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RESEARCH ARTICLE

Comparative Analysis Of Multi-Criteria Decision-Making Methods (MCDM) In Priorities Of Industrial Location Development

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Abstract: The research problem addressed in this study is determining priority areas for industrial development in Semarang City, which requires careful consideration of various supporting factors. The research aims to evaluate and compare different Multi-Criteria Decision Making (MCDM) methods to establish the priorities for developing industrial zones. The methods employed include MOORA, WASPAS, ARAS, COPRAS, and AHP. The criteria used in the evaluation include accessibility, land cost, availability of utilities, environmental impact, and socio-economic benefits. The research stages involved data collection, criteria weighting, application of the MCDM methods, and comparative analysis of the results using Spearman's rank correlation. The findings indicate that the WASPAS, MOORA, and AHP methods demonstrate strong performance with correlation values above 0.8, making them effective for ranking industrial development priorities. The study's findings provide valuable insights for decision-makers and contribute to the literature on MCDM methodologies with geographic data references.

Keywords: comparative analysis, geographic data references, industrial development, multi-criteria decision making (MCDM), priority areas

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1 Introduction

The industrial preparedness of a nation plays a crucial role in facilitating its overall growth. The assessment of industry preparedness encompasses an evaluation of the presence of industrial zones and several complementary elements. Industrial districts are designated to facilitate industrial and corporate growth and expansion. This region often comprises many manufacturing plants, storage facilities, and ancillary infrastructure. The primary aim is to enhance industrial growth and enable convenient access for enterprises engaged in it, encompassing access to transportation, water resources, energy, and other relevant factors [1]. There remains a need for further development in certain regions within the present industrial sector. The accessibility of the location, the caliber of the infrastructure, the availability of sufficient land for industrial development, market potential, environmental considerations, the availability of a skilled workforce, and geographical factors are just a few of the variables that can affect an industrial area's development priority. According to the study conducted by Nie et al. (2017) [2], the growth of industrial areas necessitates the consideration of various elements, each of which exerts its influence. In particular, the environmental and social impacts of these factors present complicated concerns that must be taken into account [3].

The government requires technological support for decision-making to effectively promote industrial development and enhance operational efficiency for enterprises. One such technology that fulfills this demand is multi-criteria decision-making (MCDM). Multi-Criteria Decision Making (MCDM) is a procedural framework that incorporates multiple criteria and alternatives to facilitate the selection of the optimal solution [4]. According to the research conducted by Siva Bhaskar and Khan (2022) [5], it was found that The methodologies are frequently employed across many disciplines, including management, business, information technology, environmental studies, and others, to address intricate challenges and facilitate informed decision-making [6]- [7]. Various methods in the field of Multi-Criteria Decision Making (MCDM) have been employed to ascertain the optimal alternatives. MOORA (Multi-Objective Optimization Based on Ratio Analysis), WASPAS (Weighted Aggregated Sum Product Assessment), ARAS (Additive Ratio Assessment), COPRAS (Complex Proportional Assessment of Alternatives), and AHP (Analytic Hierarchy Process) are some of these methods. According to Sotoudeh-Anvari (2022) [6], Several recent studies have explored the application of the Multi-Criteria Decision Making (MCDM) method in various domains. For instance, Zewdie and Yeshanew (2023) [8] investigated the integration of geophysical reference data in determining waste disposal locations. Villacreses et al. (2022) [4] focused on using MCDM to identify suitable locations for photovoltaic farming or solar cell installations. Jiang et al. (2022) [9] examined the application of MCDM in the planning of road networks. Saraswat et al. (2021) [10], Dhiman and Deb (2020) [11], and Villacrezes et al. (2017) [12] explored the use of MCDM in determining optimal areas for solar and wind farming. Budak et al. (2020) [13] investigated the application of MCDM in humanitarian aid logistics locations. Mousavi et al. (2022) [14] focused on using MCDM for flood vulnerability mapping. Finally, numerous researchers looked into the assessment of risk in multi-hazardous areas. (Lyu & Yin, 2023) [3] conducted a study on the subject matter. In order to determine the best polymer-based biomaterials for dental applications, Siva Bhaskar and Khan conducted a comparison study in 2022. Additionally, the study draws upon the work of Mousavi et al. (2022) [14] in the domain of flood susceptibility mapping, which assesses the degree of correlation between the outcomes of the MCDM method and Spearman Rank correlations.

By accessing the Scopus database, the researchers carried out a bibliometric analysis, as Aria and Cuccurullo described [15]. They retrieved information from a total of 2,000 research journal articles about MCDM research, published between 2021 and 2022. The theme maps presented in Fig.1 illustrate the findings of the researchers' document clustering analysis. These maps depict the ongoing evolution of research in Multiple Criteria Decision Making (MCDM) as well as the current trends in the fields of decision-making, Geographic Information Systems (GIS), and planning according to Aria and Cuccurullo (2017) [15].

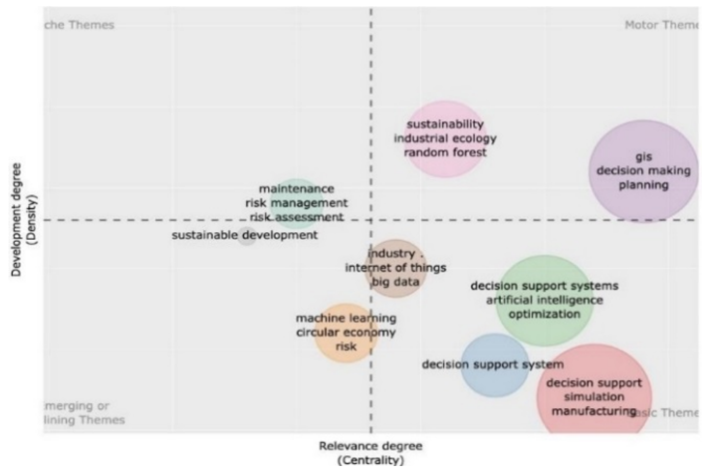

Figure 1: Trend research of multiple criteria decision-making.

The research report identifies a significant gap in existing studies related to the application of MCDM methods for industrial development prioritization. Previous studies have primarily focused on single MCDM methods or have applied these methods in different contexts such as urban planning or environmental management, but not specifically for industrial location prioritization in Semarang City. Additionally, there is a lack of comprehensive comparative analysis of multiple MCDM methods within the same study, which limits the ability to cross-validate results and identify the most effective method. This study addresses this gap by comparing five different MCDM methods (MOORA, WASPAS, ARAS, COPRAS, and AHP) and validating their results using Spearman's rank correlation, providing a more robust framework for decision-making in industrial development. Furthermore, the study incorporates a wider range of evaluation criteria (accessibility, land cost, utility availability, environmental impact, and socio-economic benefits) than many previous studies, offering a more holistic approach to industrial site selection.

