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A COMPARATIVE ANALYSIS OF MCDM METHODS BASED ON PAIRWISE COMPARISON: AHP, BWM AND FUCOM

Petra Grošelj[*], Gregor Dolinar

University of Ljubljana, Biotechnical Faculty, Slovenia

Abstract: MCDM methods based on pairwise comparisons are widely used to determine the weights of alternatives and criteria in complex problems. In this paper, we compare three of these methods: Analytic Hierarchy Process (AHP), Best-Worst method (BWM) and Full Consistency Method (FUCOM). We compared the number of pairwise comparisons required and the amount of information provided by the experts as well as the consistency of the judgments. The data came from a study on the ranking of driving parameters of business and production management in small and medium-sized enterprises. The results show that AHP with the higher requirement of pairwise comparisons also leads to very reliable weights, while a lower number of pairwise comparisons in BWM and FUCOM, as appealing as it is to the experts, could significantly reduce the input data and decisively influence the ranking of items. Our study also disproves the statement repeatedly found in the literature that BWM is more consistent than AHP due to the lower number of pairwise comparisons required. Rather, we have pointed out the problem of measuring inconsistency in BWM. For FUCOM, we have provided explicit formulas for calculating the weights.

Keywords: Multi-criteria decision making, Pairwise comparisons, Analytic Hierarchy Process, Best-Worst method, Full Consistency Method

1. INTRODUCTION

To analyze complex decision problems, multi-criteria decision-making (MCDM) provides a structured approach to evaluate and rank alternatives based on multiple, often conflicting criteria. MCDM encompasses a wide range of mathematical techniques to support decision-makers in various fields including engineering, environmental management, business, logistics, and healthcare (Sahoo & Goswami, 2023).

[*] *Corresponding author: petra.groselj@bf.uni-lj.si*

Petra Grošelj, ORCID: 0000-0001-9363-9783
Gregor Dolinar, ORCID: 0000-0001-9106-3995

In our study, we focused on pairwise comparison-based methods, in which judgments are obtained by comparing two items simultaneously. They are frequently used in practice because they are intuitively structured, place relatively low cognitive demands on the decision maker and can capture the relative importance of items. One of the well-known and most widely used methods is Analytic Hierarchy Process (AHP), which was introduced by Saaty (1980). It uses a complete set of pairwise comparisons between all items to derive their weights and includes a consistency check to assess the reliability of the judgments. While AHP provides a structured and robust framework, its reliance on numerous comparisons, especially in problems with a large number of elements to compare, can lead to increased decision maker fatigue and consequently inconsistency.

Several methods have been developed to overcome the limitations of the AHP. The Best-Worst Method (BWM) proposed by Rezaei (2015) reduces the cognitive load on decision makers by asking them to identify the best and worst elements, and then evaluate the other elements in comparison to these. This reduces the number of judgments required compared to AHP and, according to Rezaei (2015), provides more consistent comparisons.

Another more recent method based on pairwise comparison is the Full Consistency Method (FUCOM) developed by Pamučar et al. (2018), which further simplifies the comparison process by enforcing transitivity and ensuring consistency by focusing on only one set of pairwise comparisons, e.g. the best element with others or each element with the next most important element.

Beyond these methods several other methods also incorporate pairwise comparisons. For instance, PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) is an outranking method that uses pairwise comparisons of alternatives regarding the criteria (Behzadian et al., 2010). Furthermore, DEMATEL (Decision-Making Trial and Evaluation Laboratory) uses pairwise comparisons to model interdependencies among criteria, often as a pre-processing step in hybrid MCDM approaches (Si et al., 2018).

The aim of this study is a comparative analysis of three MCDM methods based on pairwise comparisons: AHP, BWM and FUCOM. Despite the large number of studies using at least two of the selected methods (Akbari et al., 2021; AL-Juaidi, 2025; Ekin & Sarul, 2022; Fazeli & Peng, 2023; Srdjevic et al., 2022), comprehensive comparisons between them are still limited, especially in terms of their efficiency, consistency assessment and practical applicability. The present study aims to fill this gap by systematically comparing AHP, BWM and FUCOM using a decision problem involving the ranking of driving parameters of business and production management in small and medium-sized enterprises (Jelačić et al., 2021). By analyzing the results, we provide insights into their theoretical and computational aspects as well as the interpretability of the results. We also provide the formulas for calculating the explicit solution for the derivation of weights in FUCOM.

