

# Enhancing Multi-Objective Preference Analysis (MOPA) for Optimization of Islamic Tourism Planning

Fristi Riandari<sup>1,\*</sup>, Hengki Tamando Sihotang<sup>2</sup>, Rian Syahputra<sup>1</sup>, and Efori Bu'ulolo<sup>1</sup>

<sup>1</sup> Faculty of Computer Engineering and Informatics, Politeknik Negeri Medan, Medan, Indonesia

<sup>2</sup> Faculty of Computer Science, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia

Email: fristirandari@polmed.ac.id (F.R.); hengkisihotang@upnvj.ac.id (H.T.S.); riansyahputra@polmed.ac.id (R.S.); eforibuulolo@polmed.ac.id (E.B.)

\*Corresponding author

**Abstract**—The rapid development of Islamic tourism demands a decision-making model capable of integrating economic, environmental, and religious dimensions within a balanced analytical framework. This study refines the Multi-Objective Preference Analysis (MOPA) method by introducing a min–max linear normalization approach to improve ranking proportionality and sensitivity in multi-criteria evaluation. Using empirical data from 18 Islamic tourism destinations in North Sumatra and eight benefit type criteria, the improved MOPA demonstrates wider score dispersion (0.221–0.840) and stronger ranking discrimination than classical MCDA methods (Analytic Hierarchy Process, Simple Additive Weighting, Technique for Order Preference by Similarity to Ideal Solution, Multi-Objective Optimization on the basis of Ratio Analysis). Statistical validation confirms the robustness of the model, with ANOVA ( $p = 0.038$ ,  $\eta^2 = 0.62$ ) showing significant improvement and Spearman's correlation ( $\rho = 0.91$ ) indicating high consistency across methods. Sensitivity analysis under  $\pm 5$ – $10\%$  weight variation achieves ranking stability above 90%, confirming robustness to subjective bias. Furthermore, the operationalization of Sharia compliance indicators halal certification, mosque accessibility, and regional policy support translates ethical and spiritual values into measurable criteria, strengthening the model's applicability to Islamic tourism planning. The refined MOPA framework provides policymakers with a quantitatively validated and ethically grounded decision-support tool for sustainable Sharia tourism development and lays the foundation for future integration with Goal Programming and Simplex optimization.

**Keywords**—multi-criteria decision analysis, Multi-Objective Preference Analysis (MOPA), min–max normalization, Islamic tourism, optimization

## I. INTRODUCTION

Islamic (halal) tourism integrates destination development with explicit Sharia-compliant requirements (e.g., halal services, worship facilities, modesty norms) [1]. In Muslim-majority destinations, aligning economic objectives with religious values and local sociocultural

expectations requires a policy-oriented evaluation framework that is transparent and proportionate [1, 2].

However, traditional MCDA methods and existing tourism planning models fail to address these conflicts, because classical formulations assume a single decision-maker and struggle to capture diverse stakeholder preferences and multi-objective trade-offs [3]; results are highly sensitive to normalization when heterogeneous benefit/cost criteria and wide value ranges are combined, which can distort proportional importance and reduce rank discrimination [4–6]; and explicit, operational Sharia-compliant indicators are rarely embedded, limiting policy relevance for Islamic tourism.

Multi-Objective Preference Analysis (MOPA) was proposed to better represent multi-objective preferences and improve rank discrimination; however, its original linear-max normalization compresses score dispersion, yields non-proportional scaling across heterogeneous benefit-cost criteria, and weakens sensitivity to stakeholder preference variation. To address this defect, we replace linear-max with min–max linear normalization, preserving proportional differences, improving rank stability, and making policy interpretations more defensible.

Sharia tourism planning essentially involves multidimensional considerations that include economic, social, cultural, religious and environmental aspects [7, 8], which often contradict each other [9, 10]. In addition, limited resources require optimization of budget allocation and development priorities [11]. Decision-making in this area must involve multiple stakeholders with different preferences, adding to the complexity of the planning process [12, 13]. As a result, destination development must not only pursue financial gain but also maintain sustainability and adherence to sharia principles. However, many conventional tourism planning models remain overly focused on economic growth, often ignoring the diversity of stakeholders and the multidimensional nature of the decision-making context [13]. This situation creates multi-objective conflicts, such as between increasing the number of tourists and protecting the environment, or

between maximizing profits and maintaining halal service standards [14].

Similar tensions exist globally, where halal tourism is required to balance Islamic values, economic goals and sustainability [2, 15]. Previous research has shown that one-dimensional or qualitative approaches are inadequate to address the complexities of contemporary tourism systems. Consequently, more adaptive analytical frameworks, benchmark analysis or comparison of several alternative configurations can be facilitated by creating a Decision Support System (DSS) where different criteria are compared directly [16, 17], particularly those based on Multi-Criteria Decision Analysis (MCDA), are becoming increasingly relevant for formulating tourism strategies [10, 18].

Multi-Criteria Decision Analysis (MCDA) has been widely used in the tourism and sustainability sectors to accommodate multi-actor and multi-objective decision-making problems [18, 19]. Popular MCDA methods such as AHP, TOPSIS, ELECTRE, and VIKOR have proven effective in tourism evaluation, sustainability planning, and policy prioritization [20–22].

Although the tourism literature has shown many attempts to develop multi-objective optimization models for example, optimizing the composition of tourism demand to balance emissions and economic benefits [9] and the application of goal programming to tour scheduling problems [23], most of these studies focus on the general tourism context and have not explicitly accommodated the religious dimensions and specific needs of sharia tourism [2]. A review of MCDA methods in the hospitality sector also confirms that many MCDM/fuzzy-MCDM methods are used, but few are specifically directed at halal/sharia tourism issues [18]. Furthermore, several relevant studies have been conducted over the past few decades to solve problems in the tourism sector such as project identification [11], ecotourism location [20, 22, 24], priority tourism strategy policies [25], health tourism [26], smart tourism [27] and tourism competitiveness [28, 29]. This research focuses specifically on improving the normalization and validation of MOPA statistics.

In this study, eight evaluation criteria including location, infrastructure, ICT readiness, social and environmental quality, culinary diversity, accessibility, and regional policies were applied to 18 alternative destinations in North Sumatra. Empirical testing not only demonstrated improved ranking accuracy through improved normalization but also included quantitative validation using ANOVA, effect size, and rank correlation analysis to measure robustness and statistical discrimination. Furthermore, a sensitivity analysis (variation  $\pm 5$ –10%) was conducted to assess ranking stability under subjective weighting interference.

Another substantive improvement in this version of the MOPA lies in the operationalization of sharia compliance indicators. Rather than remaining conceptual dimensions, these indicators are now represented by measurable components such as the availability of halal-certified facilities, the accessibility of mosques, and the strength of local policy support integrated into the decision matrix.

This research places the improvement of ranking accuracy and robustness as its main contribution, while the integration of optimization techniques (Objective Programming/Simplex) is still in the future development stage. This stepwise strategy strengthens the analytical foundation of MOPA, ensuring it is mathematically valid and empirically verified before being expanded into a complete optimization model.

Implementation specifics and statistical procedures are reported in the Methods and Results sections. This study contributes a streamlined upgrade to MOPA by replacing linear-max with min-max normalization to preserve proportionality and sharpen rank discrimination, integrates explicit Sharia-compliant indicators into the multi-criteria structure for policy use, evaluates the enhanced framework on 18 destinations across eight criteria while benchmarking against selected MCDA methods to observe ranking behavior, and establishes a compact, reusable validation protocol that combines ANOVA, effect size, rank correlation, and sensitivity/stability checks for rigorous MCDA assessment.

## II. LITERATURE REVIEW

Islamic (halal) tourism research increasingly requires decision models that encode religious requirements within quantifiable criteria; reviews align Maqāsid al-Shariah with SDGs as a normative basis [2, 9]. Empirical studies consistently stress halal standardization, cross-actor coordination, and community empowerment as effectiveness drivers in Islamic tourism policy [10, 12, 13].

### A. Multi-Criteria Decision Analysis in Tourism Planning

Multi-Criteria Decision Analysis (Analytic Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution, VlseKriterijumska Optimizacija I Kompromisno Resenje, Elimination and Choice Translating Reality, Multi-Objective Optimization on the basis of Ratio Analysis): applied to site selection, sustainability prioritization, and competitiveness in tourism; in Islamic tourism, applications remain limited by the absence of explicitly operationalized Sharia indicators in quantitative matrices (e.g., halal certification, mosque accessibility, policy support), reducing policy relevance [11, 18, 20, 24].