Certain methodologies are better suited for scenarios characterized by a multitude of alternatives and well-defined criteria, while others are more appropriate for circumstances where the alternatives are numerous and the criteria are ambiguous. According to Hezer et al. (2021) [16], The focus of this study is the prioritized development of the industrial area's location, specifically by Ministry of Public Works Regulation No. 41/PRT/M/2007. This regulation provides guidelines for the technical criteria and limitations of the Budi Power

Area, which are relevant to the industrial area under investigation. The present study examines the external comparison of the Multiple Criteria Decision Making (MCDM) approach in prioritizing industrial regions, with a specific focus on the Single Door Capital Plantation and Integrated Services Service. The data utilized in this study consist of geographical reference data or spatial data that have been obtained through the process of mapping digitization, adhering to the technical boundary criteria specific to an industrial region.

The study employed various MCDM methods (MOORA, WASPAS, ARAS, COPRAS, and AHP) to ensure robust and reliable evaluations of industrial development priorities in Semarang City. This multi-method approach allows for cross-validation of results, leveraging each method's unique strengths. The basis of comparison includes accessibility, land cost, availability of utilities, environmental impact, and socio-economic benefits, providing a comprehensive assessment across multiple dimensions with a spatial approach. The primary aim is to identify the most effective and reliable techniques for prioritizing industrial development locations, validated through Spearman's rank correlation analysis, ensuring decision-makers have robust tools for strategic planning.

In essence, this introduction lays the groundwork for a detailed exploration of MCDM methodologies in the context of industrial area development with a spatial approach, addressing a critical research gap and setting the stage for significant theoretical and practical advancements in this vital area of study.

2 Literature Review

This study incorporates five Multi-Criteria Decision-Making (MCDM) approaches, including MOORA, WASPAS, ARAS, COPRAS, and AHP, together with MCDM for organizing geographical reference research objects. Each method employs a unique approach to normalization, weighting, and aggregation of criteria, which leads to different patterns of calculation and potentially different results when ranking alternatives. The indicators or factors used so that all methods can utilize the same criteria include accessibility, land cost, availability of utilities, environmental impact, and socio-economic benefits. These criteria provide a comprehensive and consistent basis for evaluating and comparing the performance of different MCDM methods. Using these common indicators ensures that each method is assessed on the same factors, facilitating a reliable comparative analysis. The comprehensive research presented in Table 1 demonstrates that the MCDM technique exhibits diverse degrees of correlation.

The findings of the study indicate that the table presents a compilation of studies that collectively highlight the efficacy of Multi-Criteria decision-making (MCDM) approaches in addressing various complex issues encountered in real-world scenarios. Upon analyzing this research, a continuous trend becomes apparent, indicating that Multiple Criteria Decision Making (MCDM) procedures are consistently recognized as important instruments for facilitating informed decision-making in diverse fields. Upon careful examination of individual research contributions, it becomes apparent that Multiple Criteria Decision Making (MCDM) methodologies provide flexible answers to complex situations.

An example that illustrates the effectiveness of multi-criteria decision-making (MCDM) in the identification of optimal waste disposal sites within the realm of environmental considerations is the study conducted by Zewdie and Yeshanew (2023) [8]. The utilization of

Multi-Criteria decision-making (MCDM) techniques facilitates the identification and selection of areas that conform to ecological standards and are socially acceptable. In a similar vein, the research undertaken by Lyu and Yin (2023) [3] showcases the efficacy of Multi-Criteria decision-making (MCDM) in evaluating the diverse risks linked to various hazards in heavily populated regions such as Hong Kong. This application highlights the comprehensive and integrated approach of Multi-Criteria Decision Making (MCDM), which allows for the inclusion of several risk variables and criteria. The compilation of research outcomes presented in the table provides strong evidence to support the crucial role that Multiple Criteria Decision Making (MCDM) procedures play in practical decision-making. The adaptability of Multiple Criteria Decision Making (MCDM) is evident when solving complex issues related to waste management, disaster resilience, renewable energy, and supplier selection. The capacity to manage numerous criteria and sophisticated trade-offs establishes MCDM as a reliable methodology for addressing difficult decision-making scenarios.

Additionally, the analysis highlights certain constraints that are inherent in multiple-criteria decision-making (MCDM) systems. The challenges associated with the use of Multiple Criteria Decision Making (MCDM) are widely recognized due to its inherent complexity and time-intensive nature. Furthermore, the presence of intrinsic ambiguity in certain problems might lead to the inability of Multiple Criteria Decision Making (MCDM) to provide definitive and unambiguous solutions. However, it should be noted that these limitations do not detract from the effectiveness of MCDM techniques. Instead, they highlight the significance of thorough deliberation and adaptation to the specific environment. Notwithstanding these factors, the amalgamation of study findings highlights the capacity of Multiple Criteria Decision Making (MCDM) to facilitate empowerment. MCDM, or Multi-Criteria Decision Making, is a dependable tool that enhances the quality of decision-making across various domains such as environmental decisions, risk assessment, energy planning, supply chain management, and pandemic response. The research presented in this review demonstrates that in situations involving complex decisions with multiple criteria, it is imperative to recognize MCDM as a vital tool for improving decision-making that is both well-informed and successful.

Table 1: Summary of the existing literature on MCDM for organizing geographical reference research objects

No	Researcher Name	Research Title	Object	Results
1	(Zewdie & Yeshanew, 2023) [8]	GIS-based MCDM for waste disposal site selection in Dejen town, Ethiopia	Waste disposal site	Map of environmentally friendly, feasible, and acceptable waste disposal locations

Continued on the next page

No	Researcher Name	Research Title	Object	Results
2	(Liu & Yin, 2023) [3]	An improved MCDM combined with GIS for risk assessment of multi-hazards in Hong Kong	Multi-hazard risk area	The MCDM method is capable of capturing multi-hazard risks in an area
3	(Villacreses et al., 2022) [4]	Geolocation of photovoltaic farms using Geographic Information Systems (GIS) with Multiple-criteria decision-making (MCDM) methods: Case Ecuadorian energy regulation	Location of photovoltaic farms or solar cells	Be able to determine locations that have large amounts of global solar radiation, wind speed, and temperature to cool solar panels
4	(Tronnebati et al., 2022) [17]	A Review of Green Supplier Evaluation and Selection Issues Using MCDM, MP, and AI Models	Determination: Green Supplier	The most widely used MCDM methods are AHP, DEA, and TOPSIS
5	(Sotoudeh-Anvari, 2022) [6]	The applications of MCDM methods in the COVID-19 pandemic: A state-of-the-art review	The MCDM method on the topic of research on COVID-19	The MCDM method in combination with fuzzy sets has successful applications in various fields
6	(Siva Bhaskar & Khan, 2022) [5]	Comparative analysis of hybrid MCDM methods in material selection for dental applications	Determination of polymer-based bio-materials	MCDM identifies the best polymer-based biomaterials for use in dentistry
7	(Mousavi et al., 2022) [14]	Comparison of statistical and MCDM approaches for flood susceptibility mapping in Northern Iran	Flood vulnerability mapping	MCDM is able to map flood-prone areas in Iran
8	(Jiang et al., 2022) [9]	Sustainable road alignment planning in the built environment based on the MCDM-GIS method	Road network planning	MCDM can produce optimal solutions that are sustainable and comprehensive