2. DATA AND METHODOLOGY

2.1. Analytic hierarchy process

In the AHP, all pairs of items are compared using Saaty's ratio 1-9 scale. The pairwise comparison matrix A summarizes all pairwise comparisons:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}. \tag{1}$$

The vector of weights $w = (w_1, w_2, ..., w_n)$ can be derived from *A* using the eigenvector method:

$$Aw = \lambda_{\max} w, \tag{2}$$

where $\lambda_{\max}$ denotes the principal eigenvalue of the pairwise comparison matrix *A*. The consistency of the pairwise comparisons is measured by consistency ratio CR, the ratio between the consistency index (CI) and the random index (RI):

$$CR = \frac{CI}{RI};\ CI = \frac{\lambda_{\max} - n}{n-1}. \tag{3}$$

In this study (Jelačić et al., 2021), CR<0.15 was considered acceptable.

2.2. Best-worst method

BWM consists of five steps. Step 1-2: Select the best (most important) (B) and the worst (least important) (W) element from the set of *n* evaluated elements. Step 3-4: Determine the preferences of the best element over all other elements using the 1-9 scale and collect the results in the best-to-others vector $(a_{B1}, a_{B2}, ..., a_{Bn})$. Determine the preferences of all other elements over the worst element using the 1-9 scale and collect the results in the others-to-worst vector $(a_{1W}, a_{2W}, ..., a_{nW})$. Step 5: Determine the weights of elements by solving the optimization model. We have chosen the linear model (Rezaei, 2016):

$$\begin{aligned} &\min \xi \\ &\text{s.t. } \left| w_B - a_{Bj} w_j \right| \le \xi, \text{ for all } j \\ &\qquad \left| w_j - a_{jW} w_W \right| \le \xi, \text{ for all } j \\ &\qquad \sum_j w_j = 1,\ w_j \ge 0, \text{ for all } j \end{aligned} \tag{4}$$

The consistency of judgments can be measured by the output-based consistency measure ξ or by the input-based CR, where the threshold for acceptable consistency depends on the value of the pairwise comparison a_{BW} (Liang et al., 2020).

$$CR = \max_j CR_j, \text{ where } CR_j = \begin{cases} \dfrac{\left| a_{Bj} a_{jW} - a_{BW} \right|}{a_{BW}^2 - a_{BW}}, & a_{BW} > 1 \\ 0, & a_{BW} = 1 \end{cases}. \tag{5}$$

2.3. Full consistency method

The first step in FUCOM method is ranking the elements according to their importance. The second step is comparison of the ranked elements. In our study we used the comparisons of the most important element to all others. On the basis of these pairwise comparisons the comparative priorities of sequentially ranked elements $\varphi_{k/(k+1)},\ k=1,...,n$ are calculated. In the third step the weights of elements are calculated by the following model:

$$\begin{aligned}
&\min \chi \\
&\text{s.t. } \left|\frac{w_k}{w_{k+1}}-\varphi_{k/(k+1)}\right| \leq \chi,\ \text{for all } k \\
&\left|\frac{w_k}{w_{k+2}}-\varphi_{k/(k+1)}\varphi_{(k+1)/(k+2)}\right| \leq \chi,\ \text{for all } k \\
&\sum_{k=1}^{n} w_k = 1,\ w_k \geq 0,\ \text{for all } k
\end{aligned} \tag{6}$$

2.4. Data

One of the objectives of the study Sustainable Production Management Model for Small and Medium Enterprises in Some South-Central EU Countries (Jelačić et al., 2021) was to rank seven driving parameters of the business and production management system in small and medium enterprises of wood processing and furniture manufacturing in a time of disrupted market situation due to the global COVID-19 pandemic. The selected driving parameters were:

- LPOSC–Leadership, Policy, and Organizational Structure of the Company
- PCMPPD–Process Culture, Management Processes, and Production Deadlines
- RPQP–Range of Products and Quality of Products
- MMAC–Marketing and Market Activities of the Company
- HR–Human Resources
- ITMPT–Information Technology and Modern Production Technology
- EFP–Environmentally friendly production.

