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TEKNO Method: Total Evaluation based on Knowledge-driven Normalized Optimization for Multi-Criteria Decision Making

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ABSTRACT

Multi-criteria decision making (MCDM) methods play an important role in supporting decisions involving multiple criteria with different characteristics and levels of importance. However, differences in normalization procedures, criterion treatment, and aggregation mechanisms can lead to variations in the resulting preference structures. This study proposes a new MCDM method, namely total evaluation based on knowledge-driven normalized optimization (TEKNO), which integrates normalization, relative evaluation, criterion weighting, optimization-based normalization, and total evaluation into a unified decision-making framework. The proposed method is designed to transform heterogeneous decision information into comparable evaluation values while preserving the relative contribution of each criterion. The applicability of TEKNO is evaluated through two decision-making case studies involving new store location selection and leasing customer selection. The evaluation framework includes ranking analysis, comparison with established MCDM methods, Spearman rank correlation analysis, and sensitivity analysis under variations in criterion weights. The results show that TEKNO achieves a Spearman rank correlation coefficient of 1.0000 for the new store location case and 0.9964 for the leasing customer selection case, indicating very strong agreement with the reference rankings. In addition, the ranking remains unchanged across the tested sensitivity scenarios, demonstrating the stability of TEKNO under variations in criterion weights. These findings indicate that TEKNO provides a transparent, systematic, and stable alternative for MCDM applications for practical decision support where reliable ranking, methodological transparency, and robustness across alternative evaluation conditions are required. Nevertheless, broader validation using diverse datasets, decision domains, weighting schemes, and statistical evaluation techniques

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is required to further establish its generalizability and comparative performance.

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I. Introduction

Multi-Criteria Decision Making (MCDM) has developed as an important approach for solving various decision-making problems in different fields, such as management, industry, education, healthcare, information technology, environment, transportation, and even supplier selection and performance evaluation[1]. This development is driven by increasingly complex decision-making conditions that no longer only consider one aspect, but involve many alternatives and criteria with different characteristics, levels of importance, and preference directions. In such situations, decision-makers face the need to compare a number of alternatives based on criteria that can be either benefit or cost, while each criterion can have a different impact on the final outcome[2], [3]. Besides that, differences in data scales, conflicts between criteria, uneven information, and a high number of alternatives can make the evaluation process more complicated and might lead to less consistent decisions if not supported by a systematic method. That's why the need for MCDM methods that can normalize data, determine the importance of criteria, process information objectively, and accurately rank alternatives keeps growing as decision problems become more diverse and complex.

The differences in measurement scales between parameters, the nature of criteria that can be oriented towards benefits or cost reduction, and the varying importance levels of each criterion make it challenging to build an objective alternative evaluation process. This situation requires a data processing mechanism that can equalize the contribution of each criterion without losing the important information contained within[4]. On the other hand, the MCDM methods that have been developed have different approaches, assumptions, and calculation mechanisms, so the evaluation results can depend on the normalization process, weighting, or aggregation strategy used and may not always be able to represent all the characteristics of the alternatives comprehensively[5], [6]. This situation shows the need to develop a new MCDM method that has simple calculation steps and is easy to apply, uses

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measurable evaluation metrics, and is able to integrate criteria information proportionally so that it produces stable and consistent ranking of alternatives.

The normalization approach commonly used in MCDM methods still has limitations in representing the relative relationships between alternatives when the data have different characteristics and value ranges[7], [8]. The value transformation process often only serves to equalize the scale but doesn't optimally accommodate the connection between an alternative's relative position, the importance level of criteria, and the quality of the values generated during the evaluation process. In addition, separating the weighting and ranking processes can cause the information from the data and criterion weights not to be fully integrated into the formation of the alternatives' final values[9], [10]. This situation shows a need for an evaluation mechanism that can link relative information from data with the weight of criteria through a systematic procedure, so that the contribution of each criterion to the performance of alternatives can be reflected more proportionally and produce a more consistent basis for ranking[11], [12].

The total evaluation based on knowledge-driven normalized optimization (TEKNO) method is an MCDM approach designed to build an alternative evaluation process by integrating data information, relative relationships between alternatives, criteria weights, and optimization processes into a single calculation framework. The basic concept of TEKNO positions the information contained in the decision matrix as the foundation for forming evaluation values, then processes it step by step so that differences in criteria characteristics can be represented proportionally. TEKNO's mechanism includes initial normalization to align values, relative evaluation to determine an alternative's position compared to others, weighting to represent each criterion's contribution, optimization normalization to guide the processed values toward a more optimal evaluation condition, and total evaluation to combine all criteria contributions into the final value of an alternative. Unlike the MCDM approach, which tends to separate the processes of data transformation, weighting, and ranking, TEKNO connects these stages in an integrated evaluation flow. Conceptually, this approach is expected to preserve the relative information of the data while also taking into account the importance of criteria and the optimal conditions of alternatives, resulting in a ranking mechanism that is more systematic, measurable, easy to apply, and consistent in distinguishing performance between alternatives.

This study makes some key contributions to the development of MCDM methods by proposing TEKNO as a new method to evaluate and rank alternatives based on various criteria. The first contribution lies in developing normalization and evaluation procedures that use relative information from the data to get a more structured representation of the alternatives' performance. Furthermore, TEKNO introduces a total evaluation mechanism that combines the results from processing each criterion into a final value used to rank the alternatives. The reliability of the proposed method is then tested by comparing TEKNO's

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ranking results with several MCDM methods that have been used before to see the similarities and differences in the evaluation patterns. In addition, this study conducts a sensitivity analysis on changes in conditions or criteria weights as well as a ranking consistency analysis to see how stable TEKNO is when evaluation parameters change. With these contributions, this study is expected to add more options for simple, measurable MCDM approaches that have a systematic evaluation mechanism.

II. Related Work

MCDM is a decision-making approach used to determine the best alternative based on several criteria considered simultaneously. Each alternative has a different performance level for each criterion, while the criteria can have different preference directions and levels of importance[13], [14]. In general, the MCDM process starts with defining alternatives and criteria, forming a decision matrix, determining criteria weights, normalizing data, calculating evaluation scores for each alternative, and ranking them based on the final scores obtained. The decision matrix represents the initial relationship between alternatives and criteria, while weighting is used to show the relative contribution of each criterion in the evaluation process. Normalization is needed to change values with different units and ranges into a scale that can be compared, then the results are combined with weights to get a preference value as a basis for ranking.

Normalization is an important step in MCDM because data for each criterion usually has different units, ranges, and preference directions[15]–[17]. For benefit criteria, higher values indicate better performance, so the normalization process generally sets the maximum value as the best representation. On the other hand, for cost criteria, lower values are preferred, so the normalization method needs to reverse this relationship so that alternatives with lower costs or sacrifice values get higher preference scores. Various normalization techniques have been used in MCDM, like approaches based on maximum, minimum, ratio, sum, or value range. Each technique produces different data transformations and can affect the proportion of an alternative's contribution to the criteria[18], [19]. So, choosing a normalization technique isn't just about making scales even—it can also impact the final values and the ranking of alternatives, especially when there are big differences in values or uneven data distribution.

Objective weighting is used to determine the importance level of criteria based on the characteristics of the data in the decision matrix, so that reliance on subjective assessments from decision-makers can be reduced[20], [21]. Several methods have been developed with different calculation principles. Entropy assigns weights based on the level of variation or uncertainty in the information contained in a criterion, meaning criteria with more diverse information can get a larger weight contribution. Criteria Importance Through Intercriteria Correlation (CRITIC) considers a combination of data variation and conflicts or

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correlations between criteria in determining the level of importance[22], [23]. The Method based on the Removal Effects of Criteria (MEREC) evaluates changes in overall performance when a criterion is removed from the evaluation process[24], [25], while the Logarithmic Percentage Change-driven Objective Weighting (LOPCOW) uses relative changes in data to determine the weights of criteria[26], [27]. This difference in principles shows that each weighting method provides a different perspective on the information contained in the data, making the choice of weighting method an important part of building an MCDM evaluation system.

The MCDM ranking method is used to turn normalized and weighted information into preference scores that can be used to rank alternatives. Simple Additive Weighting (SAW) adds up the normalized performance values multiplied by the criteria weights[28], [29], while Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) figures out an alternative's position based on how close it is to the positive ideal solution and how far it is from the negative ideal solution[30]. MOORA evaluates by using a ratio that takes into account both benefit and cost criteria, while WASPAS combines the Weighted Sum Model and Weighted Product Model concepts to get preference values. Grey Relational Analysis (GRA) evaluates the closeness of the relationship between alternatives and the reference condition, while Multi-Attribute Utility Theory (MAUT) uses a utility function to convert the performance of criteria into utility values that can be aggregated. The diversity of these mechanisms shows that ranking methods have different mathematical characteristics in translating alternative performance into decision order, so several methods can be used as a comparison to assess the behavior and consistency of the proposed method.

A review of previous MCDM approaches shows that the processes of normalization, weighting, and ranking have various mechanisms, each with a specific focus on processing decision information[31], [32]. Some approaches emphasize scale transformation, while others focus on data variation information, inter-criteria relationships, the impact of removing criteria, or how close alternatives are to reference conditions. In this context, the TEKNO method is presented as a new approach that integrates relative information, criteria weights, and optimization processes into an overall evaluation mechanism. The TEKNO method doesn’t just use normalization to even out values, but develops a set of evaluations that includes normalization, relative evaluation, weighting, optimization normalization, and total aggregation as the basis for ranking. This position gives TEKNO room to offer an evaluation mechanism that’s different from previous methods, particularly in maintaining information about the relative relationships between alternatives while also considering the importance level of criteria. With these characteristics, TEKNO method novelty lies in integrating these evaluation stages into a single framework that’s designed to be simple, measurable, and can be tested for consistency by comparing it with various existing MCDM methods.

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III. Methodology

3.1. Research Framework

A research framework is a conceptual structure that outlines the flow and connections between processes in a study, from identifying the problem, reviewing previous research, formulating research gaps, developing the proposed approach, testing, to drawing conclusions. This framework is used to provide a systematic picture of how research problems are translated into methodological steps to achieve the set objectives. Figure 1 shows the research framework used in this study.

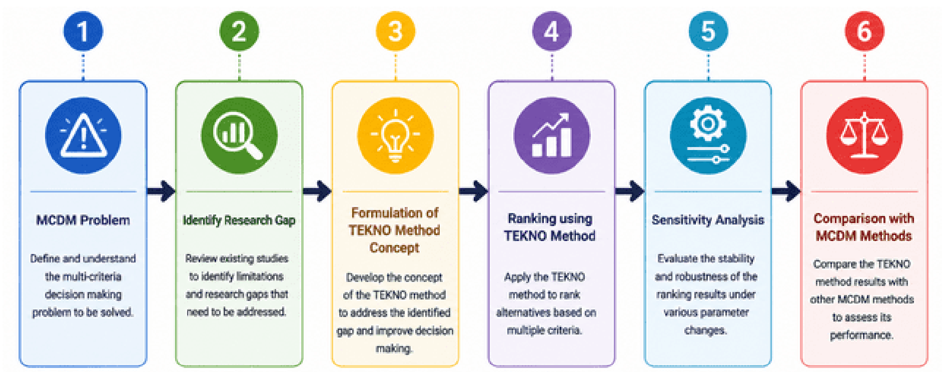

Figure 1. Research Stages

This research framework starts with identifying MCDM problems related to the complexity of evaluating alternatives based on various criteria, then continues with identifying research gaps to find limitations in existing approaches. Based on these gaps, the study formulates the TEKNO method concept as a new approach designed to systematically process information about criteria and alternatives. The formulated method is then applied to rank alternatives, producing evaluation scores and preference rankings based on TEKNO. The ranking results are then analyzed through sensitivity analysis to see how stable they are against changes in the parameters used. The final stage is done by comparing it with other MCDM methods to evaluate the characteristics, consistency, and capability of TEKNO in generating alternative rankings.