Continued on the next page

No	Researcher Name	Research Title	Object	Results
9	(Saraswat et al., 2021) [10]	MCDM and GIS-based modeling techniques for assessment of solar and wind farm locations in India	Locating solar and wind farms	MCDM was able to pinpoint suitable locations in India for solar and wind farm installations
10	(Budak et al., 2020) [13]	Real-time location system selection by using a fuzzy MCDM approach: An application in humanitarian relief logistics	Location of humanitarian aid logistics	MCDM is able to determine the best Real-time location system selection based on the resulting ranking
11	(Ozcalici & Bumin, 2020) [18]	An integrated multi-criteria decision-making model with Self-Organizing Maps for the assessment of the performance of publicly traded banks in Borsa Istanbul	Public bank performance appraisal	MCDM has a high correlation in the case of public bank performance appraisal

3 Research Method

3.1 Multi-Criteria Decision-Making (MCDM)

Multi-criteria decision-making (MCDM) is a decision-making process that integrates several criteria and alternatives in choosing the best solution [4]. This process uses various mathematical and statistical techniques to help make quality, data-based decisions [5]. MCDM methods are often used in various fields such as management, business, information technology, environment, and others to help solve complex problems and make wise decisions [6] [7]. The MCDM method has the potential to be useful in sustainability assessment by supporting decision-makers in making better decisions [19]. Each method employs a unique approach to normalization, weighting, and aggregation of criteria, which leads to different patterns of calculation and potentially different results when ranking alternatives. MOORA involves normalizing the decision matrix and then calculating a ratio for each criterion. The alternatives are ranked based on these ratios. WASPAS combines the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). It calculates a weighted sum and a weighted product separately and then combines these to rank the alternatives. ARAS method involves comparing each alternative to an ideal alternative. It sums the weighted normalized performance values and calculates a utility function for ranking. The COPRAS method calculates the significance of each alternative by evaluating the sum of the weighted normalized performance values. It takes into account both beneficial and non-beneficial criteria to rank the alternatives. AHP involves decomposing the decision problem into a hierarchy of criteria and sub-criteria. Pairwise comparisons are then made to calculate weights for each criterion, and a final composite score is calculated for ranking the alternatives. Each method represents a different group of calculation patterns. Generally speaking, the stages of the MCDM method before each of the methods in it are as follows:

a) Decision Making Matriks

$$x = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{ij} & \cdots & x_{ij} & \cdots & x_{nj} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad i = m, 0; j = 1, n \tag{1}$$

b) Normalization Decision Making Matrix

$$\bar{x} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{ij} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{nj} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{n1} & \cdots & \bar{x}_{mi} & \cdots & \bar{x}_{mn} \end{bmatrix} \quad i = \bar{m}, 0; j = 1, \bar{n} \tag{2}$$

c) Normalization Benefit Criteria

$$X_{ij} = \frac{X_{ij}}{\max X_{ij}} \tag{3}$$

d) Normalization Criteria Cost

$$X_{ij} = \frac{\min X_{ij}}{X_{ij}} \tag{4}$$

e) Weight Matrix

$$\sum_{j=1}^{n} w_j = 1 \tag{5}$$

3.2 MOORA (Multi-Objective Optimization on the basis of Ratio Analysis)

Brauers proposed the MCDM technique MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis) in 2004 as a way to resolve issues involving competing alternatives. MOORA has been widely used in parameter optimization [7]. As for the stages of the MOORA method, the process of the previous MCMD method is continued after the normalization and degradation of the criteria and expanded to the maximax and minmax stages determined by Equation 6.

$$Y_i = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j w_{ij}^* \tag{6}$$

Maximax chooses the alternative with the highest possible maximum payoff, reflecting an optimistic approach. Minimax chooses the alternative with the smallest possible maximum loss, reflecting a pessimistic approach.

3.3 WASPAS (Weighted Aggregated Sum Product Assessment)

The WASPAS method consists of the aggregation of two classic MADMs. The first method is the Weighted Sum Model (WSM), and the second is the weighted product model (WPM). The WSM method for substantial ideas is built on an indication of the total replacement score (Ai) in the form of the number of standard quality weights. Whereas the WPM is to exceed the replacement option that produces poor quality. The designation of each replacement point occurs on a scale of the value of the result of each quality, with a force equal to the weight of the quality's significance [20]. The stage of the WASPAS method continues to determine the value of Q_i on Equation 7.

$$Q_i = 0.5 \sum_{j=1}^{n} x_{ij} + 0.5 \prod_{j=1}^{n} (x_{ij}^{w_j}) \tag{7}$$

Q_i is final score that combination of WSM and WPM scores.

3.4 ARAS (Additive Ratio Assessment)

Turskis and Zavadskas were the ones who first introduced the ARAS method. ARAS measures the utility of a particular alternative to an ideal solution. The vector elements representing the ideal (alternative) solution can be formed in two ways: (1) by using expert knowledge to enter the optimal value of data outside the sample or (2) by choosing the extreme value of sample data, i.e., the minimum and maximum for cost and benefit criteria, respectively [21]. The ARAS method stage is continued by determining the optimal S_i function value and the K_i rank level value.

a) Optimum Function

$$S_i \sum_{j=1}^{n} \hat{x}_{ij}; \quad i = \overline{0, m} \tag{8}$$

b) Value of Level

$$K_i \frac{S_i}{S_0}; \quad i = \overline{0, m} \tag{9}$$

3.5 COPRAS (Complex Proportional Assessment of Alternatives)

The COPRAS method provides solutions that match the proportions of the best solutions. COPRAS concludes that the value, importance, and effectiveness of the tested version depend on a system of criteria that independently reveals alternatives and on the value and weight of the criteria [22]. The next step of the COPRAS method is to calculate the relative weight value of Q_i and the performance index value of P_i.

a) Relative Weight

$$Q_i = S_{+1} + \frac{\min S_{-1} \sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} (S - \min / S_{-i})} \quad (10)$$

Relative weights are calculated based on the maximum and minimum values of each criterion.

b) Index Performance

$$P_i = \left[\frac{Q_i}{Q_{\max}} \right] \times 100\% \quad (11)$$

Calculation of the utility degree of each strategy.

3.6 AHP (Analytic Hierarchy Process)

The AHP method allows decision-makers to prioritize alternatives based on several criteria. AHP uses hierarchies to solve complex problems and make decisions based on different criteria, and the AHP process involves creating a comparative matrix for each criterion and alternative, and then using mathematical analysis to determine the priority sequence [23]. The next stage of the AHP method is the calculation of consistency, from index coherence to consistency ratio.

a) Consistency Index (CI)

$$CI = (\lambda_{\text{maks}} - n)/n \quad (12)$$

The Consistency Index (CI) is calculated to determine the degree of consistency in the pairwise comparison matrix. It measures the deviation from perfect consistency.

b) Consistency Ratio

$$CR = \frac{CI}{IR} \quad (13)$$

The Consistency Ratio (CR) is used to determine whether the CI is acceptable. It compares the CI to the average consistency index (IR) of randomly generated matrices. If the value is more than 10%, then the judgment data assessment must be corrected. However, if the consistency ratio is ≤ 0.1, then the calculation can be correct [1].

