific decision problem under consideration.

Statistical methods are one of the most widely applied techniques in objectively determining criteria weights. These methods utilize statistical measures, such as entropy [24] or standard deviation [18], to infer the significance of each criterion. Beyond these foundational approaches, more advanced methods, such as CRiteria Importance Through Intercriteria Correlation (CRITIC) [17] and Criterion Impact LOS (CILOS) [23], aim to capture interrelationships among criteria, providing additional insights into their relative importance. Such methods are particularly valuable in situations where expert knowledge is unavailable or when the decision-making problem necessitates a more objective, data-driven approach.

In subjective approaches to determining criteria weights, methods based on pairwise comparisons between criteria are commonly employed. Prominent examples include the AHP [4] and the RANCOM method [19]. Another class of methods involves the application of linear programming, which typically requires

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DOI: 10.1007/978-3-031-97567-7_28

the decision-maker to assess the relative importance of a specific criterion compared to others, often using the least or most significant criterion as a reference point. Examples of such approaches include the Best-Worst Method (BWM) [7], Level-Based Weight Assessment (LBWA) [25], Full Consistency Method (FUCOM) [8], and Simultaneous Evaluation of Criteria and Alternatives (SECA) [2]. These methods offer systematic frameworks for subjectively deriving criteria weights while maintaining consistency in the decision-making process.

Another approach that has been recently proposed is the Equal Criteria Influence Approach (ECIA) [9], which was specifically designed to objectively determine the relevance of criteria based on their influence on the decision outcome within the context of the problem being addressed. Unlike traditional methods, ECIA introduces a novel perspective by explicitly accounting for the interplay between the criteria and the multi-criteria decision-making method employed, as well as the impact of individual criteria within a specific decision-making framework. Furthermore, the versatility of ECIA, allowing it to be applied as either an objective or subjective method, underscores its significant potential for a wide range of decision-making scenarios.

This study introduces an extension of the ECIA, adapting it to a subjective framework to facilitate its application across a broader spectrum of decision-making problems. The newly developed Subjective Equal Criteria Influence Approach (SECIA) will be evaluated by comparing its results with those obtained through two widely used methods: BWM and LBWA. The evaluation will focus on a case study assessing healthcare sectors in Eastern Europe following research made by Torkayesh et al. [15], with the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method employed to construct a comprehensive decision model. Additionally, a simulation study incorporating correlation coefficients will be conducted to provide a more detailed analysis of the differences in results across the methods. The key contributions of this paper are as follows:

- Extension of ECIA to SECIA to develop a subjective variant, enabling its application in scenarios requiring expert opinions or the subjective judgment of decision-makers.
- Comparative analysis presenting a comparative evaluation of SECIA against other methods with similar operational principles.
- Application of the proposed SECIA method to address a real-world decision-making problem.

The structure of the paper is organized as follows: Section 2 provides the preliminaries, introducing the newly proposed SECIA alongside other methods utilized in this study. Section 3.1 presents the case study, divided into two subsections: the first discusses the assessment of healthcare sectors and compares the results from different methods, while the second adopts a simulation-based approach to further analyze and characterize the proposed method. Finally, Section 4 concludes the paper by summarizing the findings, outlining key conclusions, and suggesting directions for future research and development.

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2 Preliminaries

This section outlines the methodologies employed in this study, providing a detailed explanation of the techniques utilized. The objective is to ensure transparency and reproducibility of the research findings presented in this paper.

2.1 ECIA

The primary objective of the Equal Criteria Influence Approach was to provide an approach that would take into account the influence of the criterion on the final preference values. This enables more precise modeling of the decision problem and tailoring it to the specific decision-making method employed. This novel approach provides more insightful results in the context of decision-making. The procedure is presented in the form of a flowchart in Figure 1. The *eps* value is the desired precision of the resulting weights, the lower the *eps*, the more criteria influence is equalized.

