Quality Festival 2025
ISBN 978-86-6335-121-9

Jelena Jovanovic [1]
Dragana Perisic

Research paper
DOI – 10.24874/QF.25.083

APPLICATION OF MCDM IN A SMALL SERBIAN PRINTING COMPANY

Abstract: *This paper presents the application of multi-criteria decision-making (MCDM) methods to support the selection of a printing machine in a small Serbian printing company. The study aims to select the most suitable machine among the three alternatives preselected by the company owner. In the decision-making process, seven limiting factors, i.e., criteria, were taken into consideration. The selected criteria were ranked using the AHP method, while the alternatives were evaluated and ranked using the VIKOR method. The theoretical foundations of the chosen methods are described in detail. To evaluate the most favorable alternative considering the selected criteria, the relative importance of each criterion was first determined using the mathematical formulas of the AHP method. Subsequently, taking into account the criteria weights, the requirements of each criterion, and the corresponding mathematical formulas of the VIKOR method, the alternatives were ranked and an assessment of the most favorable machine was provided.*

Keywords: *multi-criteria decision-making, AHP, VIKOR, graphic industry, printing company, printing machine*

1. Introduction

Decision-making is extremely intuitive when the problem takes into consideration one criterion. However, when decision-makers evaluate alternatives with multiple criteria, new problems appear, such as criteria weight, preference dependence, and conflicts among criteria. These problems further complicate the decision-making process, and they should be overcome by more sophisticated methods (Huang et al., 2009).

Multi-criteria decision-making (MCDM) is a tool that is used in Operations Research and Decision Theory and considers multiple criteria in a decision-making environment (Štilić & Njeguš, 2019). The MCDM process deals with situations involving the selection, sorting and ranking of the best alternative from several options based on selected criteria with the help of mathematical models (Chakraborty et al., 2024).

The problems of MCDM are widely diverse. However, even with the diversity, all the problems which are considered here share the following common characteristics (Nikolic, 2010; Hwang & Yoon, 1981, p. 2):

- Multiple objectives/attributes. A decision-maker must generate relevant objectives/attributes for each problem setting.
- Conflict among criteria
- Incommensurable units. Each objective/attribute has a different unit of measurement.
- Design/selection. Solutions to these problems are either to design the best alternative or to select the best one among previously specified finite alternatives.

Corresponding author: Jelena Jovanovic
Email: jelena.jovanovic@ftn.kg.ac.rs

In MCDM, several different methods can be used. In this work, the Analytical Hierarchy Process (AHP) method and the Multi-Criteria Compromise Ranking (VIKOR) method were used.

The Analytic Hierarchy Process (AHP) is a method in which an overall goal is followed by criteria, sub-criteria, and alternatives in a hierarchical arrangement. In this method, the problem hierarchy provides a visual and structured way of modeling the decision-making problem being considered (Chakraborty et al., 2024).

The VIKOR method (VIšekriterijumsko KOmpromisno Rangiranje) represents a commonly used method for the multi-criteria ranking that is suitable for solving various decision-making problems. It is especially suitable for situations where quantitative criteria prevail (Nikolic et al., 2010).

It is developed to solve MCDM problems with conflicting and non-commensurable attributes, assuming that compromise can be acceptable for conflict resolution, when the decision-maker wants a solution that is the closest to the positive-ideal solution (PIS) and the alternatives can be evaluated with respect to all the established attributes (Chakraborty et al., 2024).

These methods can be used in various applications such as plant location selection (Tavakkoli et al., 2011), material selection (Chatterjee et al., 2009), tool selection in Lean management (Jing et al., 2019), optimization (Tong et al., 2007), assembly line balancing (Sharma et al., 2013, 2014), product development (Soota, 2014), selection of suppliers (de Freitas et al., 2020), evaluating impacts on nature (Jovanovic et al., 2014), financial performance measurement for the wholesale and retail trade sector (İç et al., 2022), evaluation and selection of innovation projects (Samanlioglu et al., 2020), etc. It can also be used in various industries such as the food manufacturing industry (Kumar & Sodhi, 2024), tourism (Štilić & Njeguš, 2019), military industry (Aleksić et al., 2024), newsprint industry (Azizi & Azizpour, 2012), automotive industry (Surange & Bokade 2024), hotel industry (Fu et al., 2011), etc.