Twenty experts in wood processing and furniture manufacturing from Slovenia and Croatia from the fields of management, production and marketing evaluate them using AHP method.

For the derivation of weights by BWM, the parameter with the highest weight in AHP was chosen as the best and the parameter with the lowest weight in AHP as the worst. Then pairwise comparisons from AHP of these two parameters with the others were used to calculate their weights. For the derivation of weights by FUCOM, the judgments of best to others parameters already used in BWM were used.

3. RESULTS

3.1. The solution of the model in FUCOM

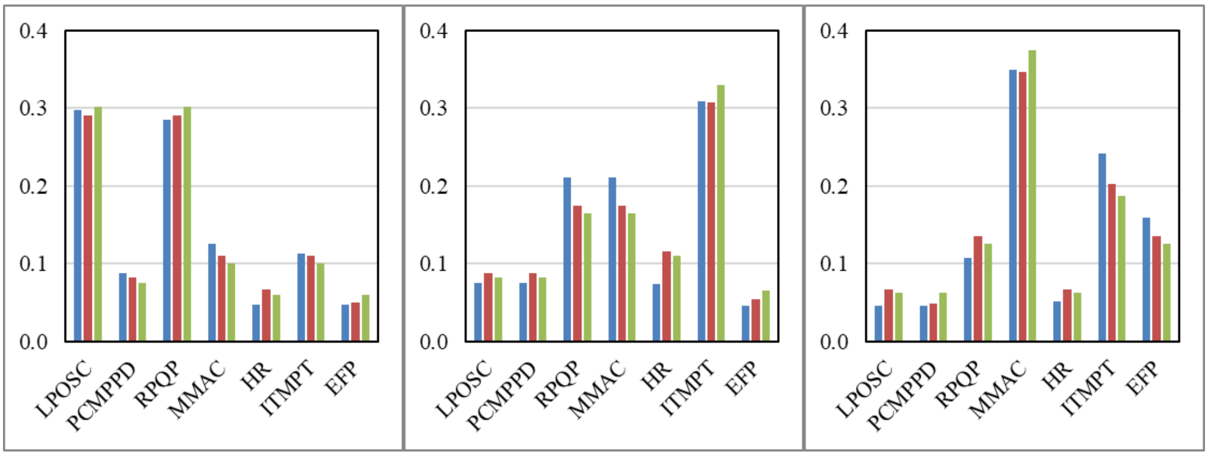
When real numbers are used for pairwise comparisons in FUCOM, the solution of the model (6) is $\chi = 0$ and the weights of the elements can be calculated explicitly, without having to solve a nonlinear model. The weights $w_1, w_2, ..., w_n$ of the elements $E_1 \pm E_2 \pm E_3 \pm \because \pm E_n$, where $\pm$ indicates "is equally important or more important" can be calculated as follows:

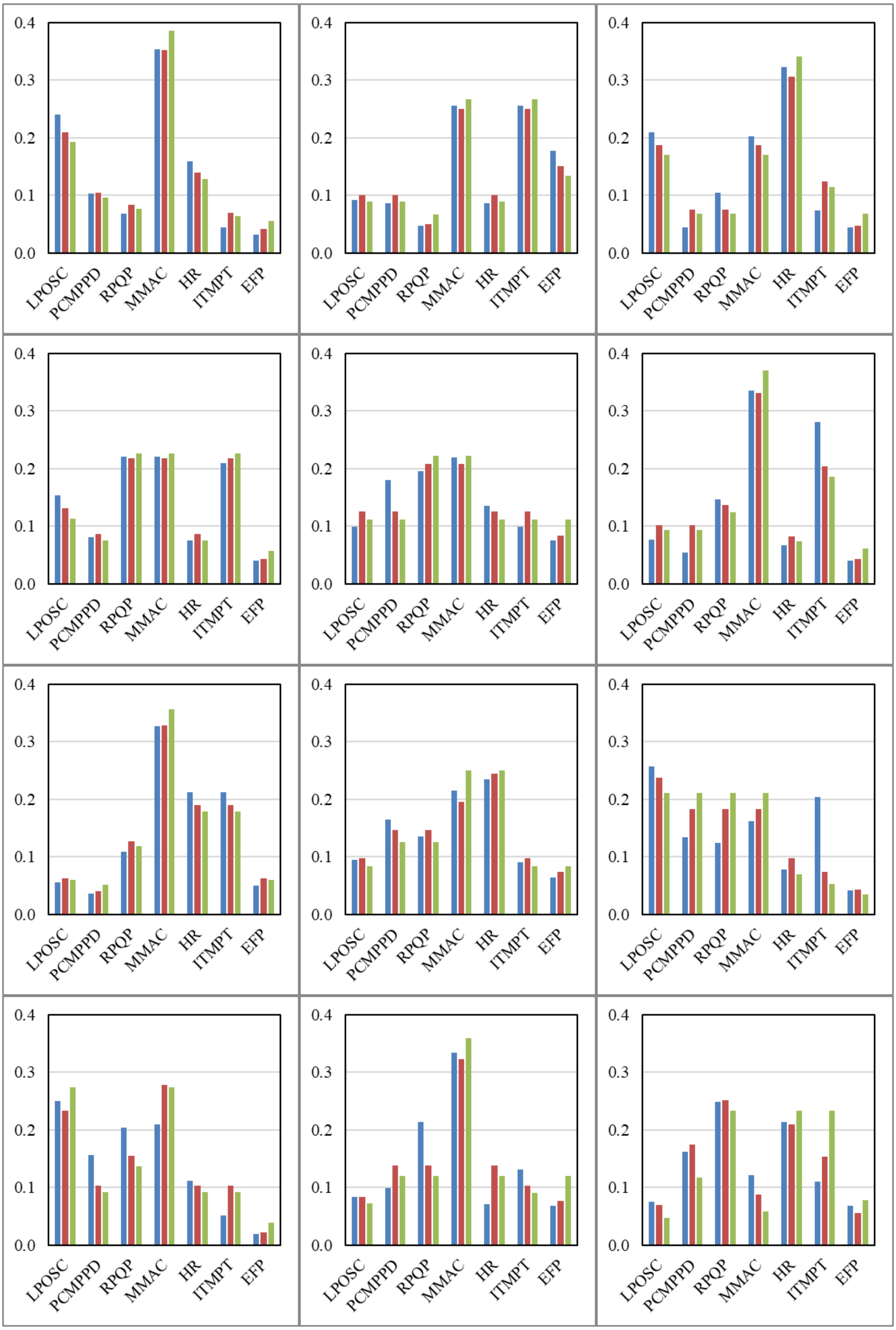
$$
\begin{aligned}
w_k &= \frac{\varphi_{k/(k+1)}\varphi_{(k+1)/(k+2)}\cdot\ldots\cdot\varphi_{(n-1)/n}}{1+\varphi_{(n-1)/n}+\varphi_{(n-2)/(n-1)}\varphi_{(n-1)/n}+\varphi_{(n-3)/(n-2)}\varphi_{(n-2)/(n-1)}+\ldots+\varphi_{1/2}\varphi_{2/3}\varphi_{3/4}\cdot\ldots\cdot\varphi_{(n-1)/n}}, \quad k=1,\ldots,n-1 \\
w_n &= \frac{1}{1+\varphi_{(n-1)/n}+\varphi_{(n-2)/(n-1)}\varphi_{(n-1)/n}+\varphi_{(n-3)/(n-2)}\varphi_{(n-2)/(n-1)}+\ldots+\varphi_{1/2}\varphi_{2/3}\varphi_{3/4}\cdot\ldots\cdot\varphi_{(n-1)/n}}
\end{aligned}
\tag{7}
$$

It is obvious that these weights fulfil the constraints $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)}\varphi_{(k+1)/(k+2)}$ for all k, so that all conditions of the FUCOM method are satisfied and complete consistency is guaranteed.