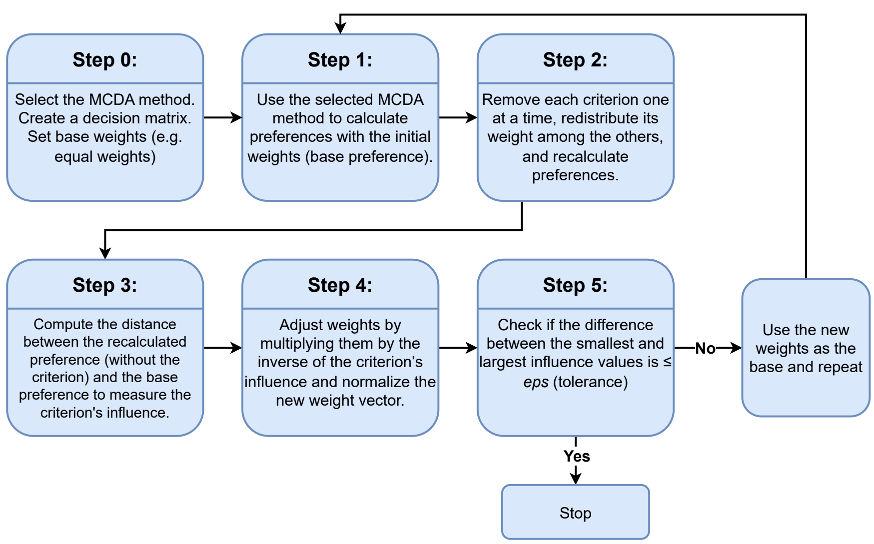

Fig. 1. Equal Criteria Influence Approach flowchart.

The ECIA procedure provides flexibility, allowing for modifications such as the use of alternative distance measures or adjustments to its objective. This study specifically aims to balance the influence of different criteria on the preference values of alternatives. The Euclidean distance metric, as illustrated in Equation (1), assesses the impact of a criterion by calculating preferences without it and comparing how much this operation impacted results.

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$$inf_i = \sqrt{\sum_{j=1}^{n} (p_j - p\prime_j)^2} \tag{1}$$

where i – criterion number, j – alternative number, inf_i – the influence of i-th criterion, p – base preference, $p\prime$ – preference without a specific criterion, n – number of alternatives

In Step 4, weights are iteratively adjusted to equalize influences using Equation (2). Weights are modified by dividing them by the influence or multiplying by the inverse, with adjustments for stability by subtracting the smallest influence value and adding an increment. The additional increment is included to ensure that the weight of the criterion with the highest influence remains unchanged.

$$nw_i = w_i \cdot \left(\frac{1}{inf_i} - min\left(\frac{1}{inf}\right) + 1 \right) \tag{2}$$

where i – criterion number, nw_i – newly calculated weight for the i-th criterion in the current iteration and will be used as w_i in the next iteration

Multi-criteria decision-making methods require weights to sum to one. After each iteration, weight vectors are normalized using Equation (3) to ensure compliance.

$$nw_i = \frac{nw_i}{\sum_{i=1}^{m} nw_i} \tag{3}$$

2.2 SECIA

The Subjective Equal Criteria Influence Approach builds upon the foundational principles of the ECIA. Its core mechanism involves the determination of criteria weights based on the impact of individual criteria on results using a selected multi-criteria decision-making method.

The enhancement proposed in this study introduces expert knowledge into the process through a subjective weight vector that reflects the relative importance of each criterion compared to the least influential criterion. This vector quantitatively expresses how much more influential a given criterion is. For instance, consider a decision problem with four criteria, where criteria C_1, C_2, and C_4 are deemed to have equal influence on the outcome, while criterion C_3 is considered twice as influential. The vector of the expected subjective influence ($vesi$) would be represented as in Equation (4)

$$vesi = [1, 1, 2, 1] \tag{4}$$

By incorporating the decision-maker's input through such a vector, SECIA modifies the ECIA procedure to account for the subjective importance of criteria. Specifically, the influence values calculated in step three of the ECIA process

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are adjusted using the provided subjective weight vector, as shown in the Equation (5)

$$inf = \frac{inf}{vesi} \tag{5}$$

This adjustment enables the integration of expert judgment into the determination of criteria weights, enhancing the ability of SECIA to address decision-making scenarios that require subjective evaluation alongside objective analysis.

2.3 BWM

The Best-Worst Method, introduced by Rezaei [12], is a multi-criteria decision-making (MCDM) approach based on pairwise comparisons. It has gained significant attention for its efficiency, reduced number of comparisons, and ability to handle inconsistencies that typically arise during the pairwise evaluation process. The method utilizes a linear mathematical model to calculate optimal criteria weights by systematically comparing the most important (best) criterion against all others and contrasting all remaining criteria against the least important (worst) criterion. This pairwise comparison yields two vectors: the "best-to-others" vector and the "others-to-worst" vector, which are then used to optimize the weights via a minimization model. The BWM ensures that weight values meet non-negativity and summation conditions while minimizing the maximum absolute deviation between the derived weights and the pairwise comparison values. Additionally, BWM incorporates a consistency ratio (CR), which evaluates the coherence of the comparison results, with lower CR values indicating higher consistency.