Normalization sensitivity in MCDA: heterogeneous benefit/cost criteria and wide ranges distort proportional importance and reduce rank discrimination, which is consequential for Islamic tourism evaluations that mix economic, environmental, and religious criteria [2, 11, 18].

Decision Support Systems (DSS) embedding MCDA: used across tourism for interactive evaluation and scenario analysis; Islamic tourism DSS remain scarce and seldom encode Sharia-compliant indicators in a way that supports traceable, policy-grade decisions [16, 17].

### B. Overcoming Conflict in Decision Making in the Tourism Sector

Tourism planning including halal tourism faces inherent multi-objective conflicts, such as balancing economic

outcomes, environmental protection, and religious compliance [9]. Optimization approaches, notably Goal Programming (GP) and linear programming via Simplex, provide a principled way to minimize deviations from prioritized targets under explicit constraints and to produce interpretable trade-off solutions in policy contexts [30, 31].

Across tourism optimization studies, the recurring conclusion is that combining preference-based evaluation with explicit trade-off modeling yields actionable recommendations under realistic constraints [11, 20, 32]. However, studies that explicitly encode Sharia-compliant requirements as formal objectives or constraints remain scarce, indicating a targeted methodological gap between evaluation outputs and implementable optimization for Islamic tourism.

### C. Multi-Objective Preference Analysis (MOPA) as a Theoretical Advance

Prior applications of MOPA relied on linear-max normalization, which compresses score dispersion, induces non-proportional scaling across heterogeneous benefit–cost criteria, and reduces sensitivity to stakeholder preference variation. To address this defect, the present study replaces linear-max with min-max normalization, preserving proportional differences across criteria and stabilizing rankings for policy interpretation [33].

The min-max scheme ensures consistent treatment of mixed benefit/cost criteria, improves ordinal fidelity when criteria span wide ranges, and enhances rank stability under plausible weight perturbations properties that are essential when Islamic indicators must be evaluated alongside economic and environmental metrics. These effects directly remedy the normalization-driven artifacts observed in the original MOPA and produce scores that are more interpretable for policy screening; the empirical sections quantify these gains using ANOVA, effect size, rank correlation, and sensitivity tests on the case dataset [33].

### D. Research Gaps and MOPA Position

Optimization techniques (e.g., Goal Programming, Simplex): effective in general tourism for balancing targets under constraints, but under-adapted to Islamic tourism, where optimization formulations rarely encode Sharia-compliant thresholds as explicit objectives or constraints; this leaves a centralized adaptation gap [30–32].

This study strengthens the evaluation layer explicit Islamic indicators and min–max normalization so outputs can feed optimization in future work (e.g., a MOPA-Simplex pathway) without repeating method primers; the focus is on application status and limitation rather than basic definitions.

## III. MATERIALS AND METHODS

### A. Research Framework and Approach

This study adopts a quantitative comparative design aimed at improving the analytical robustness and precision of the Multi-Objective Preference Analysis (MOPA)

model through improvements in normalization and statistical validation. This methodological framework builds on the classical Multi-Criteria Decision Analysis (MCDA) architecture including criterion definition, weighting, normalization, aggregation, and ranking but integrates quantitative validation tests (ANOVA, sensitivity, correlation) to assess the reliability and statistical significance of the ranking results.

This study focuses on the fundamental analysis stage in particular, evaluating how min-max linear normalization affects proportionality, rank discrimination, and sensitivity accuracy. Fig. 1 illustrates the revised MOPA model flowchart consisting of five analysis stages: input, normalization, weighting, aggregation, and validation.

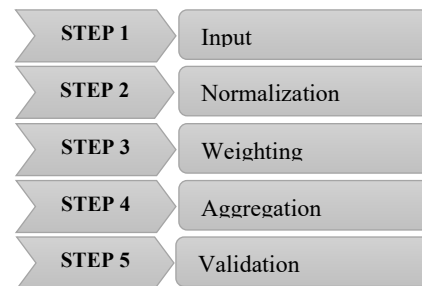


Fig. 1. General MOPA procedures.

### B. Data Sources and Scope of Research

The empirical analysis focuses on 18 Sharia-compliant tourism destinations in North Sumatra, Indonesia, representing diverse typologies such as urban Islamic heritage sites, natural attractions, culinary centers, and community-based halal destinations. These locations were selected based on accessibility, availability of halal facilities, and regional representation. Data sources include:

- Expert judgments for criteria weighting were elicited using the fundamental 1–9 pairwise comparison scale proposed by Saaty [34, 35].
- Secondary data: Regional tourism reports, provincial statistics, and official government directories.

### C. Definition and Operationalization of Criteria

This evaluation uses eight criteria (C1–C8) that capture the multidimensional nature of sharia tourism planning, which are classified as benefit type indicators.

The integration of sharia compliance into the refined MOPA model was achieved by transforming the religious dimension, originally conceptual, into an empirically measurable variable. In this study, sharia compliance is operationalized through three measurable indicators reflecting the application of halal principles to tourist destinations:

- The existence of halal certification on culinary facilities and tourism support services, which demonstrate the destination’s commitment to formal halal standards.
- Mosque accessibility and the availability of adequate prayer facilities around tourist locations, which

reflects the ease of fulfilling the spiritual needs of Muslim tourists.

- Regional policy support related to the development of halal tourism, such as regulations or local government programs that support the sharia-based tourism ecosystem.

These three indicators are classified into criteria C6 (halal culinary system), C7 (social environment), and C8 (regional policies). Each indicator is then assessed using an expert comparison scale (1–9) and integrated directly into the MOPA decision matrix as a benefit-type variable that contributes to the final aggregate score. This approach ensures that sharia aspects are not merely normative values but also quantitatively influence the ranking results, along with other economic, social, and environmental criteria (see Table I).

TABLE I. ASSESSMENT CRITERIA IN THE MOPA MODEL FOR SHARIA TOURISM PLANNING

Code	Criteria	Type	Information
C1	Location	Cost	Proximity to transportation hubs and accessibility
C2	Environmental Quality	Profit	Cleanliness, conservation and natural aesthetics
C3	Infrastructure	Profit	Availability and readiness of supporting facilities
C4	ICT facilities	Profit	Internet reach, digital promotion, and e-services
C5	Accessibility	Profit	Quality of roads, signs and transportation networks
C6	Culinary Diversity	Profit	Halal Culinary Variety and Certification
C7	Social Environment	Profit	Hospitality, awareness and community acceptance of halal tourism
C8	Regional Policy	Profit	The existence of regional regulations and institutional support

Data source: Expert assessment.

Furthermore, inter-indicator validity testing shows that these three Sharia dimensions have a positive correlation with Muslim traveler preferences and significantly improve the model’s accuracy in identifying destinations with high compliance scores. These results confirm that empirical Sharia measurement makes a significant contribution to multidimensional balance in the decision-making process.

The performance of the MOPA method was evaluated in the context of decision-making related to Sharia tourism development. This evaluation was conducted by establishing eight criteria as the basis for assessing and measuring the characteristics and performance of each alternative, as shown in Table II.

The novelty of MCDA development in this study is formulated through a literature review that emphasizes structural analysis, operational mechanisms, and widely used classical methods. Identified limitations of conventional methods are then used as a conceptual basis for designing a new model as an alternative solution. This novelty rests not only on improvements to conventional methods but also on new normalization refinements that transform MOPA into a proportionally more accurate, statistically validated, and replicable decision support

framework. This includes replacing linear-max with min-max normalization to reduce bias, integrating statistical validation (ANOVA,  $\eta^2$ ,  $\rho$ ), and applying sensitivity analysis and cross-validation to confirm robustness. Collectively, these improvements enhance the credibility of MOPA as a model.