3.2. The weights of the driving parameters

The weights of seven driving parameters were calculated by AHP, BWM and FUCOM for 20 experts (Figure 1). The consistency of the judgments was assessed by CR in AHP and by the output-based consistency measure ξ as well as by the input-based CR in BWM, while the judgments in FUCOM are completely consistent. The twenty small graphs in Figure 1 are sorted by ascending CR in AHP. The results show that the ranking and the weights of parameters are more similar in the first few graphs where the consistency of judgments in AHP is high. If the weights of the parameters are similar, their ranking may vary depending on the method. The highest weight determined by FUCOM is often slightly higher than the highest weight determined by AHP or BWM. With higher but still acceptable inconsistency of judgement AHP, the ranking and weights differ significantly between the methods.




0.4
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HR
ITMPT
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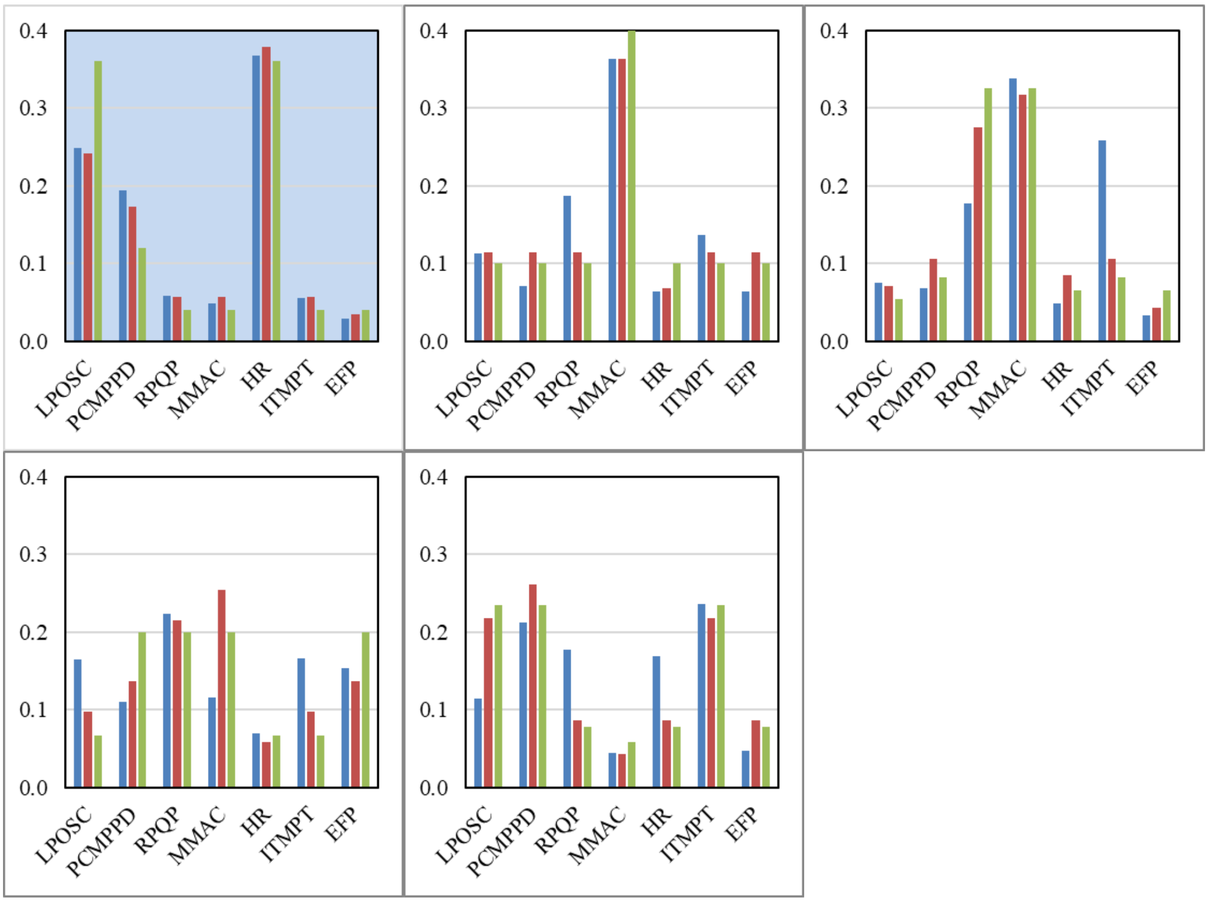