2.4 LBWA

The Level-Based Weight Assessment method, introduced by Žižović and Pamucar [25], is a recently developed subjective weighting approach designed to streamline the process of determining criteria significance. Unlike traditional pairwise comparison methods, LBWA employs a novel algorithm that groups criteria into non-decreasing significance levels, eliminating the need to redefine ordinal scales for comparison. Decision-makers (DMs) classify criteria into hierarchical levels based on their relative importance, with the most important criterion identified first. Other criteria are then grouped into levels according to their significance relative to the most important criterion, with each level representing a range of importance ratios. Within each group, integer values are assigned to criteria to represent their relative significance, while a maximum integer value (r) ensures consistency across levels. Using an elasticity coefficient and influence functions, LBWA calculates optimal weight coefficients for all criteria. This method is particularly advantageous for simplifying criteria evaluation, offering a structured and transparent process that integrates DM preferences.

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2.5 SPOTIS

The SPOTIS method represents a novel rank-reversal free approach in multi-criteria decision-making, introduced by Dezert in 2020 [5]. Unlike some other techniques, SPOTIS employs a more standardized methodology for tackling multi-criteria decision problems in which the boundaries of a problem need to be specified. An important prerequisite for implementing this method is that criteria weights must be determined before execution begins. The procedure follows a systematic series of steps outlined below.

2.6 Coefficients

In this study, four coefficients were utilized to analyze the results. Two coefficients were applied to compare the weight vectors, each normalized to values within the range $[0, 1]$. The first coefficient was Pearson's correlation coefficient [11], a widely used statistical measure for evaluating the linear correlation between two vectors. The second coefficient was the Weights Similarity Coefficient (WSC) [14], a recently introduced measure for assessing similarity between weight vectors. Among its two available variants—symmetric and asymmetric—the symmetric variant was employed in this research to ensure a balanced comparison across weight distributions.

Two additional coefficients were employed to compare the rankings derived from weight vectors generated by different methods. The first was the Weighted Spearman's correlation coefficient [3], which accounts for the positional changes in rankings, assigning greater importance to shifts occurring higher in the ranking order. The second was the Weighted Similarity (WS) coefficient [13], which emphasizes the positions closer to the top of the ranking, thereby providing additional insight into alternatives that are most critical for decision-making. These coefficients offer a more nuanced evaluation by reflecting the impact of ranking changes on decision priorities.

3 Comparative analysis

This section focuses on comparing the proposed extension of the ECIA to established methods for deriving criteria weights. A detailed evaluation is conducted using a specific case study to illustrate the practical applicability of the SECIA in solving real-world decision-making problems. Additionally, a broader comparison is undertaken through simulation studies, enabling an assessment of how the results produced by SECIA differ from those of commonly used methods in the literature. This dual approach provides insights into SECIA's effectiveness, robustness, and versatility in various decision-making scenarios.

3.1 Study case

This subsection examines the application of three weighting methods – namely, the Subjective Equal Criteria Influence Approach (SECIA), the Best-Worst

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Method (BWM), and the Level-Based Weight Assessment (LBWA) – to the evaluation of healthcare sectors in Eastern Europe. This problem was previously explored by Torkayesh et al. [15], whose primary objective was to develop an integrated multi-criteria framework for assessing healthcare systems. In their study, the authors employed the Combined Compromise Solution (CoCoSo) method, introduced by Yazdani et al. [22], which provides a comprehensive evaluation through three appraisal scores to enhance the accuracy of the assessment. In contrast, this paper employs the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method. While SPOTIS is conceptually simpler than CoCoSo, it offers a robust and stable solution that is resistant to the rank reversal problem, ensuring reliability in the evaluation process.

The evaluation problem incorporates the following criteria: C_1 – number of doctors providing direct health services to patients, C_2 – number of nurses providing direct health services to patients, C_3 – a measure of the resources available for delivering services to patients in hospitals in terms of number of beds, C_4 – number of computerized tomography scanners, C_5 – number of magnetic resonance imaging equipment, C_6 – number of radiotherapy equipment and C_7 – number of mammography machines. These criteria are analyzed in the context of seven countries: Hungary, Poland, Slovakia, Estonia, Slovenia, Latvia, and Lithuania. To formalize the evaluation, a decision matrix was constructed, as presented in Table 1.

