Journal of Administrative Science
Vol.22, Issue 1, 2025, pp.34-46
Available online at *http:jas.uitm.edu.my*

The Graphical Representation of Clothing Store Location and Its Application with Potential Method

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Abstract

Multi-criteria Decision Making (MCDM) is a widely utilized approach for addressing decision problems by assessing pairwise comparisons of alternatives. MCDM involves evaluating various elements as input and deriving weighted outcomes for each alternative. The Analytic Hierarchy Process (AHP) and Potential Method (PM) are two examples of tools within MCDM. The PM employs a directed graph known as a preference, generated through paired comparisons, to establish a value function for the set of alternatives. In this study, PM is applied to the store location selection problem, with AHP already providing results. The objective is to demonstrate the use of PM in decision-making. The obtained results are then compared, revealing similar rankings for alternatives between the two methods. Consequently, PM is deemed comparable to AHP in effectively addressing real-life problems with multiple criteria.

***Keywords**: Decision making, Multicriteria decision making, Analytic hierarchy process, Potential method*

INTRODUCTION

Received: 1 February 2025
Accepted: 1 March 2025
Published: 30 April 2025

In decision-making, identifying and selecting alternatives based on decision-maker preferences is crucial. Decisions involve considering various possibilities and choosing the option that aligns best with objectives, goals, preferences, and values (Panpatte and Takale, 2019). Multi Criteria Decision Making (MCDM) is a mathematical approach that provides tools and methodologies for decision-makers dealing with complex scenarios involving multiple criteria. Two prominent tools in MCDM to be discussed in this study are Analytic Hierarchy Process (AHP) and Potential Method (PM). The AHP, help in selecting the best alternatives by establishing ideal criteria. The AHP was introduced by Saaty in 1980 as a solution for multi-criteria decision problems (MCDMs). According to Canco et al. (2021), this approach has the benefit of efficiently managing both qualitative and quantitative data. AHP provides decision-makers with a tool to comprehend the structure of decision-

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making models, particularly for complex tasks involving subjective assessments (Guillén-Mena et al., 2023). AHP uses several levels of hierarchy, including objectives, criteria, attributes, and alternatives, to address complex problems (Terzi, 2019).

LITERATURE REVIEW

The Potential Method is a decision-making technique that utilizes graph called a "Preference graph". The preference graph is used to illustrate pairwise comparisons between alternatives (Čaklović and Kurdija, 2017). Let V present a collection of alternatives, where certain preferences are appropriately considered. The representation involves directed edges from vertex v to vertex u, indicating that alternative u is favored over alternative v (denoted as $u > v$). This relationship is visually represented in Figure 1, with the directed edge denoted by (u,v).

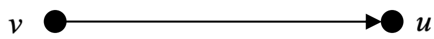

Figure 1: An alternative u is favored than alternative v
Source: Mamat et al. (2019)

The directed edge from v to u has a value, which is weight, and is denoted by $F_{(u,v)}$ if the preference is given with an intensity, such as equal, weak, moderate, strong, or absolute preferred. The direction of the edge is unnecessary if there is an equal preference (denoted by u, v), in which case $F_{(u,v)} = 0$, and edge (u,v) can be replaced by (v,u). The preference graph is characterized by the absence of loops and parallel edges. It can have at most $\binom{n}{2}$ edges (Čaklović and Radas, 2014). The definition of a preference graph is given in Definition 1 and some instances of preference graphs are illustrated in Figure 2.

Definition 1 (Čaklović & Kurdija, 2017)

A preference graph is a triple $G = (V, A, F)$ where V is a set of $n \in \bullet$ vertices, $A \subseteq V \times V$ is a set of directed edges, and $F : A \to \sim$ is a preference flow which maps

eISSN 2600-9374

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each edge (u, v) to the corresponding intensity $F_{(u,v)}$.