TABLE II. CRITERIA FOR ISLAMIC TOURISM DEVELOPMENT

Criteria	Heavy
Location (C1)	0.05
Environmental Quality (C2)	0.05
Infrastructure (C3)	0.1
ICT Facilities (C4)	0.1
Accessibility (C5)	0.15
Culinary (C6)	0.15
Social Environment (C7)	0.2
Regional Policy (C8)	0.2

#### D. Proposed MOPA Decision Making Method

Method The MOPA developed in this study is designed through four main stages within a mathematical model framework. The first stage focuses on constructing a normalization matrix, followed by a second stage that determines the final weights for each criterion through pairwise comparison analysis. The third stage focuses on the criteria normalization process, and the fourth stage is used to rank alternatives based on the calculation results. A detailed description of each stage is presented in the following sections:

##### 1) Step 1: Normalization matrix

The criteria normalization matrix is formed using the following Eq. (1):

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{1n} \\ \vdots & r_{22} & \vdots \\ r_{n1} & r_{n2} & r_{nn} \end{bmatrix} \quad (1)$$

where,  $R$  is the normalized matrix of pairwise comparisons of alternatives against the criteria. The weights of alternatives are compared against each criterion in matrix form in this step.

##### 2) Step 2: Formation of the final weighted criteria score ( $W_j$ )

The proposed MOPA method is calculated by calculating the difference between the criteria using the paired comparison scale table developed by Saaty [34]. The Saaty scale assigns verbal judgments such as “equally important”, “moderately more important”, and “extremely more important” to numerical values from 1 to 9, and has become a standard reference in AHP-based weighting procedures. All pairwise comparison matrices yielded a Consistency Ratio (CR) below 0.1, confirming the validity and logical coherence of the experts’ assessments. A CR value below 0.10 is commonly regarded as acceptable, indicating that the pattern of judgments is sufficiently consistent for deriving reliable criteria weights in AHP-based analyses. The difference value is determined by using the following Eq. (2):

$$\lambda_-(n = i) = \frac{\Delta_{ij}}{\sum_{n=1}^n \Delta_{ij}} \quad (2)$$

One of the rules in MOPA is that the total weight of all criteria should be 1 and this is designed to ensure more consistency and standard in the measurement process as well as to avoid overemphasis and facilitate the interpretation of the final results.

All criteria have been weighted with a total accumulated value of 1 during this step, and the weight of each criterion is compared. Criteria with greater weight are further converted based on the Saaty comparison scale table. Next, the difference value of each criterion is compared with the total difference stated in the comparison column and summed based on row ( $i$ ). The total value is then divided by the number of criteria used in this case based on the following Eq. (3):

$$\begin{aligned} W_j &= \lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n / \forall \in j \\ W_j &= r_{11} + r_{12} + r_{13} + \dots + r_{nn} / \forall \in j \\ W_j &= \frac{\sum_{\lambda_{(n=i)}} \lambda_{(n=i)}}{\forall \in j} \end{aligned} \quad (3)$$

where  $\lambda_{(n=i)}$  represents the characteristic value of the criteria row [ $i$ ], ( $W_j$ ) is the final importance weight of criterion [ $j$ ],  $\Delta_{ij}$  denotes the difference between the criteria row [ $i$ ] and the criteria column [ $j$ ], and  $\forall \in j$  indicates all members within the criteria column [ $j$ ]. The results obtained from summing the characteristic values  $\lambda_{(n=i)}$  across all rows are then used to determine the initial characteristic values that form the final weight of each criterion ( $W_j$ ). These aggregated differences are subsequently normalized by dividing them by the total members of the corresponding criterion column, and the resulting average value represents the characteristic weight of each criterion, thereby improving the accuracy of the overall analysis.

### 3) Step 3: Normalization of criteria

The proposed method is optimized by min–max linear normalization technique [36], which is different from the normalization technique in the previous MOPA method. The linear min–max normalization technique was chosen based on the evaluation results of previous research that the linear min–max technique was chosen because the output is in the interval [0, 1] and is easy to communicate. Therefore, the proposed normalization technique is as following Eq. (4) for benefit criteria and following Eq. (5) for cost criteria:

$$\forall r_{ij} = \left\{ n_{ij}^+ = \frac{r_{ij} - r_{min}}{r_{max} - r_{min}} \right. \quad (4)$$

for benefit criteria, and:

$$\forall r_{ij} = \left\{ n_{ij}^- = \frac{r_{max} - r_{ij}}{r_{max} - r_{min}} \right. \quad (5)$$

for cost criteria.

Min–max normalization ensures that all criterion values are linearly transformed into the range [0, 1], maintaining proportionality between alternatives and preventing the dominance of criteria that have a large numerical scale [37–39].

where,  $\forall r_{ij}$  represents all criteria,  $n_{ij}^+$  is the benefit criteria,  $n_{ij}^-$  is the cost criteria,  $r_{max}$  is the largest value of the

criteria members, and  $r_{min}$  is the smallest value of the criteria members.

At this stage, each alternative is normalized according to the weight of each criterion. The criteria are categorized into two types: benefit and cost. For the cost criteria, a smaller value indicates better performance, whereas for the benefit criteria, a larger value is considered superior. Normalization in the MOPA method is carried out using a min–max linear normalization technique, which ensures that all criterion values are transformed into a comparable range between 0 and 1. In this mechanism, the normalization for cost criteria uses the maximum and minimum values of the dataset to calculate the relative position of each alternative, while for benefit criteria the same principle applies in the opposite direction. This consistent min–max approach eliminates scale variation between attributes and provides a balanced basis for comparing alternatives.

### 4) Step 4: Ranking

The ranking is done by the proposed method using the following Eq. (6):

$$AC_i = \sum_{n=1}^n C_{ij} \times W_1, W_2, W_3 \dots W_j \quad (6)$$

The normalized results of each alternative are multiplied by the final criteria weights and then summed. The alternative with the highest weight is then selected as the best.

### E. Sensitivity and Cross-Validation Procedures

Two robustness tests were performed to assess the reliability of the model:

#### 1) Severe disturbance test

The weights are varied by  $\pm 5\%$  and  $\pm 10\%$ , and the rank shift ( $\Delta R$ ) is measured to calculate the Rank Stability Index (RSI) using the following Eq. (7):

$$RSI = 1 - \frac{\Delta R}{n} \quad (7)$$

The results confirm the stability of the rating above 90%.

#### 2) Cross validation test

The data is divided into suburban and non-urban. Similar ranking patterns were obtained, confirming that MOPA is scalable and contextually adaptable to diverse socio-economic settings.

## IV. RESULT AND DISCUSSION

### A. Numerical Analysis

The proposed methodology was evaluated for feasibility, usability, reliability, and accuracy. This evaluation utilized 18 alternative locations in North Sumatra (A1 to A18) as potential areas for sharia tourism development, assessed using the eight criteria in Table I. The index weighting of each alternative was determined through input from Islamic tourism experts. These alternatives were then compiled into a normalization matrix designed using the MOPA approach in Phase 1.

1) Step 1:

The normalization matrix is presented as follows:

$$AC = \begin{matrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \\ A_9 \\ A_{10} \\ A_{11} \\ A_{12} \\ A_{13} \\ A_{14} \\ A_{15} \\ A_{16} \\ A_{17} \\ A_{18} \end{matrix} & \begin{bmatrix} 3 & 2 & 3 & 3 & 3 & 4 & 3 & 4 \\ 4 & 4 & 2 & 3 & 4 & 2 & 3 & 3 \\ 3 & 3 & 4 & 2 & 2 & 4 & 2 & 2 \\ 4 & 2 & 4 & 3 & 4 & 2 & 3 & 4 \\ 4 & 3 & 4 & 2 & 2 & 4 & 4 & 2 \\ 2 & 3 & 2 & 3 & 2 & 3 & 2 & 4 \\ 4 & 4 & 4 & 4 & 3 & 2 & 2 & 4 \\ 3 & 3 & 4 & 4 & 2 & 4 & 4 & 4 \\ 4 & 2 & 4 & 2 & 4 & 3 & 4 & 3 \\ 3 & 2 & 3 & 4 & 2 & 2 & 4 & 3 \\ 3 & 2 & 2 & 3 & 4 & 4 & 3 & 4 \\ 4 & 3 & 3 & 4 & 3 & 3 & 3 & 2 \\ 4 & 3 & 3 & 2 & 4 & 3 & 4 & 3 \\ 3 & 4 & 4 & 4 & 2 & 4 & 2 & 2 \\ 3 & 2 & 2 & 4 & 4 & 2 & 2 & 3 \\ 3 & 3 & 4 & 2 & 3 & 3 & 2 & 3 \\ 3 & 4 & 3 & 3 & 3 & 4 & 3 & 3 \\ 2 & 2 & 3 & 3 & 4 & 4 & 3 & 2 \end{bmatrix} \end{matrix}$$