Table 1. The decision matrix for the problem of healthcare performance.

Country	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Hungary	3.32	6.51	7.02	9.19	4.70	4.70	15.32
Poland	2.38	5.10	6.62	16.88	7.93	4.56	9.59
Slovakia	3.42	5.65	5.82	17.28	9.56	11.58	19.12
Estonia	3.47	6.19	4.69	18.22	13.66	5.31	12.15
Slovenia	3.10	9.92	4.50	15.00	11.61	6.29	15.97
Latvia	3.21	4.57	5.57	39.13	13.90	5.15	26.26
Lithuania	4.56	7.71	6.56	23.33	12.37	7.42	15.91
Criteria type	$Profit$	$Profit$	$Profit$	$Profit$	$Profit$	$Profit$	$Profit$

In the referenced study, expert preference values were elicited for the Best-Worst Method (BWM) and Level-Based Weight Assessment (LBWA) methodologies. For BWM, two distinct preference vectors were required: one assessing the relative importance of each criterion in comparison to the best criterion and another evaluating the criteria relative to the worst criterion. This dual-vector approach facilitates a more thorough assessment of criteria significance but can introduce asymmetry during the comparison of the two vectors. The values of these preference vectors are provided in Tables 2 and 3.

For the Level-Based Weight Assessment (LBWA) method, criteria are grouped into hierarchical levels based on the differences in their relative importance. In the context of the analyzed problem, the authors identified two distinct levels.

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Table 2. Best-to-others vector for the BWM method.

Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_3	3	2	1	5	5	6	8

Table 3. Others-to-worst vector for the BWM method.

Worst criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_7	6	8	8	3	4	3	1

The first level encompasses the most relevant criteria and those whose relevance is equal to or at most twice as low as the best criterion. The second level includes criteria with relevance that is at least twice as low as the best criterion but no more than three times lower. The grouping of criteria into these levels is as follows:

$$S_1 = \{C_3, C_1, C_2, C_4, C_5\}$$
$$S_2 = \{C_6, C_7\}$$

Furthermore, the relative importance of each criterion within a given level must be established. The maximum relative importance corresponds to the highest number of elements across all defined levels, which, in this case, is set to a value of 5. This methodology offers a more accessible approach for decision-makers, as it minimizes discrepancies in the evaluation process that might arise due to differing perspectives. The relevance values assigned to the criteria by the authors are as follows:

$$\text{Level } S_1 : I_3 = 0, I_1 = 4, I_2 = 4, I_4 = 1, I_5 = 2$$
$$\text{Level } S_2 : I_6 = 1, I_7 = 2$$

In the application of the SECIA within this study, direct elicitation of values from experts is not feasible. However, the values assigned using the LBWA method can be converted to align with the requirements of the SECIA framework. For the analyzed problem, these transformed values are presented in Table 4.

Table 4. Values of the vector of the expected subjective influence in the problem of assessing the healthcare systems.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
esiv	2.200	2.200	3.000	2.800	2.600	1.800	1.600

Using the provided values, the criteria weights for each method were computed and are summarized in Table 5. Additionally, the impact values for each criterion, as determined by the SECIA method, are presented for informational

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DOI: 10.1007/978-3-031-97567-7_28

purposes as $SECIA_i$. It is noteworthy that the criteria weights obtained via SECIA ($SECIA_w$) differ significantly from those derived using other methods. This discrepancy arises from the unique characteristic of SECIA, which integrates the decision-making method used to compute the final ranking into its weight calculation – an approach not incorporated in the other methods.

Table 5. Weights calculated using each weighting method in the study of assessing the healthcare performance.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
BWM	0.144	0.216	0.360	0.086	0.086	0.072	0.036
$LBWA$	0.127	0.127	0.212	0.181	0.159	0.097	0.090
$SECIA_w$	0.205	0.116	0.129	0.198	0.130	0.098	0.125
$SECIA_i$	0.120	0.119	0.161	0.152	0.140	0.098	0.087

The final rankings obtained using different weight vectors are presented in Figure 4. In this decision problem, identical rankings were observed for the SECIA and LBWA methods, which may result from the use of the *esiv* vector derived from expert-defined values within the LBWA framework. However, a critical observation is that, despite yielding identical rankings, the weight vectors produced by SECIA and LBWA differ significantly. This discrepancy may either reflect the characteristics of the specific decision problem or the influence of the SPOTIS method employed for ranking, which plays a critical role in SECIA. In contrast, the rankings derived using weights determined by the BWM method differ from those obtained with SECIA and LBWA, with the corresponding weight values also exhibiting significant variation.