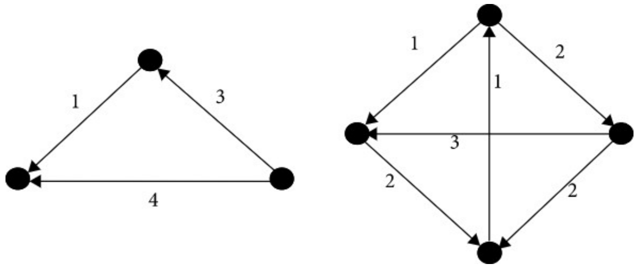

Figure 2: Preference graphs

Weightage by Potential Method

The following are the steps to determine weights and ranks by PM.

Step 1 : Build a preference graph $G = (V, E, F)$ for a given problem.

Step 2 : Construct incidence, A and flow difference, F matrices. An $m \times n$ incidence matrix is given by

$$A_{\alpha,v} = \begin{cases} -1, & \text{if the edge } \alpha \text{ leaves } v \\ 1, & \text{if the edge } \alpha \text{ enters } v \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

Step 3 : Build the Laplacian matrix, L. The Laplacian matrix is $L = A^T A$ with entries define as

$$L_{i,j} = \begin{cases} -1, & \text{if the edge } (i, j) \text{ or } (j, i), \\ \deg(i), & \text{if } i = j, \\ 0, & \text{else.} \end{cases} \tag{2}$$

such that $\deg(i)$ is the degree of vertex i.

Step 4 : Generate the flow difference, ∇. Let the flow difference be $\nabla := A^T F$. The component of ∇ is determined as below.

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$$\begin{aligned}\nabla_v &= \sum_{\alpha=1}^{m} A^T_{v.\alpha} F_\alpha \\ &= \sum_{\alpha \text{ enters } v} F_\alpha - \sum_{\alpha \text{ leaves } v} F_\alpha\end{aligned} \tag{3}$$

whereby ∇_v is the difference between the total flow which enters v and the total flow which leaves v.

Step 5 : Determine potential, X. Potential , X is a solution of the Laplacian system

$$LX = \nabla \tag{4}$$

such that $\sum X_v = 0$ on its connected components.

Step 6 : Check the consistency degree, $\beta < 12^\circ$. The measure of inconsistency is defined as

$$\text{Inc}(F) = \frac{\|F - AX\|_2}{\|AX\|_2} \tag{5}$$

where $\| . \|_2$ denotes 2-norm and $\beta = \arctan\left(\text{Inc}\left(F\right)\right)$ is the angle of inconsistency. The ranking is considered acceptable whenever $\beta < 12^\circ$.

Step 7 : Determine the weight, w. The following equation is used to obtain the weight.

$$w = \frac{a^X}{\|a^X\|_1} \tag{6}$$

where $\| . \|_1$ represents l_1-norm and parameter a is choosen to be 2 as suggested by Čaklović (2003).

Step 8 : Rank the objects by their associated weights.
Rank 1 is assigned to the object with the greatest weight, followed by the object with the second-highest weight, and the object with the least weight is placed last in the ranking.

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IMPLEMENTATION

Akalin et al. (2013) have to choose the optimal store location for the scenario depicted in Figure 3. The store location is evaluated based on four criteria: Population (C1), Retail Settlement (C2), Costs (C3), and Competition (C4). A total of 13 subcriterion must be taken into account in addressing this problem. The available alternatives are designated as A1 (Umraniye), A2 (Eskisehir Merkez), and A3 (Bodrum).