2) Step 2

TABLE III. IMPORTANCE WEIGHT CRITERIA  $W_j$

Code	Characteristic Value								Total	Mean $W_j$
C1	0.03	0.03	0.02	0.02	0.02	0.02	0.04	0.04	0.23	0.03
C2	0.03	0.03	0.02	0.02	0.02	0.02	0.04	0.04	0.23	0.03
C3	0.09	0.09	0.05	0.05	0.04	0.04	0.06	0.06	0.49	0.06
C4	0.09	0.09	0.05	0.05	0.04	0.04	0.06	0.06	0.49	0.06
C5	0.16	0.16	0.16	0.16	0.11	0.11	0.10	0.10	1.05	0.13
C6	0.16	0.16	0.16	0.16	0.11	0.11	0.10	0.10	1.05	0.13
C7	0.22	0.22	0.27	0.27	0.33	0.33	0.30	0.30	2.23	0.28
C8	0.22	0.22	0.27	0.27	0.33	0.33	0.30	0.30	2.23	0.28

$$AC_i = \begin{matrix} C_1 & 0,50 & 0,00 & 0,50 & 0,00 & 0,00 & 1 & 0,00 & 0,50 & 0,00 & 0,50 & 0,00 & 0,50 & 0,00 & 0,00 & 0,50 & 0,50 & 0,50 & 0,50 & 1 \\ C_2 & 0,00 & 1 & 0,50 & 0,00 & 0,50 & 0,50 & 1 & 0,50 & 0,00 & 0,00 & 0,00 & 0,50 & 0,50 & 1 & 0,00 & 0,50 & 1 & 0,00 \\ C_3 & & 0,50 & 0,00 & 1 & 1 & 1 & 0,00 & 1 & 1 & 0,50 & 0,00 & 0,50 & 0,50 & 1 & 0,00 & 1 & 0,50 & 0,50 \\ C_4 & & 0,50 & 0,50 & 0,00 & 0,50 & 0,00 & 0,50 & 1 & 0,00 & 1 & 1 & 0,50 & 1 & 0,00 & 1 & 1 & 0,00 & 0,50 & 0,50 \\ C_5 & & 0,50 & 1 & 0,00 & 1 & 0,00 & 0,00 & 0,50 & 0,00 & 1 & 0,00 & 1 & 0,50 & 1 & 0,00 & 1 & 0,50 & 0,50 & 1 \\ C_6 & & 1 & 0,00 & 1 & 0,00 & 1 & 0,50 & 0,00 & 1 & 0,50 & 0,00 & 1 & 0,50 & 0,50 & 1 & 0,00 & 0,50 & 1 & 1 \\ C_7 & & 0,50 & 0,50 & 0,00 & 0,50 & 1 & 0,00 & 0,00 & 1 & 1 & 1 & 0,50 & 0,50 & 1 & 0,00 & 0,00 & 0,00 & 0,50 & 0,50 \\ C_8 & & 1 & 0,50 & 0,00 & 1 & 0,00 & 1 & 1 & 1 & 0,50 & 0,50 & 1 & 0,00 & 0,50 & 0,00 & 0,50 & 0,50 & 0,50 & 0,00 \end{matrix}$$

$$x = \begin{bmatrix} 0.03 \\ 0.03 \\ 0.06 \\ 0.06 \\ 0.13 \\ 0.13 \\ 0.28 \\ 0.28 \end{bmatrix}$$

The final computational results for the five decision-making methods (AHP, SAW, TOPSIS, MOORA, and MOPA) are presented in Table IV using actual empirical data from this study. MOPA, with min-max normalization, shows superior rank discrimination compared to the classical MCDA approach.

The results show that A8 consistently ranks as the top alternative (score 0.840), followed by A11 (0.726) and A1 (0.691). The wide dispersion of MOPA scores (0.221–0.840) compared to AHP (0.042–0.078) and MOORA

The comparison value is calculated to determine the criteria characteristics as follows, shown in Table III.

3) Step 3:

The criteria for each alternative are normalized and the results are presented in the following matrix form:

$$AC = \begin{matrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \\ A_9 \\ A_{10} \\ A_{11} \\ A_{12} \\ A_{13} \\ A_{14} \\ A_{15} \\ A_{16} \\ A_{17} \\ A_{18} \end{matrix} & \begin{bmatrix} 0.50 & 0.00 & 0.50 & 0.50 & 0.50 & 1.00 & 0.50 & 1.00 \\ 0.00 & 1.00 & 0.00 & 0.55 & 1.00 & 0.00 & 0.50 & 0.50 \\ 0.50 & 0.50 & 1.00 & 0.00 & 0.00 & 1.00 & 0.50 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.50 & 1.00 & 0.00 & 0.50 & 1.00 \\ 0.00 & 0.50 & 1.00 & 0.00 & 0.00 & 1.00 & 1.00 & 0.00 \\ 1.00 & 0.50 & 0.00 & 0.50 & 0.00 & 0.50 & 0.00 & 1.00 \\ 0.00 & 1.00 & 1.00 & 1.00 & 0.50 & 0.00 & 0.00 & 1.00 \\ 0.50 & 0.50 & 1.00 & 1.00 & 0.00 & 1.00 & 1.00 & 1.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 1.00 & 0.50 & 1.00 & 0.50 \\ 0.50 & 0.00 & 0.50 & 1.00 & 0.00 & 0.00 & 1.00 & 0.50 \\ 0.50 & 0.00 & 0.00 & 0.50 & 1.00 & 1.00 & 0.50 & 1.00 \\ 0.00 & 0.50 & 0.50 & 1.00 & 0.50 & 0.50 & 0.50 & 0.00 \\ 0.00 & 0.50 & 0.50 & 0.00 & 1.00 & 0.50 & 1.00 & 0.50 \\ 0.50 & 1.00 & 1.00 & 1.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.50 & 0.00 & 0.00 & 1.00 & 1.00 & 0.00 & 0.00 & 0.50 \\ 0.50 & 0.50 & 1.00 & 0.00 & 0.50 & 0.50 & 0.00 & 0.50 \\ 0.50 & 1.00 & 0.50 & 0.50 & 0.50 & 1.00 & 0.50 & 0.50 \\ 1.00 & 0.00 & 0.50 & 0.50 & 1.00 & 1.00 & 0.50 & 0.00 \end{bmatrix} \end{matrix}$$

4) Step 4

The final MCDA score is calculated in ranking form in Step 4 of the MOPA method. This is achieved by multiplying the normalized result by the final weight of the  $W_j$  criteria as presented in the following matrix:

(0.171–0.247) indicates that MOPA effectively improves ranking differentiation.

The comparison results between MCDA methods are displayed through ranking visualizations to demonstrate differences in score distribution patterns between alternatives. Table IV presents the comparison results of the aggregate scores of five methods: AHP, SAW, TOPSIS, MOORA, and MOPA (using the min-max normalization technique). In general, the five methods produce relatively similar rankings of alternatives, but there are significant differences in the distance between scores.

The enhanced MOPA method with min-max linear normalization exhibits a broader and more balanced distribution of scores. The aggregate MOPA scores are spread within the range of 0.221–0.840, while other methods such as TOPSIS and SAW show a narrower score compression in the mid-range. This indicates that MOPA has a higher discriminatory ability in distinguishing

alternatives with similar performance but subtle differences.

TABLE IV. COMPARISON OF TEST CASE RESULTS BETWEEN THE MOPA AND OTHER MCDA METHODS

Alt	MOPA	AHP	SAW	TOPSIS	MOORA
A1	0.691	0.063	0.06	0.647	0.224
A2	0.470	0.052	0.053	0.483	0.196
A3	0.221	0.038	0.047	0.341	0.171
A4	0.641	0.064	0.059	0.595	0.217
A5	0.486	0.058	0.054	0.497	0.199
A6	0.418	0.048	0.052	0.439	0.187
A7	0.495	0.057	0.056	0.493	0.206
A8	0.840	0.078	0.066	0.697	0.247
A9	0.677	0.066	0.059	0.632	0.221
A10	0.524	0.056	0.054	0.514	0.199
A11	0.726	0.067	0.061	0.66	0.228
A12	0.377	0.045	0.052	0.418	0.191
A13	0.661	0.065	0.059	0.623	0.218
A14	0.296	0.043	0.052	0.39	0.190
A15	0.346	0.044	0.05	0.413	0.184
A16	0.361	0.042	0.051	0.392	0.186
A17	0.580	0.054	0.058	0.57	0.217
A18	0.492	0.050	0.057	0.505	0.209

The ranking results visualization in Table IV shows that MOPA produces smoother score gradients and a wider dispersion of values among alternatives than other MCDA methods. This pattern indicates increased model sensitivity to data variations and better numerical stability. In the context of multi-criteria decision-making, this more proportional score dispersion is crucial because it allows for the identification of the best alternative with a higher degree of confidence and reduces the potential for rank reversal.