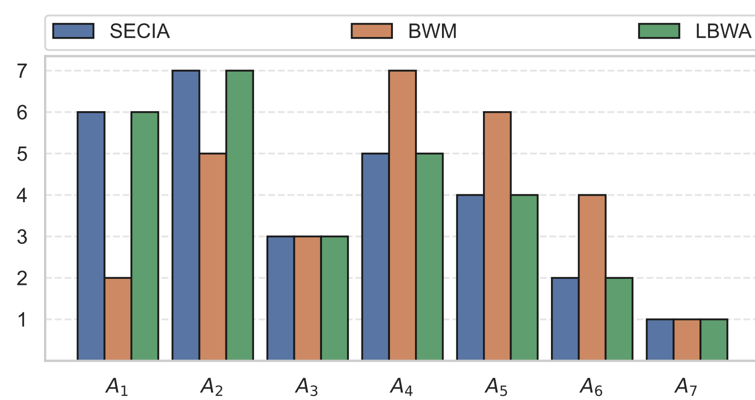

Fig. 2. Final ranking for the problem of evaluation of healthcare sectors.

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When selecting a weighting method, it is important to consider the additional information each method provides. BWM offers a consistency index, which evaluates the degree of coherence between the expert-defined vectors. LBWA simplifies the process of defining criteria relevance for decision-makers but does not provide supplementary indicators. Conversely, SECIA allows flexibility for experts in specifying criteria weights, provided their relative importance can be determined. Furthermore, SECIA uniquely quantifies the direct impact of each criterion on the final outcome, which can serve as valuable information in decision-making contexts.

3.2 Simulation

The objective of this section is to analyze the extent to which the weight values derived from the newly proposed SECIA differ from those obtained using established methods. Additionally, this section examines the variability in rankings produced by MCDM methods when applied to weight sets determined by different approaches. To achieve this, a simulation study was conducted, comparing the results generated using the BWM and LBWA with those obtained through SECIA.

Given that the methods employ different approaches to evaluating criteria, a standardized evaluation procedure was implemented. Criteria values were randomly sampled from the interval $[0.0, 0.5]$, scaled by a factor of 10, and rounded to the nearest integer. These values were initially utilized in LBWA, where a single level was constructed. Since SECIA relies on similar assumptions to LBWA for determining criteria significance, the vector employed in LBWA was normalized to the interval $[1, 2]$ to ensure higher compatibility with SECIA. It is worth noting that SECIA adopts an inverted approach compared to LBWA; therefore, the inverse of the normalized vector was used for SECIA.

For BWM, which operates on an abstract scale that does not directly correspond to the tuple representing differences in criteria significance, the vector was scaled to integer values within the interval $[1, 8]$ to comply with the requirements of BWM and employed as the best-to-others vector. Its inverse was then used as the others-to-worst vector, resulting in symmetric vectors for BWM in this simulation.

To ensure comprehensive analysis across a wide range of potential decision-making scenarios, a simulation study was conducted involving 1,000 randomly generated decision problems. For each problem, values were sampled from a uniform distribution over the interval $[0, 1]$. Each problem comprised 10 alternatives and 5 criteria, with all criteria characterized as profit type.

The comparison of the weight values derived using different methods was conducted by employing two statistical measures: the symmetric WSC and the Pearson correlation coefficient. The results are visualized as boxenplots in Figure 3. As evident from the plots, the results obtained across the methods are generally consistent, demonstrating that the newly proposed SECIA method exhibits stability and does not deviate significantly from established approaches. However, despite the overall similarity, some differences remain, underscoring

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the distinct nature of SECIA and its potential to yield varied outcomes. Notably, the weight values produced by SECIA align more closely with those of LBWA compared to BWM. This similarity could be attributed to the comparable process of determining criteria significance employed by SECIA and LBWA. In decision-making problems involving expert knowledge, these differences in weight calculations could become either more pronounced or less evident, depending on the specific context.