3.2. TEKNO Method Framework

The proposed TEKNO method is developed as a systematic framework for multi-criteria decision making that transforms the initial performance values of alternatives into a final ranking. The framework integrates a series of computational processes, including decision matrix construction, benefit-cost normalization, average-based standardization, weighted standardization, weighted value normalization, and overall score calculation. These processes are sequentially connected to ensure that the characteristics and relative importance of each criterion are appropriately incorporated into the evaluation of alternatives. The overall structure and computational framework of the proposed TEKNO method are illustrated in Figure 2.

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Figure 2. TEKNO Method Framework

The TEKNO framework presents a systematic computational structure for multi-criteria decision making that integrates data normalization, average-based standardization, criterion weighting, weighted value normalization, and overall score aggregation into a unified evaluation process. The framework transforms the initial decision matrix into a final ranking by progressively converting heterogeneous criterion values into comparable decision information. The process begins with the representation of alternative performances through the decision matrix, followed by normalization to reduce the effect of differences in measurement scales. The normalized values are subsequently processed through average-based standardization to establish a consistent reference for evaluating the relative performance of alternatives. The standardized information is then combined with criterion weights to reflect the importance of each decision criterion, followed by weighted value normalization to obtain comparable weighted contributions. Finally, the weighted contributions are aggregated to generate an overall score for each alternative, which serves as the basis for the final ranking. Alternatives with higher overall scores are considered more preferable.

The main strength of TEKNO framework lies in its integrated transformation mechanism, in which normalization, standardization, and weighting are not treated as isolated computational operations but as interconnected components of the decision process. This structure enables the method to reduce scale-related disparities while simultaneously preserving the contribution of criterion importance in the final evaluation. The average-based standardization further provides a reference-oriented representation of alternative performance, allowing the evaluation to consider the relative position of each alternative with respect to the collective performance of the decision matrix. Consequently, TEKNO provides a more structured pathway for transforming raw performance information into decision-relevant values before the final aggregation stage.

Another important advantage is its potential discrimination capability in distinguishing alternatives with relatively close performance levels. The successive transformation of normalized, standardized, and weighted values allows differences among alternatives to be retained throughout the evaluation process rather than relying solely on direct aggregation of the original decision matrix. This characteristic can be particularly useful in decision problems where

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several alternatives exhibit similar performance across multiple criteria. By incorporating criterion weights before the final aggregation, TEKNO can also emphasize differences associated with more important criteria while maintaining the contribution of less influential criteria.

The TEKNO framework also provides scale independence and computational flexibility as important methodological characteristics. Since the original criterion values are transformed before aggregation, criteria expressed in different numerical ranges can be incorporated within a common evaluation structure. This makes the framework suitable for decision problems involving heterogeneous criteria and diverse measurement units. Moreover, the computational sequence is relatively straightforward and does not require highly complex iterative optimization procedures. Such computational simplicity facilitates implementation, replication, and integration into decision support systems while maintaining a transparent relationship between input data and final ranking outcomes.

Overall, the TEKNO framework offers a unified approach that emphasizes comparability, discrimination capability, weighting sensitivity, computational simplicity, and ranking transparency. Its structured transformation of decision information provides a consistent mechanism for handling heterogeneous criteria and generating overall alternative scores. These characteristics position TEKNO as a promising MCDM method for applications requiring systematic evaluation and clear alternative prioritization. Nevertheless, the robustness and ranking stability of the proposed method should be further demonstrated through comparative experiments, sensitivity analysis, and stability assessment against established MCDM methods. Such validation is essential to empirically establish the effectiveness and generalizability of TEKNO across different decision-making scenarios.

3.3. Total Evaluation based on Knowledge-driven Normalized Optimization (TEKNO) Method

The TEKNO method is a new approach in MCDM designed to determine the priority of alternatives through a normalization process based on the characteristics of criteria and knowledge-driven evaluation. The TEKNO method integrates information from the performance values of alternatives with the criteria structure to produce evaluation scores that represent the level of excellence of each alternative more consistently. The main advantages of the TEKNO method lie in its relatively simple calculation procedure, ability to handle both benefit and cost criteria, direct use of data information in the normalization process, and generating preference values that allow alternatives to be clearly ranked. Additionally, the knowledge-driven normalized optimization approach provides flexibility in accommodating differences in scales between criteria, making it applicable to various MCDM problems with diverse data characteristics.

The TEKNO method starts by creating a decision matrix that contains the value of each alternative against all criteria as the

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initial data for decision-making using (1). Next, the decision values are normalized based on the characteristics of the benefit and cost criteria so they can be compared on the same scale using (2). The normalization results are used to calculate the relative evaluation values by comparing each value to the average of the criteria using (3). After that, the relative evaluation values are multiplied by the weights of each criterion to get the weighted contribution values using (4). These values are then normalized against the highest value in each criterion using (5). The final step is to average the normalized values to get the overall evaluation value, which serves as the basis for ranking the alternatives using (6).

$$X = [x_{ij}]_{mxn} \tag{1}$$

$$t_{ij} = \begin{cases} \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}; benefit \\ \frac{\frac{1}{x_{ij}}}{\sum_{i=1}^{m} \frac{1}{x_{ij}}}; cost \end{cases} \tag{2}$$

$$e_{ij} = \frac{t_{ij}}{\frac{1}{m}\sum_{i=1}^{m} t_{ij}} \tag{3}$$

$$k_{ij} = w_j * e_{ij} \tag{4}$$

$$n_{ij} = \frac{k_{ij}}{\max_j k_{ij}} \tag{5}$$

$$o_i = \frac{1}{n}\sum_{j=1}^{n} n_{ij} \tag{6}$$

Based on all these steps, the TEKNO method produces a final evaluation score that reflects the relative performance of each alternative by taking into account the criteria values, the benefit and cost characteristics, and the importance weights of each criterion. This evaluation score serves as the basis for ranking the alternatives, so an alternative with a higher evaluation score shows better performance and priority. In this way, the TEKNO method can provide measurable and systematic evaluation results to support decision-making in MCDM problems.

IV. TEKNO Method Implementation

4.1. Experimental Design and Evaluation Setup

The experimental design is established to evaluate the applicability and performance of the proposed TEKNO method in solving multi-criteria decision-making problems with different decision characteristics. To provide a comprehensive evaluation, TEKNO is implemented using two independent case studies representing distinct decision contexts, alternative configurations, and evaluation criteria. The use of multiple case studies enables the proposed method to be examined beyond a single decision environment and provides an opportunity to assess its applicability across different MCDM scenarios.

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For each case study, the evaluation follows a consistent computational framework, beginning with the preparation of the decision matrix and identification of the alternatives and evaluation criteria. The criteria are classified according to their respective characteristics, while criterion weights are incorporated to represent their relative importance in the decision process. The resulting decision information is subsequently processed using the TEKNO framework described in Section III to obtain the overall score and ranking of each alternative. The detailed characteristics of the alternatives, criteria, datasets, and implementation for each case study are presented separately in the following subsections.

To further assess the effectiveness of TEKNO, the experimental evaluation considers not only the resulting alternative rankings but also the consistency and reliability of the ranking outcomes. Where applicable, the results generated by TEKNO are compared with those obtained from established MCDM methods to examine similarities and differences in alternative prioritization. Additional evaluation through ranking stability and sensitivity analysis is conducted to investigate how changes in decision parameters, particularly criterion weights, may influence the resulting rankings. These evaluations provide a broader basis for examining the robustness, discrimination capability, and practical applicability of the proposed method.

The experimental setup is designed to maintain a consistent evaluation procedure across both case studies, thereby ensuring that differences in the obtained results are primarily associated with the characteristics of the decision problems rather than variations in the computational procedure. This configuration provides a systematic basis for evaluating TEKNO and supports a more objective assessment of its performance, generalizability, and potential advantages over existing MCDM approaches.

4.2. Case Study 1: Selection of New Store Location

The first case study focuses on the selection of a new store location, which is formulated as a multi-criteria decision-making problem involving several potential locations evaluated according to multiple relevant location attributes. The dataset was adopted from the [33] study that explored applying a multi-criteria decision-making approach to determine the most suitable location for a new store. The original dataset represents a practical location-selection problem and provides a suitable benchmark for evaluating the applicability of the proposed TEKNO method.

The decision problem comprises eight potential store locations, denoted as the alternatives to be evaluated. Each alternative is assessed according to six criteria, namely Rental Cost (K1), Building Area (K2), Accessibility (K3), Consumer Traffic (K4), Parking Availability (K5), and Infrastructure (K6). These criteria represent economic, physical, accessibility, and operational characteristics that may influence the suitability of a candidate location. The assessment scores of the eight alternatives across the six criteria are presented in Table 1.

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Table 1.Evaluation Scores of Candidate Store Locations[33]

Location	K1	K2	K3	K4	K5	K6
Loc-1	45	120	8	550	10	9
Loc-2	40	100	7	500	8	8
Loc-3	55	150	9	600	12	9
Loc-4	38	90	6	480	6	7
Loc-5	60	160	8	620	15	10
Loc-6	42	130	9	570	11	8
Loc-7	36	110	7	510	9	7
Loc-8	48	140	8	590	13	9

Table 1 presents the evaluation scores of the eight candidate store locations, which are adopted from the original study and used as the initial decision matrix for the TEKNO method. The evaluation data provide the performance values required to assess each alternative within the proposed framework. To maintain consistency with the original decision problem, the criterion weights are also adopted from the same study and subsequently incorporated into the TEKNO evaluation. These weights represent the relative importance assigned to each criterion and are used in the weighted standardization and weighted value normalization processes. The resulting weighted values are then aggregated to obtain the overall score of each alternative, which serves as the basis for determining the final ranking. The criterion weights adopted from the original study and used in the TEKNO evaluation are presented in Table 2.

Table 2.Criterion Weights

K1	K2	K3	K4	K5	K6
0.1713	0.1798	0.1711	0.1316	0.1996	0.1466

The criterion weights obtained from the original study are subsequently incorporated into the proposed TEKNO method. These weights are applied to the normalized and standardized evaluation values to determine the weighted contribution of each criterion, which is then aggregated to obtain the overall score and final ranking of the alternatives.

The TEKNO method begins by constructing a decision matrix containing the performance value of each alternative with respect to all criteria. The decision matrix serves as the initial input for the calculation and represents the original performance of the alternatives before any transformation is applied. Each element of the matrix represents the performance value of an alternative under a specific criterion, providing the basis for all subsequent computational stages. The decision matrix is constructed using (1), and the values obtained are presented in the following matrix.