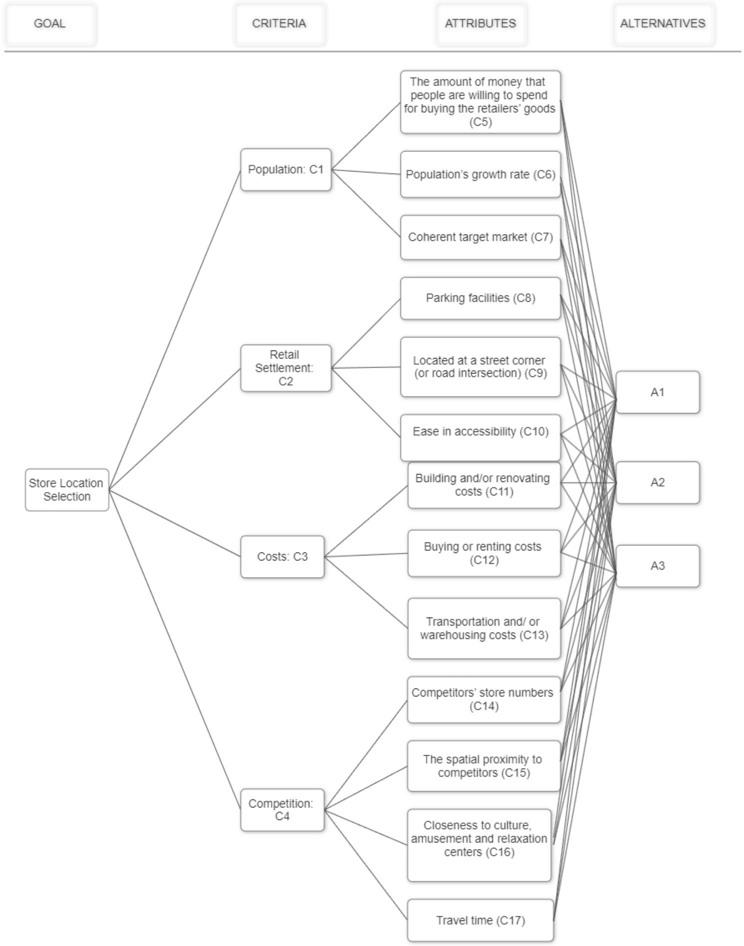

Figure 3: The hierarchical structure of store location selection
Sources: Akalin et al. (2013)

eISSN 2600-9374

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Weight Determination: Criteria

Analyzing the criteria level is the first step in dealing with hierarchical decision-making. The pairwise comparison matrix criteria of Table 1 are transformed into an information preference graph, as shown in Figure 4.

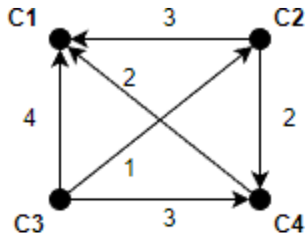

Figure 4: Preference Graph for the Criteria

The incidence matrix A and flow difference matrix F are derived using Equation 1, while the Laplacian matrix, L is computed using Equation 2, as outlined follows

$$A=\begin{bmatrix}1 & -1 & 0 & 0\\ 1 & 0 & -1 & 0\\ 1 & 0 & 0 & -1\\ 0 & 1 & -1 & 0\\ 0 & -1 & 0 & 1\\ 0 & 0 & -1 & 1\end{bmatrix},\ F=\begin{bmatrix}3\\4\\2\\1\\2\\3\end{bmatrix},\ \text{and}\ L=\begin{bmatrix}3 & -1 & -1 & -1\\ -1 & 3 & -1 & -1\\ -1 & -1 & 3 & -1\\ -1 & -1 & -1 & 3\end{bmatrix}$$

By employing Equation 3, the flow difference, ∇ is determined, and by utilizing Equation 4, the potential, X is provided as follows.

$$\nabla=\begin{bmatrix}9\\-8\\-4\\3\end{bmatrix},\ X=\begin{bmatrix}9/4\\-2\\-1\\3/4\end{bmatrix}$$

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The consistency degree, $\beta = 6.19^{\circ} < 12^{\circ}$ is generated using Equation 5. It is found that the matrix of criteria is consistent. Finally, the weight, w is calculated using Equation 6.

$$w_{C1} = \frac{2^{9/4}}{(2^{9/4} + 2^{-1} + 2^{-2} + 2^{3/4})} = 0.6617$$

$$w_{C2} = \frac{2^{-1}}{(2^{9/4} + 2^{-1} + 2^{-2} + 2^{3/4})} = 0.0696$$

$$w_{C3} = \frac{2^{-2}}{(2^{9/4} + 2^{-1} + 2^{-2} + 2^{3/4})} = 0.0348$$

$$w_{C4} = \frac{2^{3/4}}{(2^{9/4} + 2^{-1} + 2^{-2} + 2^{3/4})} = 0.2340$$

Table 1 presents the calculated weight of the criteria using PM. The result obtained through AHP (Akalin et al., 2013) are listed alongside the PM.