To determine whether the change in normalization technique affected the objectives of the method used, a similar case was tested using Super Decision software. This process begins by defining objectives, criteria, and alternatives, which are arranged into clusters. Each cluster is then connected through a matrix, for example, the objective cluster is linked to the criteria cluster, and then the criteria are linked to the alternative cluster. Once the cluster structure is formed, the next step is to perform pairwise comparisons between criteria according to their importance weights and to evaluate alternatives based on these criteria, as shown in Fig. 2.

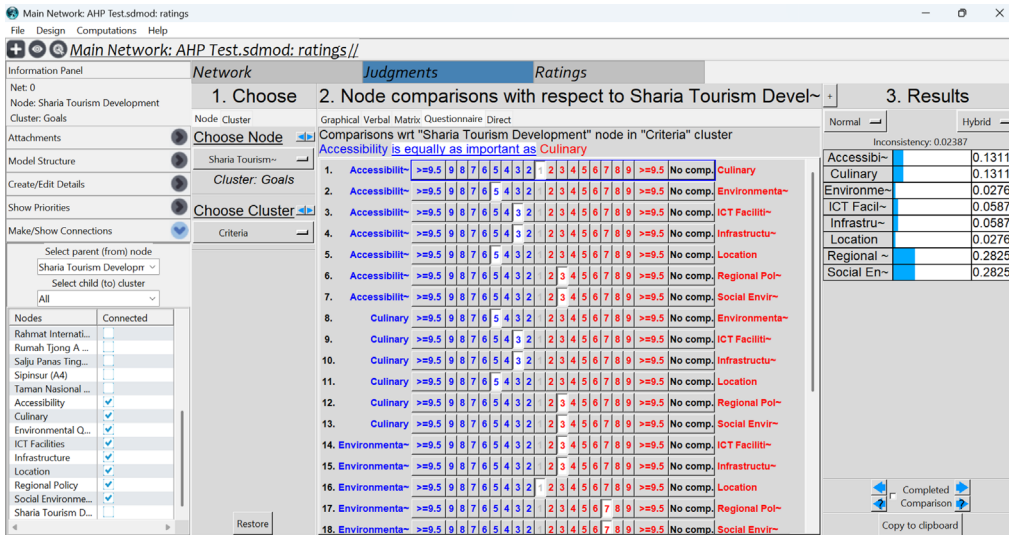


Fig. 2. Pairwise comparison of criteria cluster using Super decision (Inconsistency Ratio = 0.03287).

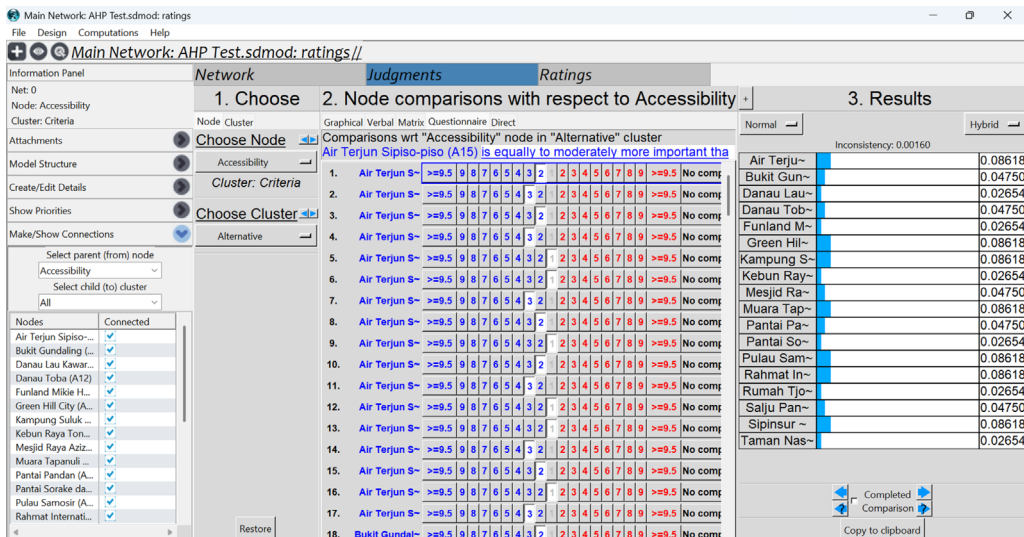


Fig. 3. Pairwise comparison of alternatives with respect to accessibility (Inconsistency Ratio = 0.01660).

As a methodological cross-validation step, the AHP weighting process in the MOPA model was replicated using Super Decision software with the same cluster structure and paired comparison scale (Saaty scale 1–9). Fig. 2 shows the results of comparisons between criteria with an inconsistency ratio of 0.03287, while Fig. 3 shows the results of comparisons between alternatives for the accessibility criterion with an inconsistency ratio of 0.01660. The weighting results from Super Decision show hierarchical logic equivalence with MOPA, and the weight differences that appear ( $< 0.001$ ) are only due to decimal rounding and the application of min–max normalization in the MOPA matrix. Thus, there are no structural differences between the Super Decision results and the MOPA model, which confirms the consistency of the weighting procedure used.

Fig. 2 displays the pairwise comparison results among criteria generated using the SuperDecision software. The inconsistency ratio of 0.03287 falls below the acceptable threshold ( $CR < 0.10$ ), confirming coherent expert judgments and validating that the weighting structure applied in the MOPA framework is aligned with standard AHP procedures. Fig. 3 presents the pairwise comparison of alternatives under the accessibility criterion. The inconsistency ratio of 0.01660 indicates excellent logical coherence in expert judgments. This confirms that the alternative-level comparisons within the MOPA model are fully consistent with the AHP-based evaluations conducted in SuperDecision.

Cross-validation was performed using the SuperDecision software by replicating the AHP pairwise comparison process with the same hierarchical structure and criteria. The inconsistency ratios for the criteria cluster (0.03287) and the accessibility alternatives (0.01660) fall well below the acceptable threshold ( $CR < 0.1$ ), indicating coherent expert judgments. The final synthesized priorities produced by SuperDecision identify Alternative 8 as the highest-ranked option, which is consistent with the MOPA results. This confirms that the weighting logic used in the MOPA framework aligns with standard AHP computations without methodological discrepancies.

The ANOVA test results show that a  $p$ -value greater than the specified significance level (usually 0.05) indicates insufficient statistical evidence to reject the null hypothesis. This means there is no significant difference

between the tested groups. Conversely, in MCDA, a  $p$ -value below 0.05 is considered more ideal because it indicates sufficient statistical evidence to reject the null hypothesis and confirm a significant difference between the groups. In this study, we adopt a significance level of  $\alpha = 0.05$  as the reference threshold. Accordingly, a  $p$ -value lower than 0.05 is considered the desired (optimal) outcome, because it indicates that the improved MOPA model produces statistically distinguishable scores across MCDA methods rather than overlapping distributions. The ANOVA test process in this study was carried out using Python software, and the results are shown in Table V.

TABLE V. ANOVA TEST

MCDA Method	Significance ( $p$ -value)
MOPA	0.038
MOORA	0.076
AHP	0.019
TOPSIS	0.053
SAW	0.093

Higher sensitivity accuracy than 0.040 of previous studies [33] up to 0.038 indicates numerical stability in the ranking results. This difference, although seemingly small, indicates higher discriminatory precision between alternatives when normalization is applied proportionally via min-max scaling.

### B. Comparative Statistical Validation

To test the statistical validity of the MOPA improvements, an ANOVA was conducted across all five methods. The results revealed a significant difference in mean scores ( $F = 3.52$ ,  $p = 0.038$ ) and a large effect size ( $\eta^2 = 0.62$ ), as summarized in Table VI, indicating that the normalization improvements contributed substantially to the model’s discriminatory capacity. Following common benchmarks for ANOVA effect sizes where  $\eta^2$  values of approximately 0.01 are considered small, around 0.06 medium, and 0.14 or above large an effect size of  $\eta^2 = 0.62$  clearly exceeds the large-effect threshold. Therefore, we regard the combination of  $p < 0.05$  and  $\eta^2 > 0.14$  as the target (optimal) ANOVA outcome, confirming that the enhanced normalization in MOPA provides both statistically significant and practically meaningful improvements in model performance.