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$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \end{array} \begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \\ x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} & x_{56} \\ x_{61} & x_{62} & x_{63} & x_{64} & x_{65} & x_{66} \\ x_{71} & x_{72} & x_{73} & x_{74} & x_{75} & x_{76} \\ x_{81} & x_{82} & x_{83} & x_{84} & x_{85} & x_{86} \end{bmatrix} \quad X = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \end{array} \begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \\ 45 & 120 & 8 & 500 & 10 & 9 \\ 50 & 100 & 7 & 550 & 8 & 8 \\ 55 & 150 & 9 & 600 & 12 & 9 \\ 38 & 90 & 6 & 480 & 6 & 7 \\ 60 & 160 & 8 & 620 & 15 & 10 \\ 42 & 130 & 9 & 570 & 11 & 8 \\ 36 & 110 & 7 & 510 & 9 & 7 \\ 48 & 140 & 8 & 590 & 13 & 9 \end{bmatrix}$$

The second stage is the normalization of the decision matrix. The normalization process transforms the original decision values into comparable values while considering the characteristics of benefit and cost criteria. This transformation reduces the influence of differences in measurement scales and ensures that the normalized values follow a consistent preference direction. Normalization is calculated using (2), the results of the normalization values are as follows.

$$t_{11} = \frac{\frac{1}{x_{11}}}{\sum_{i=1}^{8} \frac{1}{x_{i1}}} = \frac{\frac{1}{45}}{\frac{1}{45} + \frac{1}{50} + \frac{1}{55} + \frac{1}{38} + \frac{1}{60} + \frac{1}{42} + \frac{1}{36} + \frac{1}{48}} = \frac{0.0222}{0.1808} = 0.0040$$

The overall normalization scores obtained using the TEKNO method are fully presented in Table 3, providing a comparable representation of the performance values across all alternatives and criteria.

Table 3. Overall Normalization Results

Location	K1	K2	K3	K4	K5	K6
Loc-1	0.0040	0.1200	0.1290	0.1244	0.1190	0.1343
Loc-2	0.0045	0.1000	0.1129	0.1131	0.0952	0.1194
Loc-3	0.0033	0.1500	0.1452	0.1357	0.1429	0.1343
Loc-4	0.0048	0.0900	0.0968	0.1086	0.0714	0.1045
Loc-5	0.0030	0.1600	0.1290	0.1403	0.1786	0.1493
Loc-6	0.0043	0.1300	0.1452	0.1290	0.1310	0.1194
Loc-7	0.0050	0.1100	0.1129	0.1154	0.1071	0.1045
Loc-8	0.0038	0.1400	0.1290	0.1335	0.1548	0.1343

The third stage determines the relative evaluation values based on the normalized decision matrix. In this stage, each normalized value is evaluated relative to the average performance of the corresponding criterion. The average-based comparison provides a reference for determining the relative performance of each alternative within the decision set. The relative evaluation score is calculated using (3), the calculation results of the relative evaluation score are as follows.

$$e_{11} = \frac{t_{11}}{\frac{1}{8}\sum_{i=1}^{8} t_{i1}} = \frac{0.0040}{\frac{1}{8}(0.0040 + 0.0045 + 0.0033 + 0.0048 + 0.0030 + 0.0043 + 0.0050 + 0.0038)}$$
$$= \frac{0.0040}{0.0041} = 0.9832$$

The overall relative evaluation scores obtained using the TEKNO method are fully presented in Table 4, providing a comparable representation of the relative performance of all alternatives across the evaluated criteria.

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Table 4. Overall Relative Evaluation Results

Location	K1	K2	K3	K4	K5	K6
Loc-1	0.9832	0.9600	1.0323	0.9955	0.9524	1.0746
Loc-2	1.1062	0.8000	0.9032	0.9050	0.7619	0.9552
Loc-3	0.8045	1.2000	1.1613	1.0860	1.1429	1.0746
Loc-4	1.1644	0.7200	0.7742	0.8688	0.5714	0.8358
Loc-5	0.7374	1.2800	1.0323	1.1222	1.4286	1.1940
Loc-6	1.0535	1.0400	1.1613	1.0317	1.0476	0.9552
Loc-7	1.2291	0.8800	0.9032	0.9231	0.8571	0.8358
Loc-8	0.9218	1.1200	1.0323	1.0679	1.2381	1.0746

The fourth stage incorporates the criterion weights into the relative evaluation values. The relative evaluation value of each alternative is multiplied by the corresponding criterion weight to determine the weighted contribution of each criterion. This calculation enables the relative importance of the criteria to be reflected in the evaluation while maintaining the performance information obtained from the previous stage. The weighted contribution value is calculated using (4), the results of the weighted contribution calculation are as follows.

$$k_{11} = w_1 * e_{11} = 0.1713 * 0.9832 = 0.1684$$

The overall weighted contribution scores obtained using the TEKNO method are fully presented in Table 5, reflecting the weighted performance of all alternatives across the evaluated criteria.

Table 5. Weighted Contribution Results

Location	K1	K2	K3	K4	K5	K6
Loc-1	0.1684	0.1726	0.1766	0.1310	0.1901	0.1575
Loc-2	0.1895	0.1438	0.1545	0.1191	0.1521	0.1400
Loc-3	0.1378	0.2158	0.1987	0.1429	0.2281	0.1575
Loc-4	0.1995	0.1295	0.1325	0.1143	0.1141	0.1225
Loc-5	0.1263	0.2301	0.1766	0.1477	0.2851	0.1750
Loc-6	0.1805	0.1870	0.1987	0.1358	0.2091	0.1400
Loc-7	0.2105	0.1582	0.1545	0.1215	0.1711	0.1225
Loc-8	0.1579	0.2014	0.1766	0.1405	0.2471	0.1575

The fifth stage performs normalization of the weighted contribution values. The values obtained from the previous stage are normalized against the highest weighted contribution within each criterion to establish a common reference for the final aggregation. This process enables the weighted contributions of different criteria to be consistently combined while preserving their relative performance. The weighted normalization value is calculated using (5), and the results of the weighted normalization calculation are as follows.

$$n_{11} = \frac{k_{11}}{\max_j k_{i1}} = \frac{0.1684}{0.2105} = 0.8000$$

The overall weighted normalization scores obtained using the TEKNO method are fully presented in Table 6, providing a normalized representation of the weighted performance of all alternatives across the evaluated criteria.

Table 6. Weighted Normalization Results

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Location	K1	K2	K3	K4	K5	K6
Loc-1	0.8000	0.7500	0.8889	0.8871	0.6667	0.9000
Loc-2	0.9000	0.6250	0.7778	0.8065	0.5333	0.8000
Loc-3	0.6545	0.9375	1.0000	0.9677	0.8000	0.9000
Loc-4	0.9474	0.5625	0.6667	0.7742	0.4000	0.7000
Loc-5	0.6000	1.0000	0.8889	1.0000	1.0000	1.0000
Loc-6	0.8571	0.8125	1.0000	0.9194	0.7333	0.8000
Loc-7	1.0000	0.6875	0.7778	0.8226	0.6000	0.7000
Loc-8	0.7500	0.8750	0.8889	0.9516	0.8667	0.9000

The final stage calculates the overall evaluation value of each alternative by averaging its normalized weighted values across all criteria. The resulting overall evaluation value represents the aggregated performance of an alternative after considering the normalization, relative evaluation, and criterion weights throughout the TEKNO framework. The alternatives are then ranked according to their overall evaluation values, where a higher value indicates a more favorable alternative. The overall evaluation score is calculated using (6), the results of the overall evaluation calculation are as follows.

$$o_1 = \frac{1}{6}\sum_{j=1}^{6} n_{1j} = \frac{1}{6}(0.8000 + 0.7500 + 0.8889 + 0.8871 + 0.6667 + 0.9000) = 0.8154$$

The overall evaluation scores obtained using the TEKNO method are fully presented in Table 7, reflecting the final performance assessment of all alternatives based on the aggregated evaluation values.

Table 7. Overall Evaluation Results

Location	Final Score
Loc-1	0.8154
Loc-2	0.7404
Loc-3	0.8766
Loc-4	0.6751
Loc-5	0.9148
Loc-6	0.8537
Loc-7	0.7646
Loc-8	0.8720

Based on the final evaluation scores, the alternatives are subsequently arranged according to their relative performance to determine the preference order. The alternative with the highest evaluation score is considered the most preferred, while the remaining alternatives are ranked accordingly. The resulting ranking provides a clear representation of the preference order among the candidate locations and is presented in Figure 3.

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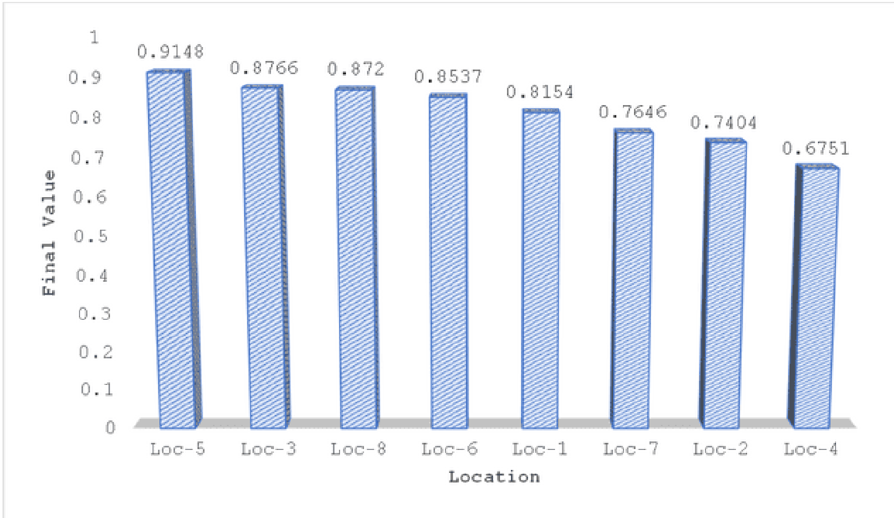

Figure 3. Alternative Rankings using the TEKNO Method

The final evaluation results provide the basis for determining the value and ranking of each alternative. Loc-5 achieves the first rank with a score of 0.9148, followed by Loc-3 with 0.8766 and Loc-8 with 0.8720. Loc-6 ranks fourth with 0.8537, while Loc-1 and Loc-7 occupy the fifth and sixth positions with scores of 0.8154 and 0.7646, respectively. Loc-2 ranks seventh with 0.7404, whereas Loc-4 obtains the eighth rank with the lowest score of 0.6751. These results represent the final preference order generated by the TEKNO method.

4.3. Case Study 3: Leasing Customer Selection

The second case study focuses on leasing customer selection, which represents a decision-making problem involving the assessment of prospective customers based on relevant financial and non-financial factors. The dataset is adopted from a previous study [34] that addressed leasing customer selection through an integrated decision support approach for improving the objectivity and consistency of customer assessment. This case study is used to further evaluate the applicability of the proposed TEKNO method in generating preference values and ranking alternatives in a credit-risk-oriented decision context.