Figure 1. The weights of seven driving parameters, calculated by AHP (blue columns), BWM (red columns) and FUCOM (green columns) for 20 experts, sorted by ascending CR in AHP

In such cases, the additional pairwise comparisons in AHP provide further information to obtain more reliable weights. For example, in the graph with the blue background, the $CR_{AHP} = 0.113$ was slightly above the threshold 0.1, the $CR_{BWM}^{input-based} = 0.250 < 0.352$ was below the threshold, while the output-based BWM consistency measure $\xi = 0.138$ was the highest among all 20 experts. The expert rated the HR parameter as the most important, with comparisons to the other parameters presented in Table 1. The FUCOM method results show only three different values for the weights, with the weights of HR and LPOSC being the highest and equal, while the weights of RPQP, MMAC, ITMPT and EFP are also equal and smallest. The BWM weights differ between HR with the highest value and LPOSC with the second highest value. However, the weights of RPQP, MMAC and ITMPT are still the same. The AHP weights of HR and LPOSC are similar to the BWM weights, while additional AHP pairwise comparisons help to assign unique weights and rankings to the other parameters.

Table 1. Pairwise comparisons of parameter HR with other parameters

Best to Others	LPOSC	PCMPPD	RPQP	MMAC	HR	ITMPT	EFP
HR	1	3	9	9	1	9	9

3.3. The consistency of the results

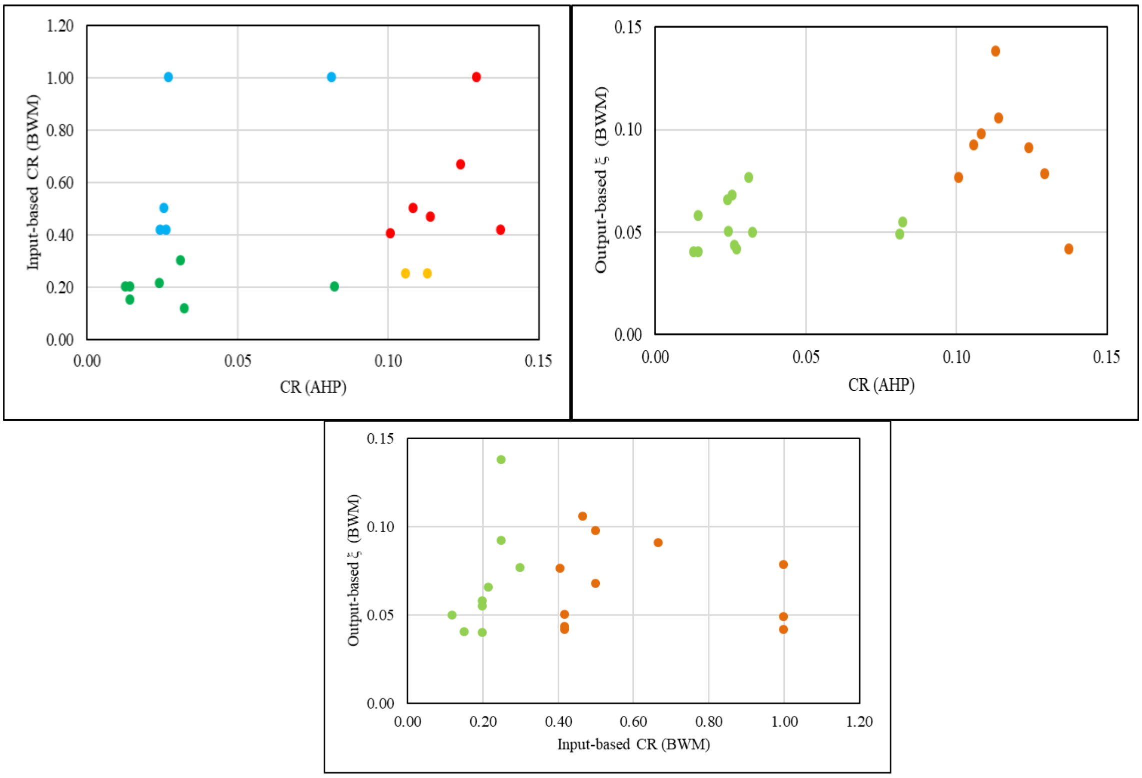

Figure 2. Correlation between consistency measures

Figure 2 shows the correlation between all three pairs of consistency measures. When comparing the consistency of pairwise comparisons in AHP and BWM, Pearson correlation coefficient indicates a higher correlation between CR (AHP) and output-based ξ (BWM) ($r_P = 0.59$) than between CR (AHP) and input-based CR (BWM) ($r_P = 0.33$). The most surprising result is the non-existent correlation between input-based CR (BWM) and output-based ξ (BWM) ($r_P = -0.02$). In Figure 1, in the upper left graph green dots represent experts with $CR_{AHP} < 0.1$ and $CR_{BWM}^{input-based} < t$, where t is the threshold for acceptable consistency, depending on a_{BW}. Blue dots represent experts with $CR_{AHP} < 0.1$ and $CR_{BWM}^{input-based} > t$ and yellow dots represent experts with $CR_{AHP} > 0.1$ and $CR_{BWM}^{input-based} < t$. Red dots represent experts with $CR_{AHP} > 0.1$ and $CR_{BWM}^{input-based} > t$. We see that all four combinations occur and that $CR_{AHP} < 0.1$ does not indicate acceptable consistency in BWM. In Figure 1, in the upper right graph green dots represent experts with $CR_{AHP} < 0.1$, while orange dots represent experts with $CR_{AHP} > 0.1$. The threshold for the acceptable output-based ξ (BWM) does not exist. The results in Figure 1, in the lower graph green dots represent experts with $CR_{BWM}^{input-based} < t$, while orange dots represent experts with $CR_{BWM}^{input-based} > t$, indicating that the measurement method of consistency of pairwise comparisons in BWM is unclear. The two measures presented provide very contradictory results and should be studied in more detail in the future.