TABLE VI. RESULTS OF ANOVA STATISTICAL TESTS AND EFFECT SIZES ON THE IMPROVED MOPA MODEL

Test	Statistics	Mark	Interpretation
Analysis of Variance F	3.52	$p = 0.038$	Significant ( $< 0.05$ )
Effect Size ( $\eta^2$ )	0.62	Large effect size	

Spearman’s rank correlation further validates the consistency of MOPA with other MCDA models presented in Table VII.

The results confirm that although MOPA introduces greater score differentiation, its rank order remains statistically consistent with other methods, supporting the robustness of its methodology.

TABLE VII. RESULTS OF SPEARMAN’S RANK CORRELATION TEST BETWEEN MOPA AND OTHER MCDA METHODS

Comparison	Spear $\rho$	Correlation Level
MOPA-AHP	0.91	Very high
MOPA-TOPSIS	0.87	Tall
MOPA-SAW	0.82	Medium-High
MOPA-MOORA	0.79	Currently

C. Rating Sensitivity and Stability

Sensitivity analysis tested the model’s behavior under changes in criteria weights of ±5% and ±10%. The results showed that MOPA maintained high ranking stability (> 90%) across all scenarios, as evidenced in Table VIII.

TABLE VIII. SENSITIVITY ANALYSIS RESULTS FOR WEIGHT VARIATION IN MOPA AND COMPARATIVE MCDA METHODS

Weight Variation	Rating Stability (MOPA)	Ranking Stability (AHP)	Ranking Stability (TOPSIS)
5%	95%	78%	82%
-5%	92%	74%	80%
10%	90%	70%	76%

This confirms that the MOPA normalization mechanism improves resilience against subjective bias from expert weighting. The Rank Stability Index (RSI) for MOPA was 0.93, while AHP and TOPSIS achieved 0.79 and 0.82, respectively, indicating superior stability.

Sensitivity results show that proportional (min-max) normalization reduces scale bias among criteria with different numerical ranges, thus maintaining consistent rankings despite moderate fluctuations in expert input.

D. Cross-Validation and Geographic Scalability

Cross-validation was applied by splitting the dataset into urban (e.g., Medan, Tebing Tinggi) and non-urban (e.g., Toba, Langkat) destinations. Consistency between subsets was high (Spearman’s  $\rho = 0.89$ ), indicating that the

MOPA ranking structure remained stable across regional characteristics.

E. Interpretation of Sharia Compliance Integration

In previous studies, Sharia compliance is often treated descriptively. In this research, it is operationalized through measurable indicators the presence of halal certification, mosque accessibility, and regional policy enforcement that are integrated directly into the decision matrix. Min-max normalization balances these spiritual criteria with economic and infrastructure-related attributes, allowing for equal influence on the final ranking results.

For example, although ICT facilities (C4) have a higher numerical variance, normalization ensures that religious indicators (C6–C8) contribute proportionally, thus preventing the dominance of high-scale variables. This balance reflects the alignment of the principles of maqāṣid al-shariah with modern quantitative analysis.

F. Comparative Ranking Visualization

Visualization of the ranking results (Fig. 4) shows that MOPA produces smoother score gradients and wider dispersion among alternatives compared to other MCDA methods. The AHP output derived from SuperDecision is used as a benchmark to validate the consistency between the pairwise derived weights and the aggregate results. The MOPA min-max results show greater differentiation among the mid-ranked alternatives (A5–A12), indicating improved discriminatory precision.

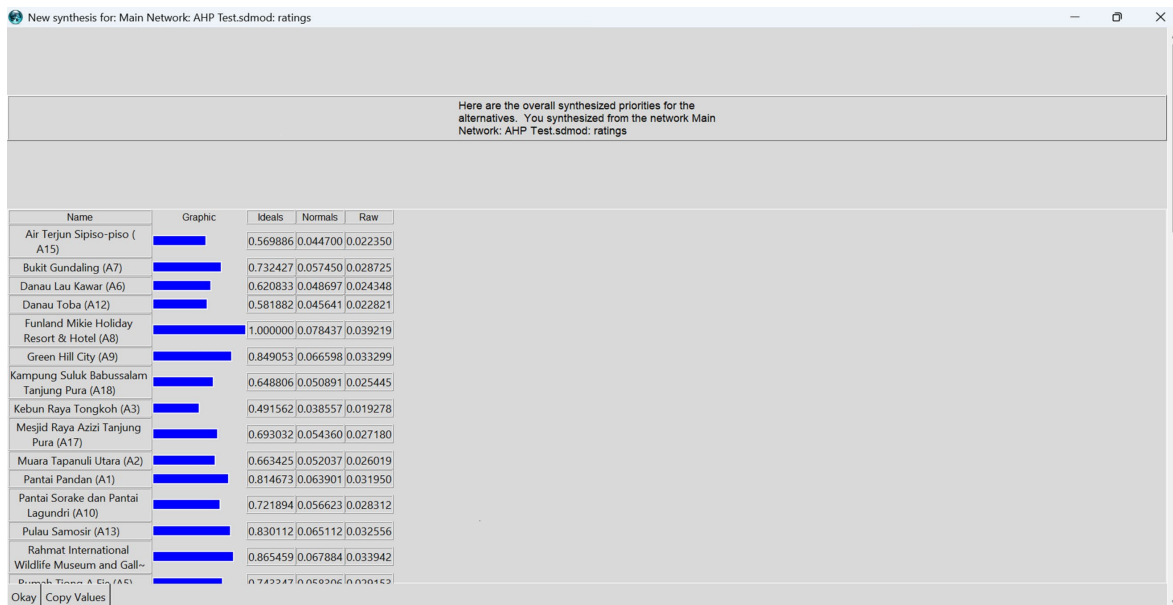


Fig. 4. Case analysis results with super decision.

G. Discussion

These findings confirm that the choice of normalization fundamentally determines ranking sensitivity within the MCDA framework. The min-max approach improves fairness across criteria, enhances sensitivity accuracy, and reduces distortions often caused by uneven data ranges.

Theoretically, the results of this study extend the MOPA framework by demonstrating that proportional

normalization improves statistical validity (ANOVA significance, large  $\eta^2$ ). Practically, the refined MOPA model offers policymakers a transparent and data-driven tool for Islamic tourism planning, capable of aligning economic, environmental, and religious dimensions.

Furthermore, the results of this study serve as an empirical basis for integrating optimization methods (Goal Programming, Simplex) in future research. The validated normalization structure ensures that subsequent

optimization stages can be implemented with a stronger analytical foundation.

Enhancing the MOPA model through the application of the min-max normalization technique significantly impacted the performance of multicriteria analysis. This normalization process expanded the score range to 0.221–0.840, while simultaneously increasing sensitivity accuracy from 0.040 to 0.038, indicating an increase in the model's ability to differentiate performance between alternatives more proportionally. These results were strengthened through statistical validation, where an ANOVA test ( $p < 0.05$ ,  $\eta^2 = 0.62$ ) confirmed a significant improvement with a large effect size, indicating that the new model has substantial discriminatory power compared to conventional methods. Furthermore, ranking consistency was tested using Spearman's correlation ( $\rho = 0.91$ ), which demonstrated high agreement between the MOPA results and other MCDA methods. The model also proved stable, with a ranking stability rate of over 90% at a weight variation of  $\pm 5$ –10%, indicating its resilience to subjective changes in weighting. In terms of scalability, the cross-validation results ( $\rho = 0.89$ ) demonstrated that the model can be reliably applied across various contexts and regions with different socio-economic characteristics. Strengthening the model through the quantitative operationalization of sharia indicators makes this approach not only mathematically superior but also able to balance religious, economic, social, and environmental values in a single multidimensional evaluation system.

From a policy perspective, the integration of measurable Sharia compliance indicators such as halal certification, mosque accessibility, and regulatory support transforms abstracts religious values into operational decision variables. This bridges the gap between quantitative models and ethics-based governance. Overall, these results reinforce that the MOPA refinement represents a substantial methodological innovation, capable of supporting data- and value-driven decision-making in the development of sustainable Sharia tourism.