3.7 Object and Criteria Research

An industrial area refers to a designated region that is specifically designated to conduct industrial activities. The relevant governmental authorities at the district or municipal level prepare and implement the Regional Space Plan, which determines this allocation. This study examines the specific geographical attributes and land suitability criteria outlined in Ministry of Public Works Regulation No. 41/PRT/M/2007 [24] about to industrial zones. The elements or criteria utilized encompass land use, geology, hydrology, road accessibility, and topography.

The concept of land use is employed to assess the capacity of land to support various activities, such as industrial development and land availability. It allows us to determine the extent to which land resources can be utilized for specific purposes. Geology refers to the study of the Earth's solid materials, including the composition and structure of rocks, minerals, and the various types of soil present in a given area. The soil properties deemed appropriate for an industrial setting include a texture ranging from medium to coarse. Hydrology pertains to the assessment and management of water resources. Accessibility pertains to the transportation infrastructure within a given region, encompassing factors such as the presence and quality of road networks, categorized according to their respective types. While topography pertains to the physical features and characteristics of a specific area, location refers to the specific position or placement of a particular landmass.

Table 2: The criteria used

No	Criteria	Category	Information
1	Distance to City Center	Cost	Location: distance to the nearest city center
2	Distance to Settlement	Benefit	The distance between the location and the nearest settlement
3	Land Type	Benefit	Type of allotment land
4	Slope	Cost	Land slope
5	Soil Type	Benefit	Type of land allotment for industrial location
6	River distance	Cost	Distance to the river as a source of water
7	Distance To Road	Cost	Distance to the main road

The study in question utilizes the parameters outlined in the Candy framework, as depicted in Table 2. These parameters specifically pertain to the evaluation of PU candy in relation to the identification of the industrial sector. The measurement provided is the distance in kilometers (km) between the specified location and the nearest city center. The measurement of the distance between a certain place and the closest settlement, shown as a polygon, is expressed in kilometers (km). Land type refers to the classification of land as specified in the space planning document of RT RW City Semarang, or, in other words, the allocation of land. The desired land type or land allocation is characterized by its non-agricultural, non-residential, and non-conversion attributes. The degree of slope inclination serves as a determining factor in assessing the level of security of the development and infrastructure. The parameters determining the incline threshold for a maximum slope of 15% are as follows: The classification of land based on its function involves the consideration of soil type as a criterion. An appropriate land option for the establishment of an industrial site would be characterized by infertile soil conditions. The subsequent classifications pertain to the various categories of soil based on their respective levels of fertility. Alluvial soil is characterized by its fertility, but grumusol soil is known for its lack of fertility. Latosol soil, on the other hand, is classified as non-fertile. The distances of rivers, measured in kilometers (km), are determined depending on the proximity of a certain site to the next river. The term road distance refers to the measurement of the spatial separation between a given place and the closest point of entry to a road network while considering the specific characteristics and classification of the road in question. Next, the weight of the criteria is determined by assessing the level of relevance or influence of each criterion on other criteria. This assessment is based on the examination of relevant documents and input from decision-makers.

The objective of this study is to determine the spatial distribution of industrial areas and identify the criteria used for their location based on spatial data analysis. Spatial data refers to the representation of geographical locations on the Earth's surface, which is widely employed in the domain of geographic information systems (GIS) [25]. Geographic data acquired through geographic queries is transformed into a criteria value for each choice, which is subsequently subjected to analysis using the Multiple-Criteria Decision-Making (MCDM) approach.

Table 3: Spatial data

Industry Location	Alt	Information	Distance
1	City Center	Point	Nearest city center point
2	Settlement	Polygon	Residentially designated land
3	Land Area	Polygon	Allotment type of land
4	Slope	Polygon	Land slope
5	Soil Type	Polygon	Soil Type
6	River	Line	River line in Java Island
7	Road	Line	Roads by road type

The spatial data utilized comprises x and y coordinates. The point type is characterized by a single X and Y value. Regarding the classification of polygons and lines, it is important to note that they are defined by a collection of coordinates that collectively determine their shape and extent.

Figure 2 depicts a digital map illustrating road lines, river lines, and city center points. This map is subsequently imported into a database and stored as coordinate data, which is then utilized for spatial querying purposes.

The digitized map depicted in Figure 3 represents land type area data, which is later integrated into the database. Each hue symbolizes a distinct category of terrain corresponding to a certain geographical region.

The digital map representation depicted in Figure 4 illustrates land usage data, which is subsequently imported into a database and stored as coordinate values. These coordinates are then utilized for spatial queries. The identical cartographic data is also utilized to determine the nearest proximity to the land area to allocate settlements. In addition to determining the land classification of the industrial site, data regarding the proximity of the industrial location to the land classification of the surrounding settlement was also collected.

The digital map visualization seen in Figure 5 depicts the inclination of the land. This visualization is subsequently imported into a database and stored as coordinate data. These coordinates are then used to execute spatial queries. Each distinct color represents a unique gradient or soil adaptability level for a specific geographical region.

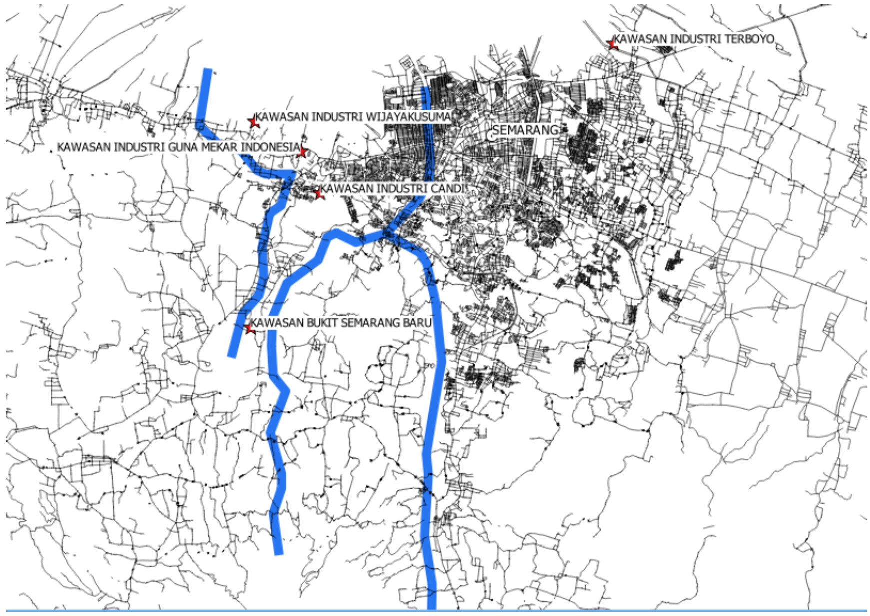

Figure 2: Depicts a digital map illustrating road lines, river lines, and city center points.