4. DISCUSSION

In the literature, many authors (Fazeli & Peng, 2023; Omrani et al., 2020) cite the reasons given by Rezaei (2015) when the BWM was first introduced as the reason for choosing the BWM instead of the AHP: fewer pairwise comparisons and greater consistency.

Table 2. Number of pairwise comparisons regarding the number of compared elements in AHP, BWM and FUCOM

Number of elements	3	4	5	6	7	8	9	*n*
AHP	3	6	10	15	21	28	36	*n(n-1)/2*
BWM	3	5	7	9	11	13	15	*2n-3*
FUCOM	2	3	4	5	6	7	8	*n-1*

Table 2 clearly shows that the number of pairwise comparison is lower for BWM and even lower for FUCOM. However, the results of our study clearly show that a lower number of pairwise comparisons is not always an advantage. While fewer pairwise comparisons can shorten the time for evaluation they provide less information that influences the calculation of weights and can therefore lead to less reliable weights. Especially in cases with low but still acceptable consistency, additional pairwise comparisons in AHP can provide crucial information that can influence the ranking of parameters. Furthermore, the cognitive load on the experts does not only depend on the number of pairwise comparisons required. In BWM, the experts have to determine the best and the worst parameter, while in FUCOM the entire ranking of the parameters has to be determined before pairwise comparisons can be performed. If the parameters are similarly important, this might not be an easy task for the experts. The authors in literature claim that the main advantage of a smaller number of pairwise comparisons is greater consistency, which is not confirmed in our study. A similar result was also presented in (Grošelj et al., 2021). Our study shows a low to medium correlation of AHP and BWM consistency. It also shows that the measurement of consistency in BWM is still an open question.

5. CONCLUSION

In the study, we have compared three MCDM methods, based on pairwise comparisons, namely AHP, BWM and FUCOM. While BWM and FUCOM are more often used in recent studies, with the main reason being fewer pairwise comparisons and greater consistency, those reasons are often not justified. Our study shows the problems in measuring consistency in BWM and does not confirm the claim of greater consistency compared to AHP. For FUCOM, we presented formulas to calculate consistent weights without solving a nonlinear model. The consistency of the weights combined with a very low number of pairwise comparisons makes FUCOM an attractive method. However, the amount of information in FUCOM is also very small compared to AHP. We therefore conclude that AHP is indeed a very sound method, and that while the higher number of pairwise comparisons required may be a disadvantage for AHP, it is also its advantage in terms of providing more information that yields very reliable weights. More in-depth analysis is needed in the future to better substantiate our claims.