The leasing customer selection problem is evaluated using seven criteria, consisting of six benefit criteria and one cost criterion. CR-1 represents Monthly Income, CR-2 Job Stability, CR-3 Credit History, CR-5 Collateral Value, CR-6 Customer's Age, and CR-7 Home Ownership Status, all classified as benefit criteria, while CR-4 Installment-to-Income Ratio is classified as a cost criterion. These criteria collectively represent the financial capacity, creditworthiness, financial burden, security, and personal characteristics of prospective customers. The assessment scores of the alternatives across the selected criteria are presented in Table 8.

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Table 8.Customer Evaluation Data[34]

Customer	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
Customer 1	6500000	4	4	32	120000000	32	3
Customer 2	5800000	3	3	35	100000000	29	2
Customer 3	7200000	6	5	28	150000000	41	3
Customer 4	4900000	2	3	40	90000000	27	1
Customer 5	8000000	7	5	25	180000000	45	3
Customer 6	6000000	5	4	30	130000000	38	2
Customer 7	5200000	3	2	42	80000000	26	1
Customer 8	7500000	6	5	27	160000000	40	3
Customer 9	6800000	4	4	33	140000000	35	2
Customer 10	4500000	2	2	45	80000000	25	1
Customer 11	8300000	8	5	22	200000000	48	3
Customer 12	5600000	4	3	36	110000000	31	2
Customer 13	6900000	5	4	31	145000000	37	3
Customer 14	7800000	7	5	26	170000000	43	3
Customer 15	5000000	3	3	38	95000000	28	2

Table 8 presents the evaluation scores of the prospective leasing customers, which are adopted from the original study and used as the initial decision matrix for the TEKNO method. The evaluation data represent the performance of each customer across the selected criteria. To maintain consistency with the original decision problem, the criterion weights are also adopted from the same study and incorporated into the TEKNO evaluation. These weights are subsequently applied to obtain the weighted evaluation values and final scores of the alternatives. The criterion weights used in the TEKNO evaluation are presented in Table 9.

Table 9.Criterion Weights

CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
0.13923	0.14898	0.14290	0.13952	0.14223	0.13971	0.14742

The criterion weights obtained from the original study are subsequently incorporated into the proposed TEKNO method. These weights are applied to the normalized and standardized customer evaluation values to determine the weighted contribution of each criterion, which is then aggregated to obtain the overall evaluation score and final ranking of the prospective leasing customers.

The TEKNO method begins by constructing a decision matrix containing the performance value of each alternative with respect to all criteria. The decision matrix serves as the initial input for the calculation and represents the original performance of the alternatives before any transformation is applied. Each element of the matrix represents the performance value of an alternative under a specific criterion, providing the basis for all subsequent computational stages. The decision matrix is constructed using (1), and the values obtained are presented in the following matrix.

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$$X=\begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} & x_{17} \\ x_{21} & x_{22} & x_{23} & x_{13} & x_{25} & x_{26} & x_{27} \\ x_{31} & x_{32} & x_{33} & x_{33} & x_{35} & x_{36} & x_{37} \\ x_{41} & x_{42} & x_{43} & x_{43} & x_{45} & x_{46} & x_{47} \\ x_{51} & x_{52} & x_{53} & x_{53} & x_{55} & x_{56} & x_{57} \\ x_{61} & x_{62} & x_{63} & x_{63} & x_{65} & x_{66} & x_{67} \\ x_{71} & x_{72} & x_{73} & x_{73} & x_{75} & x_{76} & x_{77} \\ x_{81} & x_{82} & x_{83} & x_{83} & x_{85} & x_{86} & x_{87} \\ x_{91} & x_{92} & x_{93} & x_{93} & x_{95} & x_{96} & x_{97} \\ x_{101} & x_{102} & x_{103} & x_{103} & x_{105} & x_{106} & x_{107} \\ x_{111} & x_{112} & x_{113} & x_{113} & x_{115} & x_{116} & x_{117} \\ x_{121} & x_{122} & x_{123} & x_{123} & x_{125} & x_{126} & x_{127} \\ x_{131} & x_{132} & x_{133} & x_{133} & x_{135} & x_{136} & x_{137} \\ x_{141} & x_{142} & x_{143} & x_{143} & x_{145} & x_{146} & x_{147} \\ x_{151} & x_{152} & x_{153} & x_{153} & x_{155} & x_{156} & x_{157} \end{bmatrix} \quad X=\begin{bmatrix} 6500000 & 4 & 4 & 32 & 12000000 & 32 & 3 \\ 5800000 & 3 & 3 & 35 & 10000000 & 29 & 2 \\ 7200000 & 6 & 5 & 28 & 15000000 & 41 & 3 \\ 4900000 & 2 & 3 & 40 & 9000000 & 27 & 1 \\ 8000000 & 7 & 5 & 25 & 18000000 & 45 & 3 \\ 6000000 & 5 & 4 & 30 & 13000000 & 38 & 2 \\ 5200000 & 3 & 2 & 42 & 8500000 & 26 & 1 \\ 7500000 & 6 & 5 & 27 & 16000000 & 40 & 3 \\ 6800000 & 4 & 4 & 33 & 14000000 & 35 & 2 \\ 4500000 & 2 & 2 & 45 & 8000000 & 25 & 1 \\ 8300000 & 8 & 5 & 22 & 20000000 & 48 & 3 \\ 5600000 & 4 & 3 & 36 & 11000000 & 31 & 2 \\ 6900000 & 5 & 4 & 31 & 14500000 & 37 & 3 \\ 7800000 & 7 & 5 & 26 & 17000000 & 43 & 3 \\ 5000000 & 3 & 3 & 38 & 9500000 & 28 & 2 \end{bmatrix}$$

The second stage is the normalization of the decision matrix. The normalization process transforms the original decision values into comparable values while considering the characteristics of benefit and cost criteria. This transformation reduces the influence of differences in measurement scales and ensures that the normalized values follow a consistent preference direction. Normalization is calculated using (2), the results of the normalization values are as follows.

$$t_{11}=\frac{x_{11}}{\sum_{i=1}^{15} x_{i1}}=\frac{6500000}{\begin{array}{c}6500000+5800000+7200000+4900000+8000000+6000000\\+5200000+7500000+6800000+4500000+8300000+5600000\end{array}}$$
$$=\frac{6500000}{96000000}=0.0677$$

The overall normalization scores obtained using the TEKNO method are fully presented in Table 10, providing a comparable representation of the performance values across all alternatives and criteria.

Table 10. Overall Normalization Results

Customer	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
Customer 1	0.0677	0.0580	0.0702	0.0149	0.0615	0.0610	0.0882
Customer 2	0.0604	0.0435	0.0526	0.0136	0.0513	0.0552	0.0588
Customer 3	0.0750	0.0870	0.0877	0.0171	0.0769	0.0781	0.0882
Customer 4	0.0510	0.0290	0.0526	0.0119	0.0462	0.0514	0.0294
Customer 5	0.0833	0.1014	0.0877	0.0191	0.0923	0.0857	0.0882
Customer 6	0.0625	0.0725	0.0702	0.0159	0.0667	0.0724	0.0588
Customer 7	0.0542	0.0435	0.0351	0.0114	0.0410	0.0495	0.0294
Customer 8	0.0781	0.0870	0.0877	0.0177	0.0821	0.0762	0.0882
Customer 9	0.0708	0.0580	0.0702	0.0145	0.0718	0.0667	0.0588
Customer 10	0.0469	0.0290	0.0351	0.0106	0.0410	0.0476	0.0294
Customer 11	0.0865	0.1159	0.0877	0.0217	0.1026	0.0914	0.0882
Customer 12	0.0583	0.0580	0.0526	0.0133	0.0564	0.0590	0.0588
Customer 13	0.0719	0.0725	0.0702	0.0154	0.0744	0.0705	0.0882
Customer 14	0.0813	0.1014	0.0877	0.0184	0.0872	0.0819	0.0882
Customer 15	0.0521	0.0435	0.0526	0.0126	0.0487	0.0533	0.0588

The third stage determines the relative evaluation values based on the normalized decision matrix. In this stage, each normalized value is evaluated relative to the average performance of the corresponding criterion. The average-based comparison provides a reference for

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determining the relative performance of each alternative within the decision set. The relative evaluation score is calculated using (3), the calculation results of the relative evaluation score are as follows.

$$e_{11} = \frac{t_{11}}{\frac{1}{15}\sum_{i=1}^{15} t_{i1}} = \frac{0.0677}{\frac{1}{15}(0.0677 + 0.0604 + 0.0750 + 0.0510 + 0.0833 + 0.0625 + 0.0542 + 0.0781 + 0.0708 + 0.0469 + 0.0865 + 0.0583 + 0.0719 + 0.0813 + 0.0521)}$$

$$= \frac{0.0677}{0.0667} = 1.0156$$

The overall relative evaluation scores obtained using the TEKNO method are fully presented in Table 11, providing a comparable representation of the relative performance of all alternatives across the evaluated criteria.

Table 11. Overall Relative Evaluation Results

Customer	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
Customer 1	1.0156	0.8696	1.0526	0.9817	0.9231	0.9143	1.3235
Customer 2	0.9063	0.6522	0.7895	0.8975	0.7692	0.8286	0.8824
Customer 3	1.1250	1.3043	1.3158	1.1219	1.1538	1.1714	1.3235
Customer 4	0.7656	0.4348	0.7895	0.7853	0.6923	0.7714	0.4412
Customer 5	1.2500	1.5217	1.3158	1.2565	1.3846	1.2857	1.3235
Customer 6	0.9375	1.0870	1.0526	1.0471	1.0000	1.0857	0.8824
Customer 7	0.8125	0.6522	0.5263	0.7479	0.6154	0.7429	0.4412
Customer 8	1.1719	1.3043	1.3158	1.1634	1.2308	1.1429	1.3235
Customer 9	1.0625	0.8696	1.0526	0.9519	1.0769	1.0000	0.8824
Customer 10	0.7031	0.4348	0.5263	0.6981	0.6154	0.7143	0.4412
Customer 11	1.2969	1.7391	1.3158	1.4279	1.5385	1.3714	1.3235
Customer 12	0.8750	0.8696	0.7895	0.8726	0.8462	0.8857	0.8824
Customer 13	1.0781	1.0870	1.0526	1.0133	1.1154	1.0571	1.3235
Customer 14	1.2188	1.5217	1.3158	1.2082	1.3077	1.2286	1.3235
Customer 15	0.7813	0.6522	0.7895	0.8267	0.7308	0.8000	0.8824

The fourth stage incorporates the criterion weights into the relative evaluation values. The relative evaluation value of each alternative is multiplied by the corresponding criterion weight to determine the weighted contribution of each criterion. This calculation enables the relative importance of the criteria to be reflected in the evaluation while maintaining the performance information obtained from the previous stage. The weighted contribution value is calculated using (4), the results of the weighted contribution calculation are as follows.

$$k_{11} = w_1 * e_{11} = 0.13923 * 1.0156 = 0.1414$$

The overall weighted contribution scores obtained using the TEKNO method are fully presented in Table 12, reflecting the weighted performance of all alternatives across the evaluated criteria.