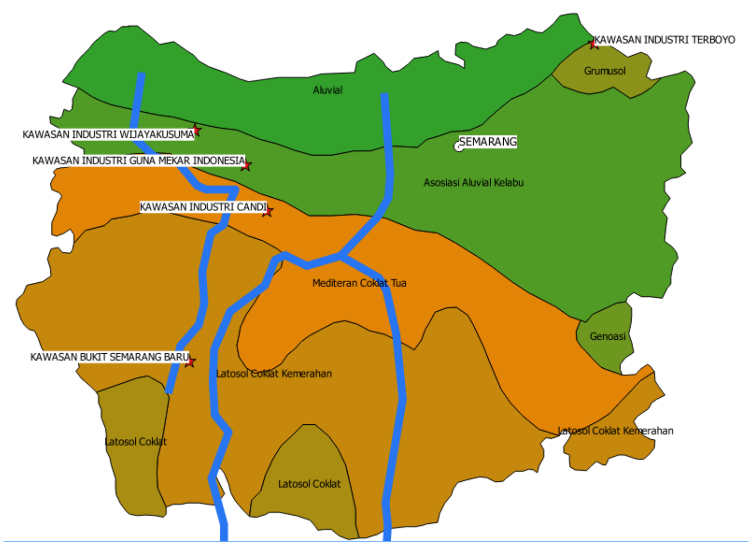

Figure 3: Represents land type and area data.

3.8 Research Plan

Temporal and spatial aspects of the research The research was undertaken over a period of seven months to collect data for subsequent comparative analysis. The study was conducted in Semarang City. Materials and Equipment In this section, we will discuss the

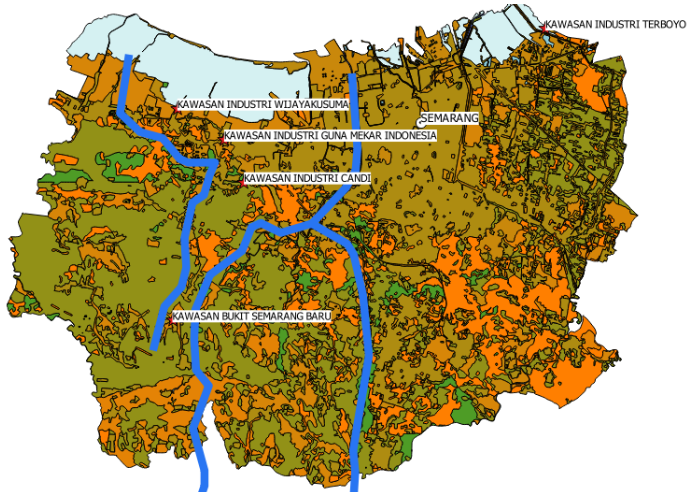

Figure 4: Illustrates land usage data.

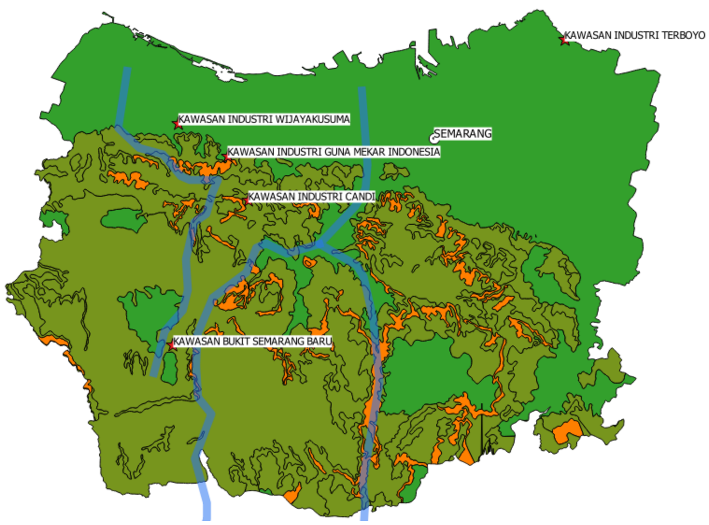

Figure 5: Depicts the inclination of the land.

materials and equipment used in the study. The materials refer to the substances or components utilized in the experiment, while the equipment pertains to The research utilized essential map pictures, Geographic Information System (GIS) software, Google Colab, and a Database Management System (DBMS) program.

The present study aims to conduct a comparative analysis of Multiple Criteria decision-making (MCDM) methods, specifically MOORA, WASPAS, ARAS, COPRAS, and AHP approaches. Spatial data digitized using Geographic Information System (GIS) software is utilized to get alternative data and criteria. The process of modeling is simulated using the Python programming language. The design of the research is depicted in Figure 6, presented below.

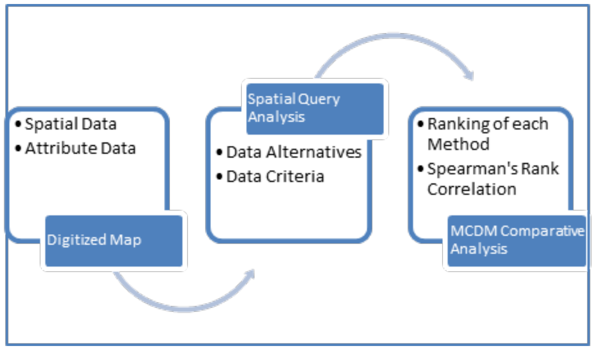

Figure 6: The design of the research.

The process of digitization involves converting an image map into a vector format in order to get both spatial and attribute data. Spatial query analysis is conducted subsequent to the importation of map digitization into the database management system (DBMS) in order to get alternative data and criteria. The procedure concludes with the Multi-Criteria Decision Making (MCDM) comparative analysis method.

Literature-based data collection strategies This methodology is employed to acquire supplementary data regarding research subjects as well as references about supportive ideas and methodologies via scholarly books and journals. The process of digitizing map data involves the conversion of secondary data sources, such as administrative boundary maps, spatial planning maps, land type maps, road networks, and river networks, into a digital format. The data analysis method has three different steps: spatial query analysis, perpendicular analysis using five Multi-Criteria Decision Making (MCDM) methods (MOORA, WASPAS, ARAS, COPRAS, and AHP), and correlation analysis using the Rank Spearman approach. The research process typically consists of several distinct stages. These stages serve as a framework for conducting a systematic and rigorous investigation. This investigation encompasses multiple stages, as depicted in Figure 7.

The present study utilizes secondary data sourced from the Central Statistics and Open Data Agency of Semarang City. The initial phase is the digitization procedure for each criterion, which entails converting image maps into vector format to get both spatial and attribute data. Spatial query analysis is conducted after the importation of map digitization into the database management system (DBMS). This process aims to acquire alternative data and criteria by utilizing spatial analysis capabilities, such as spacing and points in polygons, among others. Spatial analysis findings are utilized as valuable data within the decision-making framework. The procedure of any Multiple Criteria Decision Making (MCDM) approach is iterative until the ultimate result of the computation is achieved. The survey findings were juxtaposed with data about the prioritization of mining activities in industrial zones within Semarang City. Procedures for Analyzing Variable Data The variable data analysis strategy, as utilized in this work, pertains to the external consequence of the Multi-Criteria Decision Making (MCDM) method, namely the process of translation. The Spearman Rank correlation approach is employed to study the outcomes of each Multiple Criteria Decision Making (MCDM) method. This method is used to assess the degree