Table 1: *Matrix Comparison of Criteria*

Goal: Selection Criteria of Retail Store Location	C1	C2	C3	C4	AHP	Rank	PM	Rank
Population (C1)	1	4	5	3	0.526	1	0.6617	1
Retail Settlement (C2)	1/4	1	2	1/3	0.124	3	0.0696	3
Costs (C3)	1/5	1/2	1	1/4	0.077	4	0.0348	4
Competition (C4)	1/3	3	4	1	0.272	2	0.2340	2

Weight Determination: Subcriteria

Figure 5 is the preference graph that transform information from Table 2 show the pairwise comparison matrix criteria C1.

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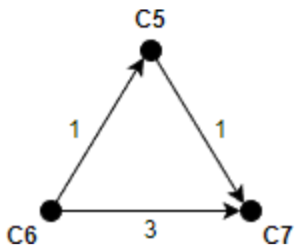

Figure 5: Preference Graph for Subcriteria of C1

Then, the weight of subcriteria with respect to C1 are presented as in Table 2.

Table 2: *Matrix Comparison of Subcriteria C1*

Attributes of Population (C1)	C5	C6	C7	AHP	Rank	PM	Rank
C5	1	2	1/2	0.214	2	0.2553	2
C6	1/2	1	1/4	0.107	3	0.1013	3
C7	2	4	1	0.429	1	0.6434	1

Weight Determination: Alternatives for criteria C1

Figure 6 is the preference graph that transform information from Table 3 which show the comparison matrix for alternatives using pairwise comparison matrix criteria C1.

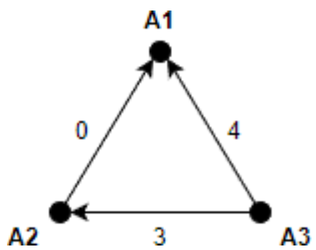

Figure 6: Preference graph for alternatives for C1

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Table 3: *Matrix Comparison of Alternatives for Criteria C1*

Alternatives	A1	A2	A3	AHP	Rank	PM	Rank
A1	1	1	5	0.350	1	0.5341	1
A2	1	1	4	0.325	2	0.4239	2
A3	1/5	1/4	1	0.075	3	0.0421	3

Weight Determination: Alternatives for Subcriteria C5

Figure 7 is the preference graph that transform information from Table 4 which show the pairwise comparison matrix for the alternative concerning subcriteria C5.

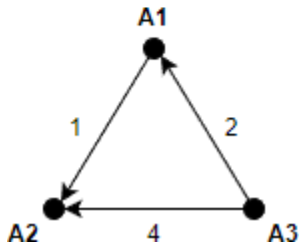

Figure 7: Preference Graph for Alternatives for C5

Table 4: *Matrix Comparison of Alternatives for Criteria C5*

Alternatives	A1	A2	A3	AHP	Rank	PM	Rank
A1	1	1/2	3	0.232	2	0.2689	2
A2	2	1	5	0.436	1	0.6777	1
A3	1/3	1/5	1	0.082	3	0.0534	3

The Global Weight: The Main Goal

Once the weights are determined, the optimization of the final ranking will be made to find the best alternatives and then compare with the result obtained from AHP. To get the final result, first is multiplying the weight of criteria corresponding to its sub-criteria to get local weightage as shown in Table 5.