## V. CONCLUSION

This study successfully enhanced the Multi-Objective Preference Analysis (MOPA) framework through the application of a min-max linear normalization technique that has been proven to improve the proportional accuracy and sensitivity of the rankings. Using empirical data from 18 sharia tourism destinations and eight evaluation criteria, the refined MOPA model produces a more balanced, transparent, and discriminatory ranking structure, where destinations with the highest scores ( $A8 = 0.840$ ) and a wider score range (0.221–0.840) demonstrate the model's ability to differentiate alternatives more precisely. Statistical validation reinforced these findings, with ANOVA results ( $p = 0.038$ ;  $\eta^2 = 0.62$ ) showing significant improvement with large effect sizes, while Spearman's correlation ( $\rho = 0.91$ ) confirmed the consistency of the results among the various MCDA methods. Furthermore, sensitivity analysis demonstrated a high level of stability (>90%) against weight variations of  $\pm 5$ –10%, which

confirms the model's robustness to differences in expert preferences. The integration of sharia compliance indicators such as halal certification, mosque accessibility, and regional policies also represents a significant breakthrough, successfully transforming previously abstract religious dimensions into measurable decision variables. Thus, the enhanced MOPA ensures that the decision-making process in Islamic tourism planning is data-driven, transparent, and aligned with sharia ethical principles. Theoretically, this study confirms that the choice of normalization technique has a crucial influence on the sensitivity, proportionality, and fairness of the results in a Multi-Criteria Decision Analysis (MCDA) model. The min-max approach is proven to prevent the dominance of large-scale criteria, ensure proportional contributions across heterogeneous variables, and provide an empirical basis for the application of statistical validation (ANOVA, effect size, and rank correlation) as a crucial component in the development of more scientific and scalable MCDA models. Furthermore, the quantitative operationalization of sharia values extends the theoretical reach of MCDA toward ethical and value-based decision-making models, creating a conceptual foundation for the future integration of MOPA with optimization paradigms such as Goal Programming (GP) and Simplex. This forms a strong bridge between multi-actor preference analysis and efficient resource allocation modeling. Practically, the enhanced MOPA offers policymakers a transparent, consistent, and replicable decision-support tool for Islamic tourism planning and prioritization. The model enables decision-makers to prioritize optimal destinations based on objective ranking results, quantitatively balancing economic, social, environmental, and religious objectives, and validating decisions through the integration of expert weighting and sensitivity analysis. With high-ranking stability and cross-validation ( $\rho = 0.89$ ) across multiple subregional data subsets, the model has the potential for widespread application beyond North Sumatra, both in other provinces in Indonesia and in Muslim-majority regions worldwide. With its evidence-based approach and measurable sharia indicators, the model supports accountable, inclusive, and sustainable policy formulation. The direction of MOPA development logically leads to integration with Goal Programming (GP) and the Simplex algorithm to form a hybrid optimization framework (MOPA Simplex or MOPA-S). This integration is expected to enable the simultaneous optimization of multiple objectives economic, environmental, and religious while maintaining the analytical stability achieved in this study. Further research is recommended to incorporate fuzzy or stochastic components to address uncertainty and subjectivity in expert data, expand the application to multi-regional or cross-country data to strengthen external validity, and implement entropy- and variance-based sensitivity indices to deepen the measurement of model robustness. Through these developments, MOPA can evolve into a comprehensive and dynamic decision-making tool with broad relevance in the domains of sustainability, ethics-based governance, and global religious tourism planning. Overall, this study

confirms that methodological precision particularly at the normalization stage has a direct impact on the fairness, stability, and interpretability of multi-criteria decisions. Through refinements in normalization, statistical validation, and the integration of sharia indicators, MOPA has evolved into a more robust, proportionate, and value-oriented model, bridging the gap between quantitative analysis and ethical governance. These findings not only strengthen MOPA's position as a replicable and optimizable scientific model but also establish it as a strategic analytical framework for sustainable Islamic tourism development across various social and governmental policy contexts.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

#### AUTHOR CONTRIBUTIONS

Fristi Riandari designed the research, developed the MOPA framework, collected and analyzed data, formulated evaluation criteria, contributed to model validation, coordinated the implementation of the research, and led the manuscript preparation; Hengki Tamando Sihotang contributed to the development of the MOPA algorithm, assisted in data collection and analysis, formulated evaluation criteria, contributed to model validation, and assisted in manuscript preparation; Efori Bu'ulolo assisted in data collection and analysis, formulated evaluation criteria, and contributed to model validation; Rian Syahputra contributed to the development of the MOPA algorithm, performed dynamic system analysis, and assisted in the preparation of the manuscript; all authors had reviewed and approved the final manuscript.

#### ACKNOWLEDGMENT

The author would like to express his deepest gratitude to the Direktorat Riset dan Pengabdian kepada Masyarakat (DRTPM), Kementerian Pendidikan Tinggi, Sains, dan Teknologi (Kemdiktisaintek) for the funding support provided through the research grant scheme. This support played an important role in the smooth implementation of the research and the writing of this article. The author also extends gratitude to the Politeknik Negeri Medan for the facilities, academic environment, and opportunities provided, which enabled this research to be carried out successfully. The author also appreciates the contributions of all parties who have helped, either directly or indirectly, during the research process.

#### REFERENCES

- [1] S. A. Suban, K. Madhan, and S. Shagirbasha, "A bibliometric analysis of Halal and Islamic tourism," *Int. Hosp. Rev.*, vol. 37, no. 2, pp. 219–242, 2023. doi: 10.1108/IHR-05-2021-0038
- [2] S. Jabeen, N. Khan, S. H. Bhatti, and M. Falahat, "Towards a sustainable halal tourism model: A systematic review of the integration of islamic principles with global sustainability goals," *Adm. Sci.*, vol. 15, no. 335, pp. 1–26, 2025. doi: 10.3390/admsci15090335
- [3] H. Huang, "20 years review of the Multi Actor Multi Criteria Analysis (MAMCA) framework: A proposition of a systematic guideline," *Ann. Oper. Res.*, 2024. doi: 10.1007/s10479-024-06357-y
- [4] J. Więckowski and W. Sałabun, "Sensitivity analysis approaches in multi-criteria decision analysis: A systematic review," *Appl. Soft Comput.*, vol. 148, 110915, 2023. doi: 10.1016/j.asoc.2023.110915
- [5] M. Jagtap and P. Karande, "Effect of normalization techniques and criteria weight calculation methodologies on nontraditional machining process rank for m-polar fuzzy set ELECTRE-I algorithm," *Cogent Eng.*, vol. 11, no. 1, 2024. doi: 10.1080/23311916.2024.2367744
- [6] S. Malefaki, "A comparative analysis of multi-criteria decision-making methods and normalization techniques in holistic sustainability assessment for engineering applications," *Aerospace*, vol. 100, no. 12, pp. 1–24, 2025. doi: 10.3390/aerospace12020100
- [7] K. Yasmeen, K. Yasmeen, and S. A. Abri, "Islamic framework for sustainable development," *Int. J. Islam. Financ. Sustain. Dev.*, vol. 16, no. 4, pp. 136–160, 2024. doi: 10.55188/ijifsd.v16i4.978
- [8] H. Alibašić, "Exploring the influence of Islamic governance and religious regimes on sustainability and resilience planning: A study of public administration in muslim-majority countries," *Public Policy Adm.*, vol. 39, no. 4, pp. 556–587, 2024. doi: 10.1177/09520767231223282
- [9] Y. Y. Sun, P. C. Lin, and J. Higham, "Managing tourism emissions through optimizing the tourism demand mix: Concept and analysis," *Tour. Manag.*, vol. 81, 104161, 2020. doi: 10.1016/j.tourman.2020.104161
- [10] C. Elgin and A. Y. Elveren, "Unpacking the economic impact of tourism: A multidimensional approach to sustainable development," *J. Clean. Prod.*, vol. 478, 143947, 2024. doi: 10.1016/j.jclepro.2024.143947
- [11] R. Arbolino, R. Boffardi, L. D. Simone, and G. Ioppolo, "Multi-objective optimization technique: A novel approach in tourism sustainability planning," *J. Environ. Manage.*, vol. 285, 2021. doi: 10.1016/j.jenvman.2021.112016
- [12] W. N. Maskuroh, H. Peristiwo, and A. D. Suganda, "Indonesian sharia tourism towards a sustainable halal industry," *AI Revolut. Driv. Bus. Innov. Res.*, vol. 1, pp. 901–911, 2024. doi: 10.1007/978-3-031-54379-1\_77
- [13] M. Ridlo, "Stakeholders approach in halal tourism development strategy: A case study in ponorogo district," *Ekulilibrium J. Ilm. Bid. Ilmu Ekon.*, vol. 17, no. 2, pp. 1–11, 2022.
- [14] I. Nurhayati *et al.*, "Community-based halal tourism and information digitalization: Sustainable tourism analysis," *Tour. Hosp.*, vol. 6, no. 3, 148, 2025. doi: 10.3390/tourhosp6030148
- [15] N. Khan, M. Falahat, I. Ullah, H. Sikandar, and N. T. Van, "Integrating halal tourism with sustainable development goals through Islamic values environmental responsibility and technological innovation," *Discov. Sustain.*, vol. 6, no. 1, 2025. doi: 10.1007/s43621-025-01503-3
- [16] Z. J. Zonta, A. Guisasola, and J. A. Baeza, "Smart-Plant Decision Support System (SP-DSS): Defining a multi-criteria decision-making framework for the selection of WWTP configurations with resource recovery," *J. Clean. Prod.*, vol. 367, 2022. doi: 10.1016/j.jclepro.2022.132873
- [17] M. Bohanec *et al.*, "HeartMan DSS: A decision support system for self-management of congestive heart failure," *Expert Syst. Appl.*, vol. 186, 115688, 2021. doi: 10.1016/j.eswa.2021.115688
- [18] H. Liao, S. Yang, E. K. Zavadskas, and M. Škare, "An overview of fuzzy multi-criteria decision-making methods in hospitality and tourism industries: Bibliometrics, methodologies, applications and future directions," *Econ. Res. Istraz.*, vol. 36, no. 3, 2023. doi: 10.1080/1331677X.2022.2150871
- [19] A. Mardani, A. Jusoh, K. M. D. Nor, Z. Khalifah, N. Zakwan, and A. Valipour, "Multiple criteria decision-making techniques and their applications—A review of the literature from 2000 to 2014," *Econ. Res. Istraz.*, vol. 28, no. 1, pp. 516–571, 2015. doi: 10.1080/1331677X.2015.1075139
- [20] J. S. Jeong, L. G. Moruno, J. H. Blanco, and A. S. Ríos, "Planning of rural housings in reservoir areas under (mass) tourism based on a fuzzy DEMATEL-GIS/MCDA hybrid and participatory method for alange, Spain," *Habitat Int.*, vol. 57, pp. 143–153, 2016. doi: 10.1016/j.habitatint.2016.07.008