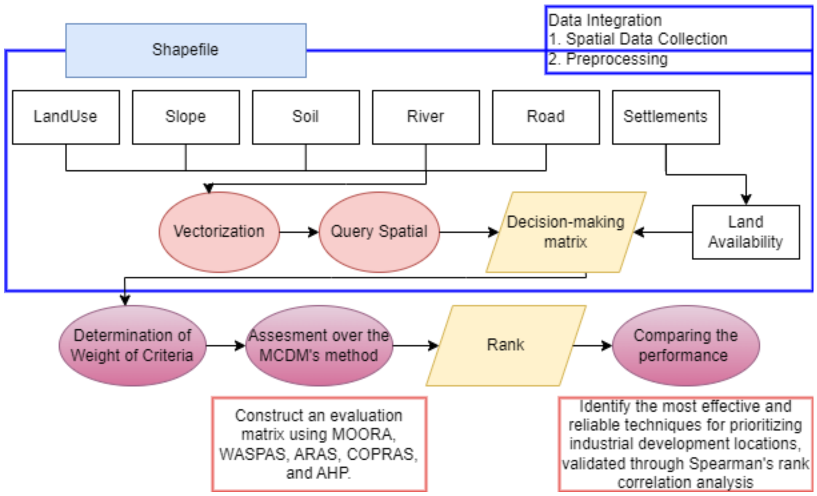

Figure 7: The investigation encompasses multiple stages.

of ranking compatibility that arises from the priority factors associated with the development of an industrial region. The correlation results span a range of values between 0 and 1. A higher value approaching 1 indicates superior performance of the Multiple Criteria Decision Making (MCDM) method.

4 Results

The utilized data source is secondary data digitization in a spatially formatted shapefile (shp), which adheres to the criteria and data categories described in Table 2 and Table 3. The spatial data is imported into the database and stored as coordinates. These coordinates are then used to run spatial queries in order to acquire the criteria value for each alternative. The following presents the quantitative assessment of each criterion for every alternative outcome of the spatial query.

Table 4: Criteria location distance to road

Industry Location	Alt	Information	Distance
Bukit Semarang Baru	A1	Main road	7.112
Guna Mekar Indonesia	A2	Main road	0.148
Candi	A3	Main road	1.294
Terboyo	A4	Main road	1.290
Wijayakusuma	A5	Main road	0.572

The table representation in Table 4 illustrates the quantitative assessment of the distance criterion for various possible industry locations to the arterial path. The spatial query utilizing the SDO_DISTANCE concept identifies five alternative or industry locations that have the shortest distance to the road line. SDO_DISTANCE is a function used to calculate the distance between two spatial geometries. The distance is determined by measuring the distance from the location point to the road line.

Table 5: Location criteria by land type

Industry Location	Alt	Information	Suitability
Bukit Semarang Baru	A1	Irrigation Rice Fields	No
Guna Mekar Indonesia	A2	Settlement	No
Candi	A3	Garden	Yes
Terboyo	A4	Pond	Yes
Wijayakusuma	A5	Settlement	No

The data presented in Table 5 illustrates the criterion value of land suitability for every potential industry location. There are five alternative or industry locations that generate land suitability descriptions specifically for non-cultivation, non-conservation, and non-agricultural purposes. A spatial query that makes use of the JOIN function and the SDO_CONTAINS concept in the database determines the alternative location. SDO_CONTAINS is a function used to determine if one spatial geometry contains another spatial geometry. This query is run on the land area.

Table 6: Location criteria with land slope

Industry Location	Alt	Slope
Bukit Semarang Baru	A1	0.25
Guna Mekar Indonesia	A2	0.02
Candi	A3	0.02
Terboyo	A4	0.02
Wijayakusuma	A5	0.15

Table 6 depicts the relationship between the criterion value and land inclination for each possible location within the industry. There are five alternative or location industries that contribute to the valuation of land inclination, expressed as a percentage value of inclinations. The alternate approach to querying involves employing the SDO_CONTAINS concept and JOIN functions in the databases to determine the spatial relationship between the queried area of land and the designated space.

Table 7: Land type and location criteria

Industry Location	Alt	Type of soil	Fertility
Bukit Semarang Baru	A1	Reddish Brown Latosol	Not Fertile
Guna Mekar Indonesia	A2	Gray Alluvial Association	Fairly Fertile
Candi	A3	Dark Brown Mediterranean	Not Fertile
Terboyo	A4	Grumusol	Not Fertile
Wijayakusuma	A5	Gray Alluvial Association	Fairly Fertile

The values of the criterion against the soil type for each alternative industry location are depicted in Table 7. This study aims to provide a comprehensive analysis of soil types and fertility in five alternative or industrial locations. The question examines alternate locations within the study region, taking into consideration the different soil types and their corresponding fertility levels. These soil types include Alluvial, which is deemed to have sufficient fertility; Grumusol, which is considered non-fertile; and Latosol, which is characterized as unfertile. The retrieval procedure employs a spatial query technique that utilizes the SDO_CONTAINS concept and leverages the JOIN function within the database.

Table 8: Location distance criteria to the nearest river

Industry Location	Alt	Distance
Bukit Semarang Baru	A1	0.469
Guna Mekar Indonesia	A2	1.026
Candi	A3	1.436
Terboyo	A4	7.208
Wijayakusuma	A5	1.377

The values for river distance criteria for each alternative industry location relative to the river line are depicted in Table 8. The spatial query utilizing the SDO_DISTANCE concept identifies the five alternative or industry locations that produce the shortest riverline distance. Each data point will be used to determine the shortest distance to the mapped river line that has been saved in the database.

Table 9: Location distance to city center criteria

City	Distance	Alt	Industry Location
Semarang	13.235	A1	Bukit Semarang Baru
Semarang	8.236	A2	Guna Mekar Indonesia
Semarang	7.786	A3	Candi
Semarang	6.516	A4	Terboyo
Semarang	10.177	A5	Wijayakusuma

The data presented in Table 9 illustrates the quantitative representation of the location distance requirement for the city center. The spatial query technique of SDO_DISTANCE is employed to calculate the distances from a central point to five alternative or industry sites. The distance is determined by measuring the distance from the designated location point to the central point of the city.

Table 10: Location distance criteria to settlements

Industry Location	Alt	Information	Distance
Bukit Semarang Baru	A1	Settlement	0.089
Guna Mekar Indonesia	A2	Settlement	0.363
Candi	A3	Settlement	0.167
Terboyo	A4	Settlement	0.749
Wijayakusuma	A5	Settlement	0.434

Table 9 illustrates the distance criterion value of the location of the settlement. There are five potential industries or locations that can be considered when determining the distance between a community and its surrounding area. By using the spatial query method SDO_DISTANCE, this is possible. This method utilizes the concept of distance to describe the land characteristics of a given settlement.