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Table 5: *Local Weightage of Criteria Concerning the Subcriteria*

Criteria / Sub-criteria	C1 (0.6617)	C2 (0.0696)	C3 (0.0348)	C4 (0.2340)	Local	Rank
C5	0.2553	-	-	-	0.1689	2
C6	0.1013	-	-	-	0.0670	4
C7	0.6434	-	-	-	0.4257	1
C8	-	0.1013	-	-	0.0071	9
C9	-	0.6434	-	-	0.0448	5
C10	-	0.2553	-	-	0.0178	8
C11	-	-	0.1554	-	0.0054	10
C12	-	-	0.7830	-	0.0272	6
C13	-	-	0.0617	-	0.0021	11
C14	-	-	-	0.3077	0.0720	3
C15	-	-	-	0.3077	0.0720	3
C16	-	-	-	0.0769	0.0180	7
C17	-	-	-	0.3077	0.0720	3

Then, the global weightage value is obtained by multiplying local weightage in Table 6 with the corresponding value of the alternatives. After getting the value, global weight is determined by summarizing all value within the alternatives. Table 6 show the global weightage and final ranking using PM.

Table 6: *Global Weightage of Alternatives with Respect to the Sub-criteria*

Alternatives / Sub-criteria	A1	A2	A3
C5	0.0454	0.1145	0.0090
C6	0.0454	0.0180	0.0036
C7	0.2064	0.2064	0.0129
C8	0.0024	0.0024	0.0024
C9	0.0438	0.0006	0.0003
C10	0.0014	0.0022	0.0142
C11	0.0015	0.0037	0.0003
C12	0.0042	0.0213	0.0017

eISSN 2600-9374

C13	0.0016	0.0003	0.0001
C14	0.0488	0.0194	0.0038
C15	0.0606	0.0076	0.0038
C16	0.0092	0.0073	0.0015
C17	0.0044	0.0112	0.0564
Global weight	0.4751	0.4149	0.0917
Final Ranking	1	2	3

CONCLUSION

The comparison of final results between PM and AHP is presented in Table 7. According to the PM analysis, the highest weight is assigned to A1 (0.4751), followed by A2 (0.4149), with A3 receiving the lowest weight (0.0917). Similarly, AHP results also indicate that A1 has the highest weight (0.126), followed by A2 (0.070), and A3 with the lowest weight (0.016). Consequently, the consistent alignment of weights between PM and AHP affirms the final ranking as A1>A2>A3 for the alternatives.

Table 7: *Comparison of Weight and Ranking between PM and AHP*

Alternatives	AHP	Rank	PM	Rank
A1	0.126	1	0.4751	1
A2	0.070	2	0.4149	2
A3	0.016	3	0.0917	3

The results from PM demonstrate consistency, aligning with the outcomes from AHP. In conclusion, PM is emphasized for its effectiveness in tackling store location problem and can further be applied to decision-making involving multiple criteria.

The AHP and PM provide an effective decision-making frameworks in complex and multi criteria situations, such as store location selection. AHP prioritizes factor by structuring the problem into quantitative comparisons, while PM highlights these comparisons with a directed graph that clearly illustrates the relationship between criteria. Futhermore, the graphical representation by PM improves clarity, which allows decision makers to visualize how some factors are depend on or lead into other factors, which facilitates better and faster decisions. By demonstrating its compatibility with well-known methodologies such as AHP and its flexibility for ranking, the PM becomes

eISSN 2600-9374

a tool to enhance the quality and confidence of decisions in the context of store location selection and beyond.

Acknowledgements

The authors gratefully acknowledge the Universiti Teknologi MARA Shah Alam. The authors extend their heartfelt gratitude to the reviewers for their invaluable and insightful suggestions.

Funding

No funding

Author contributions

Khairunnisha Amira Johar, Mohammad Adam Hafiz Nor Mohd Amin, Muhammad Fared Tuah conceived and planned the experiments. They carried out the experiments and simulations. Siti Salwana Mamat contributed to the interpretation of the results and took the lead in writing the manuscript.

Conflict of interest

The authors affirm that there are no conflicts of interest related to the subject matter or materials discussed in this manuscript.

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eISSN 2600-9374