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REFERENCES

Akbari, M., Meshram, S. G., Krishna, R., Pradhan, B., Shadeed, S., Khedher, K. M., Sepehri, M., Ildoromi, A. R., Alimerzaei, F., & Darabi, F. (2021). Identification of the groundwater potential recharge zones using MCDM models: full consistency method (FUCOM), best worst method (BWM) and analytic hierarchy process (AHP). *Water Resources Management*, *35*, 4727-4745. https://doi.org/https://doi.org/10.1007/s11269-021-02924-1

AL-Juaidi, A. E. (2025). Enhancing flood vulnerability assessment in eastern Jeddah watersheds using advanced multicriteria decision analysis and sensitivity evaluation. *Environment, Development and Sustainability*, 1-28. https://doi.org/https://doi.org/10.1007/s10668-025-06098-3

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European journal of Operational research*, *200*(1), 198-215. https://doi.org/https://doi.org/10.1016/j.ejor.2009.01.021

Ekin, E., & Sarul, L. S. (2022). Investigation of smart city components by AHP-BWM-FUCOM and DEMATEL methods. *Alphanumeric Journal*, *10*(2), 197-222. https://doi.org/https://doi.org/10.17093/alphanumeric.1210018

Fazeli, H. R., & Peng, Q. (2023). Integrated approaches of BWM-QFD and FUCOM-QFD for improving weighting solution of design matrix. *Journal of Intelligent Manufacturing*, *34*(3), 1003-1020. https://doi.org/https://doi.org/10.1007/s10845-021-01832-w

Grošelj, P., Dolinar, G., & Šmidovnik, T. (2021). *Comparison of Best-Worst Method and Analytic Hierarchy Process* Proceedings of the 16th International Symposium on Operational Research in Slovenia, SOR'21, Ljubljana.

Jelačić, D., Pirc Barčić, A., Oblak, L., Motik, D., Grošelj, P., & Jošt, M. (2021). Sustainable production management model for small and medium enterprises in some south-central EU countries. *Sustainability*, *13*(11), 6220. https://doi.org/https://doi.org/10.3390/su13116220

Liang, F., Brunelli, M., & Rezaei, J. (2020). Consistency issues in the best worst method: Measurements and thresholds. *Omega*, *96*, 102175. https://doi.org/https://doi.org/10.1016/j.omega.2019.102175

Omrani, H., Alizadeh, A., & Naghizadeh, F. (2020). Incorporating decision makers' preferences into DEA and common weight DEA models based on the best–worst method (BWM). *Soft Computing*, *24*, 3989-4002. https://doi.org/https://doi.org/10.1007/s00500-019-04168-z

Pamučar, D., Stević, Ž., & Sremac, S. (2018). A new model for determining weight coefficients of criteria in mcdm models: Full consistency method (fucom). *symmetry*, *10*(9), 393. https://doi.org/https://doi.org/10.3390/sym10090393

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49-57.

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. *Omega*, *64*, 126-130. https://doi.org/https://doi.org/10.1016/j.omega.2015.12.001

Saaty, T. L. (1980). *The analytic hierarchy process*. McGraw-Hill.

Sahoo, S. K., & Goswami, S. S. (2023). A comprehensive review of multiple criteria decision-making (MCDM) Methods: advancements, applications, and future directions. *Decision Making Advances*, *1*(1), 25-48. https://doi.org/https://doi.org/10.31181/dma1120237

Si, S.-L., You, X.-Y., Liu, H.-C., & Zhang, P. (2018). DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications. *Mathematical Problems in Engineering*, *2018*, 3696457. https://doi.org/10.1155/2018/3696457

Srdjevic, B., Srdjevic, Z., Reynolds, K. M., Lakicevic, M., & Zdero, S. (2022). Using analytic hierarchy process and best–worst method in group evaluation of urban park quality. *Forests*, *13*(2), 290. https://doi.org/https://doi.org/10.3390/f13020290