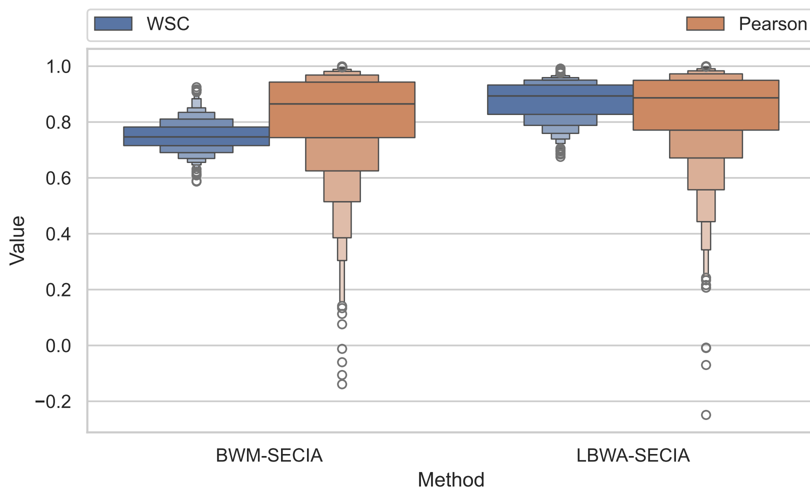

Fig. 3. Final ranking for the problem of evaluation of healthcare sectors.

In addition to analyzing the correlation of weight values, evaluating the influence of the derived criteria weights on the final ranking is critical. This analysis was conducted using Weighted Spearman coefficients and Weighted Similarity metrics, with the results illustrated in Figure 4. The findings indicate that SECIA is more closely aligned with LBWA than with BWM, as reflected in higher values and reduced variability across both metrics in the LBWA-SECIA comparison. Weighted Similarity consistently yields higher values than Weighted Spearman, suggesting a stronger resemblance in ranking distributions across scenarios. However, outliers are present in both comparisons, highlighting instances of significant deviations, potentially caused by differences in the assignment of criteria importance or problem-specific factors. These results emphasize SECIA's distinct methodological approach while demonstrating its stability and compatibility with other established techniques, particularly LBWA.

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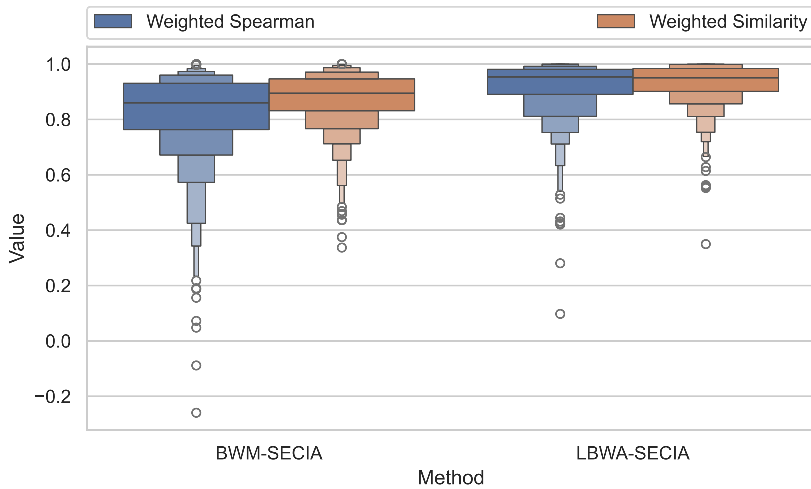

Fig. 4. Final ranking for the problem of evaluation of healthcare sectors.

4 Conclusion

This study introduces an extension of the Equal Criteria Influence Approach (ECIA) to a subjective framework, termed SECIA, and compares its performance against widely employed methods with similar functionality. The analysis includes its application in a real-world decision-making problem and simulation-based study. The findings demonstrate SECIA's strong potential within multi-criteria decision-making (MCDM) frameworks, owing to its ability to directly adjust the influence of individual criteria on the final outcomes. Furthermore, SECIA exhibits stability and aligns well with results obtained from established methods, whose effectiveness has been extensively validated in prior research. These characteristics underscore the practicality and relevance of SECIA in the context of MCDM and MCDA applications.

Future research should focus on applying the proposed method to a broader range of real-world decision-making problems and incorporating insights from domain experts regarding the determination of criteria relevance to optimize the decision-making process. Additionally, formalizing the method mathematically, such as through linear programming formulations, would enhance its theoretical foundation. Exploring alternative approaches for measuring the impact of criteria on outcomes and enabling experts to define criteria significance could further refine the method. Extensive simulation studies incorporating a wider array of metrics and comparison with additional methods of similar operational characteristics would be valuable for validating the robustness and versatility of the approach.

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DOI: 10.1007/978-3-031-97567-7_28

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DOI: 10.1007/978-3-031-97567-7_28

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