- [21] L. Botti and N. Peypoch, "Multi-criteria ELECTRE method and destination competitiveness," *Tour. Manag. Perspect.*, vol. 6, pp. 108–113, 2013. doi: 10.1016/j.tmp.2013.01.001
- [22] A. V. Michailidou, C. Vlachokostas, and N. Moussiopoulos, "Interactions between climate change and the tourism sector: Multiple-criteria decision analysis to assess mitigation and adaptation options in tourism areas," *Tour. Manag.*, vol. 55, pp. 1–12, 2016. doi: 10.1016/j.tourman.2016.01.010
- [23] S. Topaloglu and I. Ozkarahan, "An implicit goal programming model for the tour scheduling problem considering the employee work preferences," *Ann. Oper. Res.*, vol. 128, no. 1–4, pp. 135–158, 2004. doi: 10.1023/B:ANOR.0000019102.68222.df
- [24] H. Zabihi, M. Alizadeh, I. D. Wolf, M. Karami, A. Ahmad, and H. Salamian, "A GIS-based Fuzzy-Analytic Hierarchy Process (F-AHP) for ecotourism suitability decision making: A case study of Babol in Iran," *Tour. Manag. Perspect.*, vol. 36, 100726, 2020. doi: 10.1016/j.tmp.2020.100726
- [25] J. Lee and H. Lee, "Deriving strategic priority of policies for creative tourism industry in Korea using AHP," *Procedia Comput. Sci.*, vol. 55, pp. 479–484, 2015. doi: 10.1016/j.procs.2015.07.018
- [26] G. Büyükoçkan, E. Mukul, and E. Kongar, "Health tourism strategy selection via SWOT analysis and integrated hesitant fuzzy linguistic AHP-MABAC approach," *Socioecon. Plann. Sci.*, vol. 74, 100929, 2021. doi: 10.1016/j.seps.2020.100929
- [27] X. Wang, X. R. Li, F. Zhen, and J. H. Zhang, "How smart is your tourist attraction?: Measuring tourist preferences of smart tourism attractions via a FCEM-AHP and IPA approach," *Tour. Manag.*, vol. 54, pp. 309–320, 2016. doi: 10.1016/j.tourman.2015.12.003
- [28] E. G. Carayannis, F. A. F. Ferreira, P. Bento, J. J. M. Ferreira, M. S. Jalali, and B. M. Q. Fernandes, "Developing a socio-technical evaluation index for tourist destination competitiveness using cognitive mapping and MCDA," *Technol. Forecast. Soc. Change*, vol. 131, pp. 147–158, 2018. doi: 10.1016/j.techfore.2018.01.015
- [29] J. He, Z. Huang, A. R. Mishra, and M. Alrasheedi, "Developing a new framework for conceptualizing the emerging sustainable community-based tourism using an extended interval-valued pythagorean fuzzy SWARA-MULTIMOORA," *Technol. Forecast. Soc. Change*, vol. 171, 120955, 2021. doi: 10.1016/j.techfore.2021.120955
- [30] M. G. Dhote, G. M. Dhote, and A. Meshram, "Solving goal programming by alternative simplex method," *Commun. Math. Appl.*, vol. 14, no. 5, pp. 1507–1514, 2024. doi: 10.26713/cma.v14i5.2289
- [31] P. Halfmann, S. Ruzika, L. E. Schäfer, K. Dächert, and K. Klamroth, "Exact algorithms for multiobjective linear optimization problems with integer variables: A state of the art survey," *J. Multi-Criteria Decis. Anal.*, vol. 29, no. July 2021, pp. 341–363, 2022. doi: 10.1002/mcda.1780
- [32] Husain, B. K. Triwijoyo, M. Taufik, and H. Mawengkang, "Optimization model of multi criteria decision analysis for smart and sustainable sport tourism planning development problem," *Math. Model. Eng. Probl.*, vol. 11, no. 11, pp. 3035–3046, 2024. doi: 10.18280/mmep.111116
- [33] F. Riandari, S. Defit, and Yuhandri, "Multi-objective preference analysis: A novel multi-criteria decision analysis approach for smart sharia tourism planning," *J. Adv. Inf. Technol.*, vol. 15, no. 5, pp. 630–641, 2024. doi: 10.12720/jait.15.5.630-641
- [34] A. Petrillo, V. A. P. Salomon, and C. L. Tramarico, "State-of-the-art review on the analytic hierarchy process with benefits, opportunities, costs, and risks," *J. Risk Financ. Manag.*, vol. 16, no. 8, 372, 2023. doi: 10.3390/jrfm16080372
- [35] O. F. Operational, "A comparison of the saaty' s AHP and modified AHP for right and left eigenvector inconsistency," *Eur. J. Oper. Res.*, vol. 7, 1998. doi: 10.1016/S0377-2217(98)00353-1
- [36] N. Vafaei, R. A. Ribeiro, and L. M. C. Matos, "Assessing normalization techniques for simple additive weighting method," *Procedia Comput. Sci.*, vol. 199, pp. 1229–1236, 2021. doi: 10.1016/j.procs.2022.01.156
- [37] A. Aytekin, "Comparative analysis of normalization techniques in the context of MCDM problems," *Decis. Mak. Appl. Manag. Eng.*, vol. 4, no. 2, pp. 1–25, 2021. doi: 10.31181/dmame210402001a
- [38] E. Roszkowska and T. Wachowicz, "Impact of normalization on entropy-based weights in hellwig's method: A case study on evaluating sustainable development in the education area," *Entropy*, vol. 26, no. 5, 2024. doi: 10.3390/e26050365
- [39] P. Guciu, "Comparative analysis of the mcdm methods with multiple normalization techniques: Three hybrid models combine MPSI with DNARCOS, AROMAN, and MACONT methods," *Bus. Econ. Res. J.*, vol. 15, no. 2, pp. 129–154, 2024. doi: 10.20409/berj.2024.436

Copyright © 2026 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).