The outcome of the spatial query then transforms into the decision matrix data, as depicted in Table 11 presents the relevant data or information. The resulting matrix is a representation of the values assigned to each criterion for each alternative. This matrix is then

Table 11: Decision matrix

Criteria Category		cost	benefit	cost	benefit	cost	cost	benefit
Weight		5	3	2	2	3	5	4
Code	Alternative	City	Land	Slope	Land	River	Road	Settlement
A1	Bukit Semarang Baru	13.24	0.00	0.15	5.00	0.47	7.11	0.09
A2	Guna Mekar Indonesia	8.24	0.00	0.02	2.00	1.03	0.15	0.36
A3	Candi	7.79	5.00	0.25	5.00	1.44	1.29	0.17
A4	Terboyo	6.52	5.00	0.50	0.00	7.21	1.29	0.09
A5	Wijayakusuma	10.18	0.00	0.02	2.00	1.38	0.57	0.43

normalized using appropriate procedures and taking relevant considerations into account. Whether the focus is on the benefit or the cost determines the categorization of criteria. This distinction is important as each category of criterion and technique exhibits distinct commonalities in the normalization process.

4.1 MOORA

Table 12: Maximax and min-max

Everything	**Industrial Location**	**Max**	**Min**	**Yi (Max-Min)**
A1	Bukit Semarang Baru	0.05	0.38	-0.336
A2	Guna Mekar Indonesia	0.02	0.11	-0.089
A3	Candi	0.13	0.21	-0.074
A4	Terboyo	0.13	0.23	-0.091
A5	Wijayakusuma	0.02	0.14	-0.126

Table 13: Validation results with spearman rank

Area	**MOOR**	**Priority (DPMPTSP)**
Bukit Semarang Baru	5	5
Guna Mekar Indonesia	2	3
Candi	3	2
Terboyo	1	1
Wijayakusuma	4	4
Validation: *Spearman Rank*		0.9

The Yi value presented in Table 12 represents the ultimate value derived using the MOORA approach, which serves as a point of reference in the alternative equation. According to the findings of the MOORA approach, it has been determined that the A3 alternative exhibits the highest value, therefore making it the most favorable option. The observed Yi value is negative due to a higher count of criteria falling under the cost category compared to the benefit category. The determination of the highest value is contingent upon the subtraction of the lowest negative value. The present study focuses on the validation procedure utilizing secondary area priority data obtained from the DPMPTSP

(Department of Investment and Integrated Services) of Semarang City. The explanation for the study is that the validation process was conducted using Spearman Rank correlation analysis to compare the results obtained from the MOORA approach with the secondary priority data (DPMPTSP). This validation is presented in Table 13. The obtained correlation coefficient is 0.9, indicating a strong positive relationship between the rankings generated by the MOORA technique and the priority assigned to the secondary data of the DPMPTSP. This is demonstrated in alternatives 2 and 3, which encompass distinct rankings. The correlation coefficient of 0.9 suggests a strong alignment between the Moora approach and the actual determination of priority industry locations.

4.2 WASPAS

Table 14: Results of the WASPAS method

Everything	Industrial Location	WSM	WPM	Qi	Rank
A1	Bukit Semarang Baru	0.3	0.000	0.2	5
A2	Guna Mekar Indonesia	0.6	0.000	0.3	3
A3	Candi	0.5	0.337	0.4	2
A4	Terboyo	0.7	0.453	0.6	1
A5	Wijayakusuma	0.4	0.000	0.2	4

Table 15: Calculation of correlation rank spearman

Area	MOOR	Priority (DPMPTSP)
Bukit Semarang Baru	5	5
Guna Mekar Indonesia	3	3
Candi	2	2
Terboyo	1	1
Wijayakusuma	4	4
Validation: *Spearman Rank*		1.00

The WASPAS approach uses the value of Qi as the measurement's rejection criterion. The Qi value is derived from the WSM and WPM values associated with each choice. The results of the WASPAS approach are presented in Table 14. According to the analysis, the Terboyo Industry Location, also known as WASPAS, Alternative 4, is identified as the industry location with the highest priority. The Candi Industry Locations, which have priority 2, follow it. The subsequent step involves doing a comparative analysis between the results generated by the WASPAS technique and the actual data priority acquired from the DPMPTSP website. The Spearman Rank correlation computation yielded a correlation value of 1, as shown in Table 15. The data indicates that the ranking results obtained from the WASPAS approach are equivalent to the priority assigned to the industry location. According to the findings of the industry location priority study, the Waspas technique reveals that the alternatives have equal rankings.

Table 16: Results of the ARAS method

Everything	Industrial Location	Σij	To	Rank
A0		0.293604		
A1	Bukit Semarang Baru	0.149254	0.50835	3
A2	Guna Mekar Indonesia	0.196891	0.67060	1
A3	Candi	0.151470	0.51590	2
A4	Terboyo	0.135536	0.46163	4
A5	Wijayakusuma	0.121300	0.41314	5

Table 17: Calculation of correlation rank spearman

Area	MOOR	Priority (DPMPTSP)
Bukit Semarang Baru	3	5
Guna Mekar Indonesia	1	3
Candi	2	2
Terboyo	4	1
Wijayakusuma	5	4
Validation: *Spearman Rank*		0.10

4.3 ARAS

The Ki value serves as the comparative metric in the ARAS approach. The ARAS Method incorporates a distinction in the inclusion of either a zero alternative value or an ideal alternative. Table 16 presents the computed Ki values. The findings presented in Table 16 illustrate the outcomes of the comparison conducted using the ARAS technique. In this analysis, the Mekar Indonesia Usage Location, also referred to as Alternative 2, is identified as an industrial location with the highest priority. Following this, the Candi Industry Location is assigned the second highest priority. The subsequent step involves conducting a comparison between the outcomes derived from the ARAS method computation and the factual data priorities acquired from the DPMPTSP website. The Spearman Rank Correlation technique is utilized to compare the rank output of the Aras technique. The findings presented in Table 17 demonstrate the outcomes of a validation process using the Spearman Rank correlation method. This validation involved a comparison between the outputs of the ARAS model and the secondary priority data (DPMPTSP). The obtained correlation coefficient is 0.1. This suggests that the output of ARAS can be characterized as not aligning with the secondary factual data of DPMPSP. The ranking findings are consistent only for alternative 3, but the distances for the other alternatives are significantly different.

4.4 COPRAS

The COPRAS approach utilizes the Ui value as the final calculation. The Ki value calculation result is presented in Table 18. autoreftab18 presents the COPRAS method calculations, illustrating the prioritization of locations for the use of Mekar Indonesia or alternative 2. The analysis reveals that the industrial location holds the highest priority, denoted as primary priority, while the Terboyo industry location holds the second highest priority, denoted as priority 2. The subsequent step involves doing a comparison between the

Table 18: Results of the COPRAS method

Everything	Industrial Location	Ui	Rank
A1	Bukit Semarang Baru	0.31200	5
A2	Guna Mekar Indonesia	1.00000	1
A3	Candi	0.76000	4
A4	Terboyo	0.92100	2
A5	Wijayakusuma	0.79300	3

Table 19: Calculation of correlation rank spearman

Area	MOOR	Priority (DPMPTSP)
Bukit Semarang Baru	5	5
Guna Mekar Indonesia	1	3
Candi	4	2
Terboyo	2	1
Wijayakusuma	3	4
Validation: *Spearman Rank*		0.50

output generated by the Copras technique and the actual data priority acquired from the DPMPTSP online page. Table 19 shows The Spearman Rank Correlation method is used to compare the ranking results of the Copras method, specifically the Dominance-based Rough Set Approach to Multi-Attribute Decision Making with Probabilistic Rough Numbers (DPMPTSP). The obtained correlation coefficient is 0.5. This observation suggests that the COPRAS approach may yield outputs that exhibit lower levels of consistency with the secondary fact data of DPMPTSP. However, other possibilities have relatively short distances that are not strongly connected.