Table 12. Weighted Contribution Results

Customer	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
Customer 1	0.1414	0.1295	0.1504	0.1370	0.1313	0.1277	0.1951
Customer 2	0.1262	0.0972	0.1128	0.1252	0.1094	0.1158	0.1301
Customer 3	0.1566	0.1943	0.1880	0.1565	0.1641	0.1637	0.1951
Customer 4	0.1066	0.0648	0.1128	0.1096	0.0985	0.1078	0.0650
Customer 5	0.1740	0.2267	0.1880	0.1753	0.1969	0.1796	0.1951

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Customer 6	0.1305	0.1619	0.1504	0.1461	0.1422	0.1517	0.1301
Customer 7	0.1131	0.0972	0.0752	0.1044	0.0875	0.1038	0.0650
Customer 8	0.1632	0.1943	0.1880	0.1623	0.1751	0.1597	0.1951
Customer 9	0.1479	0.1295	0.1504	0.1328	0.1532	0.1397	0.1301
Customer 10	0.0979	0.0648	0.0752	0.0974	0.0875	0.0998	0.0650
Customer 11	0.1806	0.2591	0.1880	0.1992	0.2188	0.1916	0.1951
Customer 12	0.1218	0.1295	0.1128	0.1217	0.1203	0.1237	0.1301
Customer 13	0.1501	0.1619	0.1504	0.1414	0.1586	0.1477	0.1951
Customer 14	0.1697	0.2267	0.1880	0.1686	0.1860	0.1716	0.1951
Customer 15	0.1088	0.0972	0.1128	0.1153	0.1039	0.1118	0.1301

The fifth stage performs normalization of the weighted contribution values. The values obtained from the previous stage are normalized against the highest weighted contribution within each criterion to establish a common reference for the final aggregation. This process enables the weighted contributions of different criteria to be consistently combined while preserving their relative performance. The weighted normalization value is calculated using (5), and the results of the weighted normalization calculation are as follows.

$$n_{11} = \frac{k_{11}}{\max\limits_{j} k_{i1}} = \frac{0.1414}{0.1806} = 0.7831$$

The overall weighted normalization scores obtained using the TEKNO method are fully presented in Table 13, providing a normalized representation of the weighted performance of all alternatives across the evaluated criteria.

Table 13. Weighted Normalization Results

Customer	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
Customer 1	0.7831	0.5000	0.8000	0.6875	0.6000	0.6667	1.0000
Customer 2	0.6988	0.3750	0.6000	0.6286	0.5000	0.6042	0.6667
Customer 3	0.8675	0.7500	1.0000	0.7857	0.7500	0.8542	1.0000
Customer 4	0.5904	0.2500	0.6000	0.5500	0.4500	0.5625	0.3333
Customer 5	0.9639	0.8750	1.0000	0.8800	0.9000	0.9375	1.0000
Customer 6	0.7229	0.6250	0.8000	0.7333	0.6500	0.7917	0.6667
Customer 7	0.6265	0.3750	0.4000	0.5238	0.4000	0.5417	0.3333
Customer 8	0.9036	0.7500	1.0000	0.8148	0.8000	0.8333	1.0000
Customer 9	0.8193	0.5000	0.8000	0.6667	0.7000	0.7292	0.6667
Customer 10	0.5422	0.2500	0.4000	0.4889	0.4000	0.5208	0.3333
Customer 11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Customer 12	0.6747	0.5000	0.6000	0.6111	0.5500	0.6458	0.6667
Customer 13	0.8313	0.6250	0.8000	0.7097	0.7250	0.7708	1.0000
Customer 14	0.9398	0.8750	1.0000	0.8462	0.8500	0.8958	1.0000
Customer 15	0.6024	0.3750	0.6000	0.5789	0.4750	0.5833	0.6667

The final stage calculates the overall evaluation value of each alternative by averaging its normalized weighted values across all criteria. The resulting overall evaluation value represents the aggregated performance of an alternative after considering the normalization, relative evaluation, and criterion weights throughout the TEKNO framework. The alternatives are then ranked according to their overall evaluation values, where a higher value indicates a more

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favorable alternative. The overall evaluation score is calculated using (6), the results of the overall evaluation calculation are as follows.

$$o_1 = \frac{1}{7}\sum_{j=1}^{7} n_{1j} = \frac{1}{7}(0.7831 + 0.5000 + 0.8000 + 0.6875 + 0.6000 + 0.6667 + 1.0000) = 0.7196$$

The overall evaluation scores obtained using the TEKNO method are fully presented in Table 7, reflecting the final performance assessment of all alternatives based on the aggregated evaluation values.

Table 14. Overall Evaluation Results

Customer	Final Score
Customer 1	0.7196
Customer 2	0.5819
Customer 3	0.8582
Customer 4	0.4766
Customer 5	0.9366
Customer 6	0.7128
Customer 7	0.4572
Customer 8	0.8717
Customer 9	0.6974
Customer 10	0.4193
Customer 11	1.0000
Customer 12	0.6069
Customer 13	0.7803
Customer 14	0.9152
Customer 15	0.5545

Based on the final evaluation scores, the prospective leasing customers are subsequently arranged according to their relative performance to determine the preference order. The customer with the highest evaluation score is considered the most preferred, while the remaining customers are ranked accordingly. The resulting ranking provides a clear representation of the preference order among the prospective leasing customers and is presented in Figure 4.

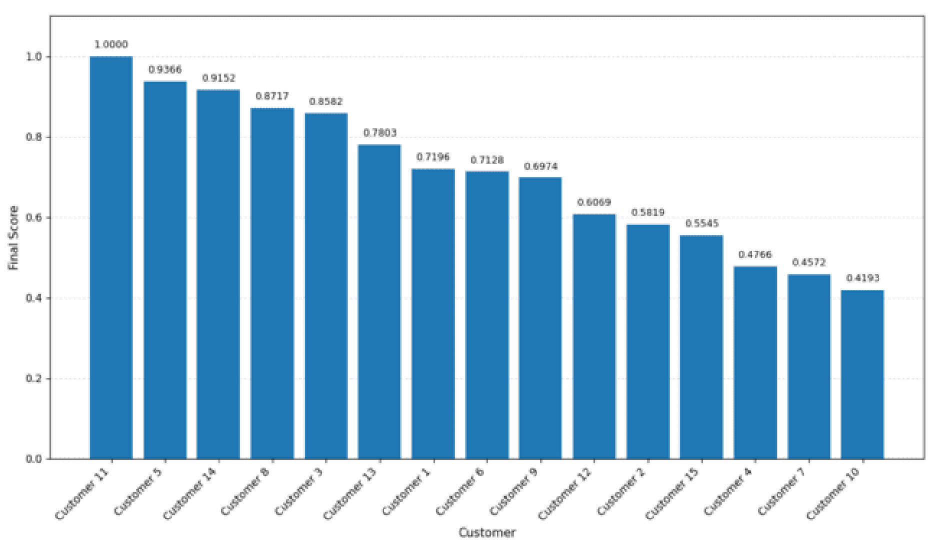

Figure 4. Alternative Rankings using the TEKNO Method

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The ranking results using the TEKNO method show a pretty clear difference in Final Scores among the 15 customers evaluated. Customer 11 got the highest score of 1.0000, taking first place and becoming the best-performing option. Next in line are Customer 5 with a score of 0.9366, Customer 14 with 0.9152, and Customer 8 with 0.8717, indicating relatively high performance compared to the other options. Meanwhile, Customers 3 through 12 scored between 0.6069 and 0.8582, while Customers 2, 15, 4, 7, and 10 are at a lower evaluation level with scores of 0.5819, 0.5545, 0.4766, 0.4572, and 0.4193, respectively. That pattern shows that TEKNO can create clear value differentiation between customers, so each option can be ranked according to its performance, and Customer 11 can be set as the top option based on the total evaluation score.

V. Result and Discussion

The proposed TEKNO method is evaluated through a series of analyses to assess its performance and reliability in solving multi-criteria decision-making problems. The analysis first examines the dataset to describe the characteristics of the alternatives and criteria involved in the decision-making process. The TEKNO method is subsequently applied to obtain the preference scores and ranking of the alternatives. The resulting ranking is then compared with those generated by several established MCDM methods to examine ranking consistency and the relative performance of TEKNO. Correlation analysis is performed to determine the degree of agreement between TEKNO and the comparative methods, while sensitivity analysis is used to assess the stability of the ranking results when criterion weights are varied. These findings are further interpreted in the discussion to provide insights into the behavior, consistency, robustness, and practical applicability of the proposed TEKNO method.

5.1. Dataset Analysis

To examine the applicability of the proposed TEKNO method across different decision-making contexts, two datasets with distinct characteristics are considered. The datasets represent different types of MCDM problems and contain variations in the number of alternatives, decision criteria, and measurement scales. This diversity enables the proposed method to be evaluated under different data structures and performance conditions. The analysis of each dataset focuses on the distribution and variation of criterion values, the differences in alternative performance, and the challenges associated with handling heterogeneous decision information. The characteristics of both datasets are presented and analyzed below as the basis for the subsequent implementation of TEKNO and comparison with other MCDM methods.

The first dataset, Evaluation Scores of Candidate Store Locations, consists of eight alternative store locations (Loc-1 to Loc-8) evaluated using six criteria, namely K1 to K6. The dataset presents numerical

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evaluations with considerably different value ranges across the criteria. K1 ranges from 36 to 60, K2 from 90 to 160, K3 from 6 to 9, K4 from 480 to 620, K5 from 6 to 15, and K6 from 7 to 10. These differences indicate that the criteria are measured on different numerical scales, making direct aggregation of the original values inappropriate. Therefore, an effective normalization mechanism is required to transform the heterogeneous criterion values into comparable values before calculating the overall preference of each location.

The distribution of the store-location data also demonstrates variation among the alternatives. Loc-5 records relatively high values across several criteria, including K1, K2, K4, K5, and K6, while Loc-4 generally presents lower values across most criteria. The remaining alternatives exhibit intermediate and varying combinations of criterion values. Such characteristics provide an appropriate testing environment for TEKNO because the alternatives do not exhibit identical performance patterns across all criteria. The presence of these variations allows the proposed method to evaluate trade-offs among multiple criteria rather than determining the preferred alternative based on a single dominant attribute.

The second dataset, Customer Evaluation Data, contains 15 alternatives, from Customer 1 to Customer 15, evaluated according to seven criteria, CR-1 to CR-7. The numerical values exhibit substantially different scales, with CR-1 ranging from 4,500,000 to 8,300,000, CR-2 from 2 to 8, CR-3 from 2 to 5, CR-4 from 22 to 45, CR-5 from 80,000,000 to 200,000,000, CR-6 from 25 to 48, and CR-7 from 1 to 3. The large differences in magnitude, particularly between monetary and non-monetary criteria, further emphasize the need for normalization. In addition, the wider number of alternatives provides a more extensive decision space for examining the ability of TEKNO to distinguish between competing customer profiles.

Overall, the two datasets provide complementary testing scenarios for evaluating the proposed TEKNO method. The first dataset contains a relatively small number of alternatives with six criteria, whereas the second includes more alternatives and seven criteria with substantially heterogeneous numerical scales. Both datasets contain meaningful variations in the performance values, allowing the ranking mechanism to identify differences in overall alternative performance. These characteristics are particularly relevant for evaluating a knowledge-driven normalized optimization approach because TEKNO must convert different criterion scales into comparable measures while preserving the relative decision information. The use of two datasets with different structures therefore provides a broader basis for examining the consistency, discrimination capability, and robustness of the proposed method.

5.2. TEKNO Method Ranking Results

The application of the TEKNO method to the two datasets produces a set of preference scores that reflects the overall performance of each alternative across the considered criteria. These scores are used to

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establish the final ranking by considering the normalized contribution of each criterion and the corresponding criterion weights. A higher TEKNO score indicates a more favorable overall performance, whereas a lower score represents a less preferred alternative. The resulting rankings for the store-location and customer datasets are presented to identify the best-performing alternatives and to examine the ability of TEKNO to differentiate alternatives based on their multidimensional performance.

The ranking obtained using the proposed TEKNO method is compared with the original ranking to examine whether the method can reproduce the relative position of the alternatives consistently. The comparison focuses on the rank order generated by TEKNO against the reference ranking, allowing changes in the position of each alternative to be identified. Alternatives that maintain similar positions indicate that TEKNO is able to preserve the underlying preference structure of the original decision data, while differences in ranking may indicate the influence of the normalization and optimization processes applied by the proposed method. This comparison provides an initial assessment of the ranking consistency of TEKNO before further evaluation using comparative MCDM methods and statistical correlation analysis. The comparison of the original ranking and the ranking generated by TEKNO is presented in Figure 5.

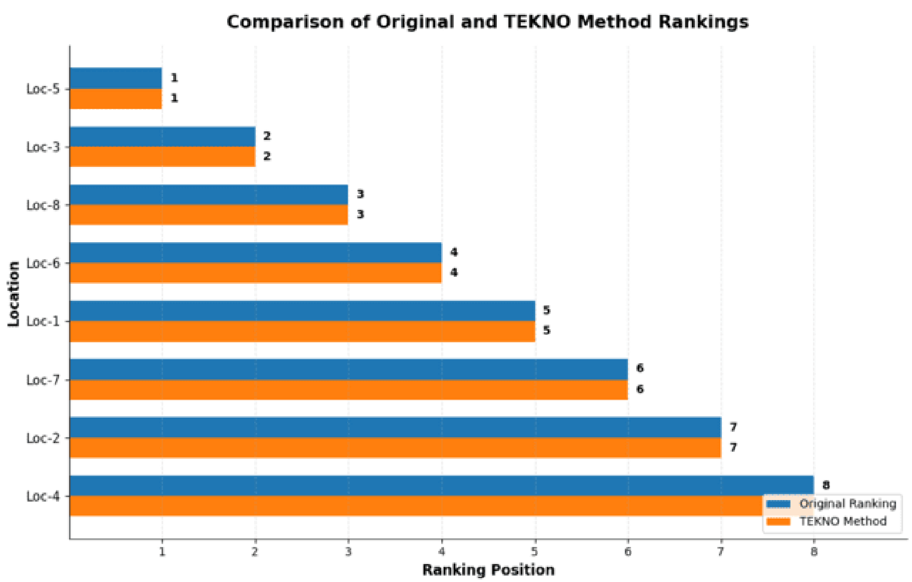

Figure 5. Ranking Comparison in Selection of New Store Location

The ranking results show a perfect consistency between the original ranking and the ranking generated by the proposed TEKNO method for the Selection of New Store Location case. Loc-5 maintains the first position, followed by Loc-3, Loc-8, Loc-6, and Loc-1 in second to fifth positions, respectively. Similarly, Loc-7, Loc-2, and Loc-4 retain the sixth, seventh, and eighth positions. No alternative experiences a change in rank, indicating that TEKNO successfully reproduces the original preference order across all eight candidate locations. This result

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provides an initial indication of the high-ranking consistency and stability of TEKNO when applied to the store-location selection dataset.

The ranking generated by the proposed TEKNO method is compared with the original ranking in the Leasing Customer Selection case to assess the consistency of customer preferences identified by the proposed approach. The comparison evaluates the relative positions of the 15 customers based on their overall performance across the seven evaluation criteria. A close correspondence between the TEKNO ranking and the original ranking indicates that the method can effectively preserve the preference structure of the initial evaluation, whereas changes in position reflect differences arising from the normalization, weighting, and optimization processes incorporated into TEKNO. This comparison is important for determining whether TEKNO can produce a reliable ordering of leasing customers while maintaining meaningful distinctions among alternatives with different performance characteristics. The comparison between the original ranking and the ranking produced by TEKNO for the Leasing Customer Selection case is presented in Figure 6.

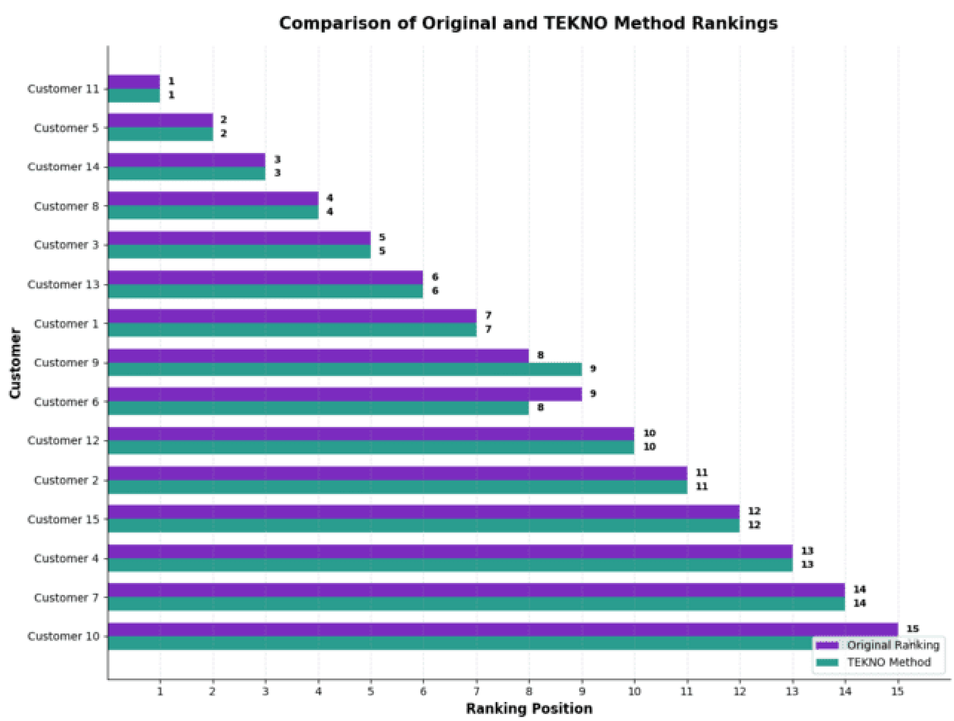

Figure 6. Ranking Comparison in Leasing Customer Selection

In the Leasing Customer Selection case, the ranking results indicate a very high level of consistency between the original ranking and the ranking generated by the TEKNO method. Among the 15 alternatives, 14 customers retain exactly the same ranking positions, from Customer 11 in first place to Customer 10 in fifteenth place. The only changes occur between Customer 9 and Customer 6, where Customer 9 moves from eighth to ninth place, while Customer 6 improves from ninth to eighth place. This exchange indicates that the difference is limited to two

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adjacent alternatives, while the overall ranking structure remains unchanged. Therefore, TEKNO demonstrates a strong ability to preserve the preference order of the original evaluation and provides highly consistent ranking results for the Leasing Customer Selection case.

Overall, the ranking results from the two case studies demonstrate the strong consistency of the proposed TEKNO method in identifying and ordering the preferred alternatives. In the Selection of New Store Location case, TEKNO reproduces the original ranking exactly, with all eight locations maintaining their respective positions from first to eighth. In the Leasing Customer Selection case, TEKNO also produces a highly consistent ranking, with 14 of the 15 customers retaining their original positions and only a single exchange occurring between Customer 6 and Customer 9. These findings indicate that TEKNO can effectively preserve the preference structure of the reference rankings across datasets with different numbers of alternatives and criteria. The high consistency observed in both cases provides an initial indication of the reliability and ranking stability of TEKNO, supporting its further evaluation through comparison with other MCDM methods, correlation analysis, and sensitivity analysis.

5.3. Sensitivity Analysis

The sensitivity analysis is conducted to examine the robustness and stability of the ranking generated by the proposed TEKNO method under changes in the criterion weights[35], [36]. Since criterion weights can influence the relative importance assigned to each evaluation factor, variations in these weights may affect the preference scores and ranking positions of the alternatives. The analysis therefore evaluates how changes in the weighting configuration influence the resulting rankings across the two case studies. A stable ranking under different weight scenarios indicates that TEKNO is less sensitive to changes in decision-maker preferences and can provide reliable results under varying evaluation conditions. The sensitivity analysis thus provides additional evidence regarding the robustness of the proposed TEKNO method beyond the initial ranking consistency assessment.

The sensitivity analysis for the Selection of New Store Location case is conducted by systematically varying the criterion weights to examine the robustness of the TEKNO ranking results. A total of 24 test scenarios are constructed by increasing and decreasing the original criterion weights by 0.05 and 0.10, respectively, while the remaining weighting structure is adjusted accordingly to maintain a valid weighting configuration. Each scenario is recalculated using the TEKNO method to observe changes in the preference scores and ranking positions of the eight candidate store locations. The analysis focuses on whether the leading alternatives remain stable when the relative importance of the evaluation criteria changes. A ranking that remains unchanged or exhibits only minor positional shifts across the tested scenarios indicates that the TEKNO method provides robust decision outcomes and is not excessively dependent on a particular weighting configuration. The complete ranking

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results obtained from the 24 sensitivity test scenarios for the Selection of New Store Location case are presented in Figure 7.

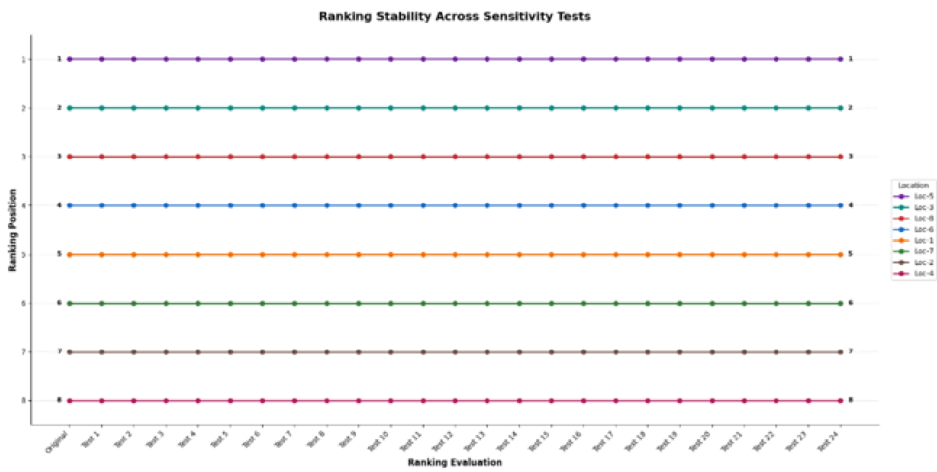

Figure 7. Sensitivity Analysis of Ranking in New Store Location

The sensitivity analysis for the Selection of New Store Location case shows complete consistency between the original ranking and all 24 test scenarios. Loc-5 consistently maintains the first position, followed by Loc-3, Loc-8, Loc-6, and Loc-1 in the second to fifth positions, respectively. Meanwhile, Loc-7, Loc-2, and Loc-4 remain in sixth, seventh, and eighth positions throughout all tests. No ranking changes occur for any alternative across the 24 scenarios, indicating that the TEKNO ranking is completely stable under the applied variations in criterion weights. This finding demonstrates that the selection of Loc-5 as the best store location is robust and does not depend on a particular weighting configuration. Overall, the unchanged ranking across all sensitivity tests confirms the strong stability and robustness of the TEKNO method in the Selection of New Store Location case.