4.5 AHP

Table 20: Results of the AHP method

Everything	Industrial Location	AHP	Rank
A1	Bukit Semarang Baru	0.3	5
A2	Guna Mekar Indonesia	0.6	2
A3	Candi	0.5	3
A4	Terboyo	0.7	1
A5	Wijayakusuma	0.4	4

The Analytic Hierarchy Process (AHP) employs a distinct procedural approach in comparison to the preceding MCDM method. The initial step involves assessing the assessment of the relative importance of each criterion and then calculating the Consistency Ratio (CR) value, yielding a result of 0.9. The observed weight has a level of consistency that does not exceed 0.10. Subsequently, the procedure advances to the computation of the normalization of the weighted matrix and the assessment of its aggregate. The table presents the outcomes derived from the use of the Analytic Hierarchy Process (AHP) methodology.Table 20 shows the results of the comparisons using the analytic hierarchy process (AHP) method, focusing

Table 21: Calculation of correlation rank spearman

Area	**MOOR**	**Priority (DPMPTSP)**
Bukit Semarang Baru	5	5
Guna Mekar Indonesia	2	3
Candi	3	2
Terboyo	1	1
Wijayakusuma	4	4
Validation: *Spearman Rank*		0.90

on the Terboyo location, or alternative 2, which is called an industrial location with primary priority. The subsequent step involves doing a comparative analysis between the outcomes derived from the Analytic Hierarchy Process (AHP) computation and the factual priority data acquired from the DPMPTSP website. The Spearman Rank Correlation Method is utilized to compare the rank results obtained using the AHP Method.

Table 21 presents the outcomes of the validation process using the Spearman Rank correlation approach. This validation involved comparing the results obtained through the Analytic Hierarchy Process (AHP) with the secondary data on priority received from the Department of Planning, Monitoring, and Evaluation of Regional Development (DPMPTSP). The obtained correlation coefficient is 0.9. This suggests that the Analytic Hierarchy Process (AHP) method demonstrates a correspondence with the secondary factual data of the Directorate General of Regional Autonomy and Local Government Administration (DPMPTSP). The correlations exhibit a strong positive association, approaching a value of 1, between two alternatives that possess distinct ranks.

5 Discussion

The Spearman Rank correlation value exhibits considerable variability for both the MOORA method and the AHP method, with a correlation value of 0.9 for both methods. The WASPAS approach emerges as the method exhibiting the highest correlation value, which is equal to 1. The COPRAS approach exhibits a somewhat lower correlation value of 0.5, whereas the ARAS method demonstrates a correlation value of 0.1. Presented here is a comprehensive graphic illustrating the hierarchical arrangement of the Multiple Criteria Decision Making (MCDM) methods, together with the accompanying secondary empirical data about the Dynamic Programming Multi-Objective Traveling Salesman Problem (DPMPTSP).

Figure 8 illustrates the disparities denoted by each approach to alternatives 3 and 4, wherein the distances yield diminished correlation values. Figure 9 shows that based on the Spearman Rank correlation values, it can be shown that three approaches, namely WASPAS, MOORA, and AHP, exhibit strong performance with correlation coefficients over 0.8. So, we can conclude that the Multi-Criteria Decision Making (MCDM) method, which involves adding up the weighted normalization matrix, works well in this situation. Methods that incorporate additional comparative phases, such as ARAS and COPRAS, exhibit suboptimal performance.

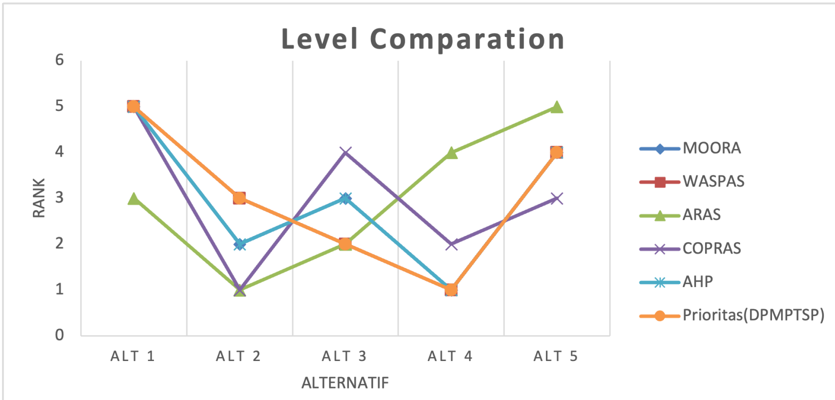

Figure 8: Comparison result.

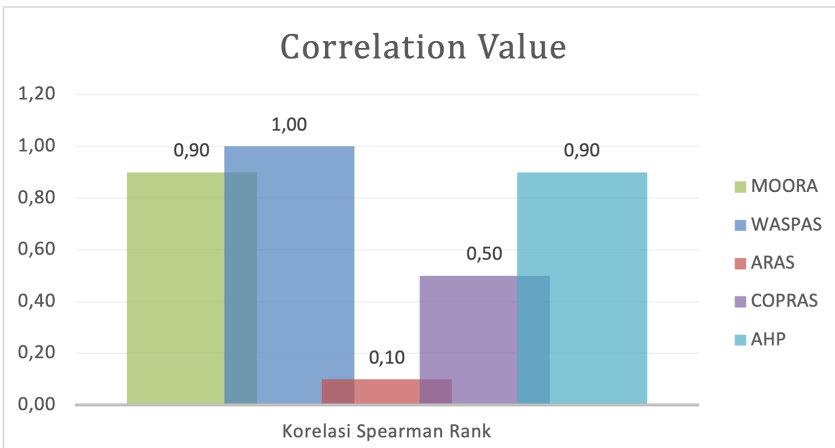

Figure 9: Correlation value.

6 Conclusion

The study's result pertains to the evaluation of the efficacy of the MCDM method in ascertaining the prioritization of industrial location development. WASPAS, MOORA, and AHP approaches have strong performance. Conversely, methods incorporating supplementary comparison stages, such as ARAS and COPRAS, demonstrate inferior performance. In comparing different MCDM methods, it is common to observe varying results due to differences in the underlying principles and processes of each method. When a method that uses utility aggregation yields better results compared to a method that relies on optimal value comparisons, it is important to understand the reasons behind this difference. The performance of the MCDM approach in this example is commendable, as it effectively measures the aggregation of the weighted normalization matrix. This study proposes that the geographical data of an industrial region should be considered as an area rather than a single point to facilitate efficient search and analysis of the area. Furthermore, it is important to consider criteria that have comprehensive data support, such as electrical and communications networks, as well as flood-prone areas, when determining the optimal location for an industry. Additionally, the application of AHP methods can be considered a potential approach to the grinding method. This combination of grinding and grading methods could serve as a promising research topic. For a researcher, comparing multiple MCDM methods can lead to significant intellectual satisfaction such as knowledge expansion and analytical skill enhancement.

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