The sensitivity analysis for the Leasing Customer Selection case is performed to evaluate the robustness of the TEKNO ranking under variations in criterion weights. A total of 28 test scenarios are established by systematically increasing and decreasing the original criterion weights by 0.05 and 0.10. Each scenario is recalculated using the TEKNO procedure to determine the resulting preference scores and ranking positions of the 15 leasing customers. The analysis examines the extent to which changes in the relative importance of the evaluation criteria affect the ranking structure, particularly the positions of the highest- and lowest-ranked customers. A stable ranking across the tested scenarios indicates that the TEKNO method is robust to moderate changes in criterion weights, whereas substantial changes in ranking positions suggest greater sensitivity to specific criteria. The results of the 28 sensitivity test scenarios provide an additional assessment of the stability and reliability of TEKNO in the Leasing Customer Selection problem, with the complete ranking comparison presented in Figure 8.

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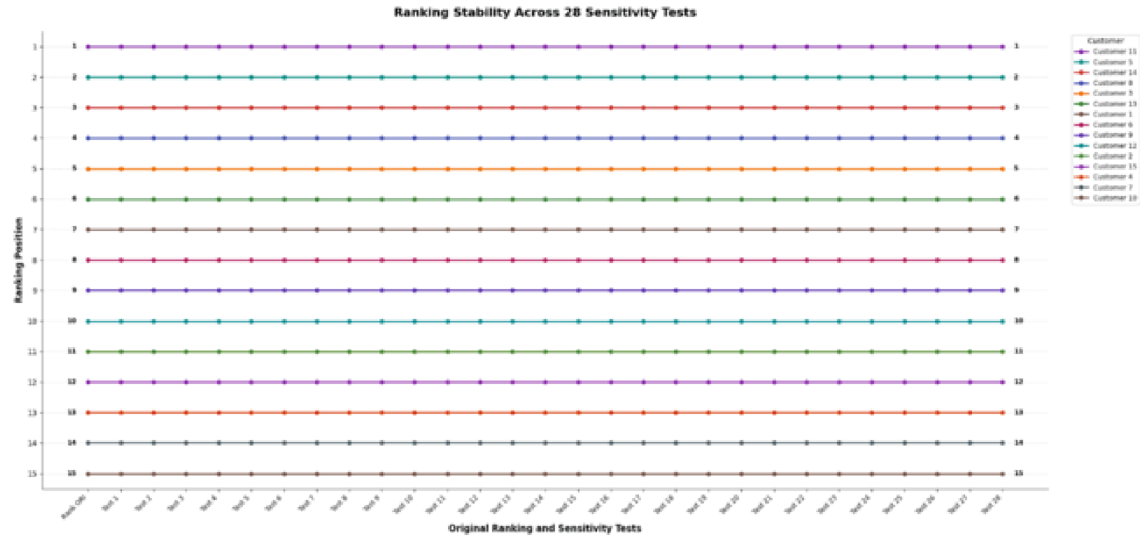

Figure 8. Sensitivity Analysis of Ranking in Leasing Customer Selection

The sensitivity analysis for the Leasing Customer Selection case demonstrates complete ranking stability across all 28 test scenarios. Customer 11, Customer 5, Customer 14, Customer 8, Customer 3, Customer 13, Customer 1, Customer 6, Customer 9, Customer 12, Customer 2, Customer 15, Customer 4, Customer 7, and Customer 10 consistently maintain their respective positions from first to fifteenth in every test. Unlike the previous ranking comparison, where Customer 6 and Customer 9 exchanged positions relative to the ORI ranking, the sensitivity analysis shows that both alternatives consistently retain their positions at 8th and 9th, respectively, throughout all 28 scenarios. Therefore, no ranking changes are observed under any of the tested weight variations. These results indicate that the TEKNO method produces a completely stable ranking for the Leasing Customer Selection dataset and is highly robust to changes in criterion weights within the tested scenarios.

5.4. Comparison with MCDM Methods

The proposed method is compared with several established MCDM methods to evaluate its performance and examine the consistency of the resulting alternative rankings. The comparison is performed under the same decision-making conditions to ensure that differences in the ranking results reflect the characteristics of each method rather than variations in the input data[37], [38]. The selected MCDM methods represent different approaches to normalization, criteria evaluation, and score aggregation, providing a broader basis for performance assessment. The rankings obtained from each method are then compared to identify similarities and differences in the ordering of alternatives. In addition, rank correlation analysis is applied to measure the level of agreement between the proposed method and the compared MCDM methods.

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This analysis provides an indication of the robustness and reliability of the proposed approach in relation to existing MCDM techniques.

The ranking results were compared across the original ranking (ORI) and five MCDM methods, namely TEKNO, Simple Additive Weighting (SAW), Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA), Grey Relational Analysis (GRA), and Multi-Attribute Utility Theory (MAUT). The original ranking was used as the reference for evaluating how closely each method reproduced the initial ordering of alternatives. The comparison focuses on the rank positions obtained by each method, allowing the consistency and differences among the resulting rankings to be identified. TEKNO represents the proposed approach, while SAW, MOORA, GRA, and MAUT are used as established MCDM methods for comparison. The resulting rank orders provide a basis for assessing the reliability and stability of TEKNO relative to existing MCDM methods, particularly in terms of its agreement with the original ranking.

The comparison was further conducted using the New Store Location case study to examine the performance of the proposed TEKNO method against the selected MCDM methods. The evaluation compares the ranking results obtained from TEKNO, SAW, MOORA, GRA, and MAUT. The comparison is intended to identify the consistency of the alternative rankings and to observe whether the proposed method produces results that are comparable with those of established MCDM approaches. The ranking comparison for the New Store Location case study is presented in Figure 9.

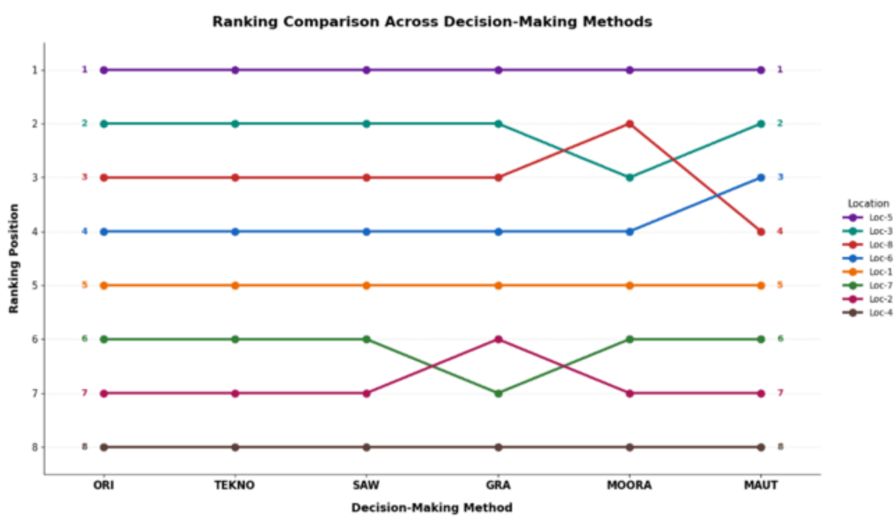

Figure 9. Comparison of MCDM Rankings in New Store Location

Based on the ranking comparison for the New Store Location case study, the TEKNO method produces exactly the same alternative ordering as the original ranking (ORI), with Loc-5 ranked first and Loc-4 ranked last. The SAW method also maintains the same ranking order as ORI and TEKNO. In contrast, GRA, MOORA, and MAUT show several changes in the positions of some alternatives, although their overall ranking patterns remain close to the original ranking. The differences are mainly observed

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among Loc-3, Loc-8, Loc-6, Loc-7, and Loc-2, while Loc-5, Loc-1, and Loc-4 retain the same positions across all methods. To quantitatively assess the agreement between the original ranking and the rankings produced by each MCDM method, Spearman Rank Correlation analysis was subsequently performed.

The comparison was also conducted using the Leasing Customer Selection case study to evaluate the performance of the proposed TEKNO method in relation to other established MCDM methods. The ranking results obtained from TEKNO, SAW, MOORA, GRA, and MAUT. This comparison aims to examine the consistency of the alternative rankings and determine the extent to which TEKNO provides results comparable to the existing methods. The ranking comparison for the Leasing Customer Selection case study is presented in Figure 10.

Figure 10. Comparison of MCDM Rankings in Leasing Customer Selection

Based on the ranking results for the Leasing Customer Selection case study, the TEKNO method produces a ranking that is highly consistent with the original ranking (ORI). The first six alternatives, namely Customer 11, Customer 5, Customer 14, Customer 8, Customer 3, and Customer 13, maintain exactly the same positions across all methods. TEKNO also preserves the original positions for Customer 1, Customer 12, Customer 2, Customer 15, Customer 4, Customer 7, and Customer 10, with only a slight change observed for Customer 6 and Customer 9. Similar variations occur in the results of GRA and MOORA, particularly in the middle-ranked alternatives, while the remaining alternatives retain their original positions. Overall, the comparison indicates that the ranking produced by TEKNO is closely aligned with ORI and shows a stable ranking pattern compared with SAW, GRA, MOORA, and MAUT.

Overall, the comparison results from the New Store Location and Leasing Customer Selection case studies demonstrate that the proposed TEKNO method produces ranking results that are highly consistent with the original rankings and comparable to those generated by established

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MCDM methods. TEKNO preserves the ranking order of most alternatives, with only minor differences observed in several positions, particularly in the Leasing Customer Selection case. The consistency observed across the two case studies indicates that TEKNO can provide stable ranking results under different decision-making contexts. These findings, together with the rank correlation analysis, support the reliability of TEKNO as an alternative MCDM method for solving multi-criteria decision-making problems.

5.5. Correlation Analysis

Correlation analysis is conducted to evaluate the degree of agreement between the ranking results generated by the proposed TEKNO method and those obtained from other established MCDM methods. This analysis provides a quantitative measure of the consistency of the alternative rankings and helps identify whether the proposed method produces results that are comparable to existing approaches. In this study, the Spearman Rank Correlation coefficient is used because the analysis focuses on the relationship between ranking positions rather than the original numerical scores. A higher correlation value indicates greater similarity between the ranking results, while a lower value indicates greater differences in the ordering of alternatives[39], [40]. The correlation results are used to further assess the consistency and stability of TEKNO across the evaluated case studies.

For the New Store Location case study, the correlation analysis was conducted to measure the level of agreement between the ranking produced by TEKNO and those generated by SAW, GRA, MOORA, and MAUT. The analysis provides a quantitative assessment of the similarity of the ranking positions obtained from each method and helps evaluate the consistency of TEKNO with the established MCDM approaches. The correlation results show a strong agreement among the evaluated methods, indicating that the differences in ranking positions are relatively small. The resulting correlation values for the New Store Location case study are presented in Figure 11.

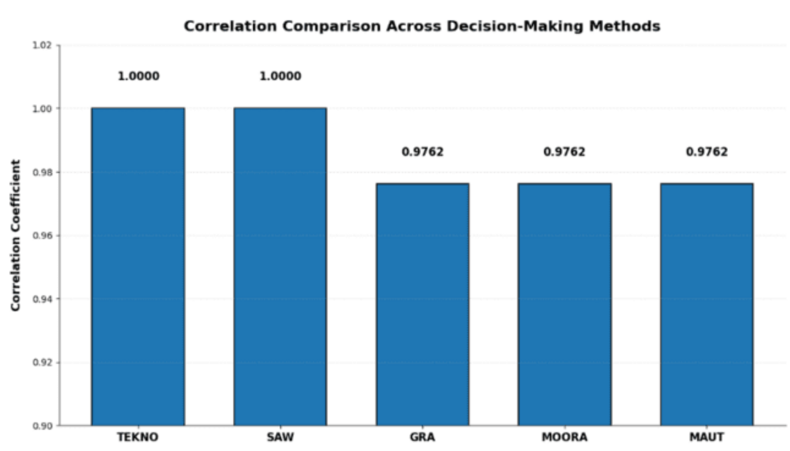

Figure 11. Correlation Value of MCDM Method in New Store Location

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The Spearman Rank Correlation results show a very high level of agreement among the MCDM methods in the New Store Location case study. TEKNO and SAW achieve a perfect correlation value of 1.0000, indicating that both methods produce ranking orders that are fully consistent with the reference ranking. Meanwhile, GRA, MOORA, and MAUT each obtain a correlation value of 0.9762, demonstrating a very strong agreement despite minor differences in the ranking positions. Overall, these results show that TEKNO provides a highly consistent ranking for the New Store Location case study and produces results that are comparable with those obtained using the established MCDM methods.

For the Leasing Customer Selection case study, the correlation analysis was conducted to measure the level of agreement between the ranking produced by TEKNO and those generated by SAW, GRA, MOORA, and MAUT. The analysis provides a quantitative assessment of the similarity of the ranking positions obtained from each method and helps evaluate the consistency of TEKNO with the established MCDM approaches. The correlation results show a strong agreement among the evaluated methods, indicating that the differences in ranking positions are relatively small. The resulting correlation values for the Leasing Customer Selection case study are presented in Figure 12.

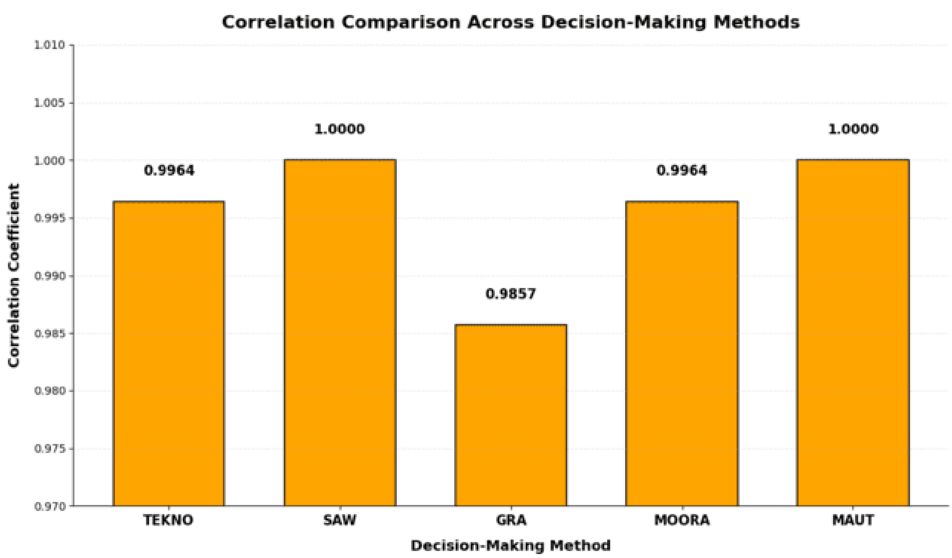

Figure 12. Correlation Value of MCDM Method in Leasing Customer Selection

The Spearman Rank Correlation results show a very high level of agreement among the MCDM methods in the Leasing Customer Selection case study. SAW and MAUT achieve a perfect correlation of 1.0000, indicating identical ranking patterns between these methods and the reference ranking. TEKNO and MOORA also demonstrate a very strong correlation of 0.9964, while GRA records a correlation of 0.9857. These results indicate that all evaluated methods produce highly consistent rankings, with TEKNO showing a ranking pattern that is very close to the results of the other

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MCDM methods. Overall, the high correlation values support the stability and consistency of the ranking results obtained in this case study.

Overall, the Spearman Rank Correlation analysis demonstrates a high degree of consistency between TEKNO and the established MCDM methods across both case studies. The correlation values remain very high, with TEKNO achieving perfect agreement in the New Store Location case and a correlation of 0.9964 in the Leasing Customer Selection case. Although several methods show minor differences in ranking positions, the overall ordering of alternatives remains highly consistent. These findings indicate that TEKNO is capable of producing stable and comparable ranking results across different decision-making contexts, supporting its applicability as an alternative MCDM method for multi-criteria decision-making problems.

5.6. Discussion

The ranking results demonstrate that the proposed TEKNO method is able to distinguish the performance of alternatives across different multi-criteria decision-making contexts. In the New Store Location case, Loc-5 achieves the highest final score of 0.9148, followed by Loc-3 with 0.8766 and Loc-8 with 0.8720, while Loc-4 obtains the lowest score of 0.6751. The ranking indicates that Loc-5 provides the most favorable overall performance after considering the six evaluation criteria and their respective weights. In the Leasing Customer Selection case, Customer 11 obtains the highest score of 1.0000, followed by Customer 5, Customer 14, and Customer 8 with scores of 0.9366, 0.9152, and 0.8717, respectively. At the lower end of the ranking, Customer 10 records the lowest score of 0.4193, followed by Customer 7 and Customer 4. These results show that TEKNO can produce clear preference values and differentiate alternatives according to their combined performance across multiple criteria.

The comparison with established MCDM methods shows that TEKNO produces ranking patterns that are closely aligned with the original ranking and the results of other approaches. In the New Store Location case, TEKNO reproduces the original ranking exactly, while SAW also maintains the same ordering, and only minor positional differences are observed in GRA, MOORA, and MAUT. A similar pattern is found in the Leasing Customer Selection case, where TEKNO preserves the positions of 14 out of 15 customers relative to the original ranking, with only Customer 6 and Customer 9 exchanging positions. The first six customers in the leasing case also maintain identical positions across the evaluated methods, indicating a strong agreement in identifying the leading alternatives. These results suggest that the normalization, weighting, and aggregation procedures applied in TEKNO can generate preference structures that are comparable with established MCDM methods. Therefore, the proposed method provides a consistent alternative for ranking problems in which different criteria and decision contexts must be considered simultaneously.

The consistency and stability analysis provides further evidence of the reliability of the ranking results generated by TEKNO. The ranking

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comparison shows that TEKNO reproduces the original ordering completely in the New Store Location case, while only a minor change involving two adjacent alternatives occurs in the Leasing Customer Selection case. This consistency is also supported by the Spearman Rank Correlation results, where TEKNO achieves a correlation value of 1.0000 in the New Store Location case and 0.9964 in the Leasing Customer Selection case. These values indicate that the ranking produced by TEKNO is highly consistent with the reference ranking across both decision contexts. The sensitivity analysis further shows that no ranking changes occur across the 24 tested weight scenarios for New Store Location and the 28 tested scenarios for Leasing Customer Selection. The combined results indicate that TEKNO maintains a stable preference order even when the criterion weights are varied within the tested configurations.

The results highlight several strengths of TEKNO in handling multi-criteria decision-making problems with different data structures and decision characteristics. The method is applied to two datasets with different numbers of alternatives, criteria, and numerical scales, while maintaining a consistent computational framework across both cases. Its normalization and weighted evaluation stages enable heterogeneous criterion values to be transformed and combined into an overall evaluation score, allowing alternatives to be compared using a common preference measure. The results also show that TEKNO can preserve the underlying preference structure of the reference rankings while providing clear differentiation among alternatives. The high correlation values and stable rankings under the tested weight variations further indicate that TEKNO can be applied to decision problems where ranking consistency is an important consideration. However, the current evaluation is based on only two case studies and specific sensitivity scenarios, so further testing with larger and more diverse datasets is needed to examine the method under broader decision-making conditions.

VI. Conclusion

This study introduced Total Evaluation based on Knowledge-driven Normalized Optimization (TEKNO) as a new MCDM method designed to provide a systematic and interpretable mechanism for evaluating and ranking alternatives under multiple criteria. The main contribution of TEKNO lies in the integration of benefit and cost normalization, relative evaluation, criterion weighting, optimization-based normalization, and total aggregation into a single decision-making procedure. This structure enables the method to preserve the relative information contained in the decision matrix while incorporating the importance of individual criteria into the final evaluation. The empirical application across two distinct decision-making contexts demonstrates that TEKNO is capable of generating coherent preference structures and maintaining consistency when applied to datasets with different characteristics. More importantly, the agreement observed with reference and established MCDM rankings, together with the stability observed under variations in

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criterion weights, provides empirical support for the methodological soundness of the proposed framework. These findings position TEKNO as a promising alternative for MCDM applications in which transparent evaluation, ranking consistency, and sensitivity to criterion importance are important considerations. However, the contribution of this study should be interpreted within the scope of the datasets and experimental settings examined, as the current validation does not establish that TEKNO universally outperforms existing MCDM methods. Future studies should therefore extend the validation to larger and more heterogeneous datasets, additional application domains, different objective and subjective weighting schemes, and broader statistical and sensitivity-testing procedures. Such investigations would provide a stronger basis for assessing the generalizability, computational behavior, and comparative advantages of TEKNO and for further refining the method for practical decision-support applications.

CRediT Authorship Contribution Statement

Yuri Rahmanto: Methodology, Writing – Original Draft Preparation, Writing – Review & Editing. **Ryan Randy Suryono:** Conceptualization, Data curation, Formal analysis, Writing – Review & Editing. **Dedi Darwis:** Investigation, Software, Writing – Review & Editing. **Abhishek R. Mehta:** Validation, Writing – Original Draft Preparation. **Auliya Rahman Isnain:** Visualization, Writing – Original Draft Preparation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Declaration of Generative AI and AI-assisted Technologies in The Writing Process

The authors used Generative Artificial Intelligence to improve the writing clarity of this paper. They reviewed and edited the AI-assisted content and take full responsibility for the final publication.

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