The paper addresses the issue of selecting the most suitable printing machine in a small Serbian printing company. In collaboration with the company owner, seven limiting factors, i.e., criteria, were taken into account in the decision-making process.

2. Theoretical foundations of applied methods

In this work, the AHP and VIKOR methods will be used when choosing the most favorable alternative. The AHP method will be applied to determine the weight of the criteria, while the VIKOR method will be applied when ranking the alternatives. The theoretical foundations of the selected methods are given below.

2.1. AHP method

According to Saaty (Saaty, 1980, p.19), there are 4 ways to determine the priority of criteria:

1. Sum the elements in each row and normalize by dividing each sum by the total of all the sums, thus, the results now add up to unity. The first entry of the resulting vector is the priority of the first activity; the second of the second activity, and so on.
2. Take the sum of the elements in each column and form the reciprocals of these sums. To normalize so that these numbers add to unity, divide each reciprocal by the sum of the reciprocals.
3. Divide the elements of each column by the sum of that column (i.e., normalize the column) and then add the elements in each resulting row and divide this sum by the number of elements in the row. This is a process of averaging over the

normalized columns.

4. Multiply the n elements in each row and take the n^{th} root. Normalize the resulting numbers.

In this paper third way will be used. While using the AHP method for determining criteria weight, the procedure goes as follows (Saaty, 1987; Rao, 2007; Hwang & Yoon, 1981):

Step 1: creating a pairwise comparison matrix.

A pairwise comparison matrix (A) is created by mutual comparison of criteria with the help of Saaty's scale (Table 1). Values (a_{ij}) can range from 1 to 9 if the observed criterion is more important than the criterion with which it is compared, and 1 to 1/9 if the observed criterion is less important than the criterion with which it is compared. It should be noted that values are based on the decision-maker's preference. The size of the matrix is determined by the number of criteria n. The estimation number is equal to $n(n-1)/2$. The layout of matrix A is presented by the following relation:

$$A = (a_{ij})_{n,n}, a_{ij} = \begin{cases} \emptyset, i \geq j \\ a_{ij}, i < j \end{cases}$$

Table 1. Saaty's scale (Saaty, 2008)

Scale	Definition
9	Extreme importance
8	Very, very strong
7	Very strong
6	Strong plus
5	Strong importance
4	Moderate plus
3	Moderate importance
2	Weak or slight moderate
1	Equal importance

Step 2: creating a normalization matrix.

To define the normalization matrix, it is necessary to create a comparison matrix *(B)* where the elements of the matrix (b_{ij}) are defined by the following relation:

$$B = (b_{ij})_{n,n}, b_{ij} = \begin{cases} 1, i = j \\ b_{ij} = a_{ij}, i < j \\ b_{ij} = \dfrac{1}{b_{ji}}, i > j \end{cases}$$

After that, it is needed to add values by columns (β_j).

$$\beta_j = \sum_{i=1}^{n} b_{ij}, j = \overline{1,n}$$

Step 3: creating the eigenvectors matrix.

Based on the eigenvectors matrix, the relative importance of each criterion is obtained.

To obtain the eigenvector matrix, the criterion values (b_{ij}) must be divided by the total sum of the values for the corresponding criterion (β_j). The elements of the eigenvector matrix (P_{ij}) are derived using the following relation:

$$P_{ij} = \frac{b_{ij}}{\beta_j}, i = \overline{1,n} \wedge j = \overline{1,n}$$

Then it is necessary to add up the values for each row.

$$d_i = \sum_{j=1}^{n} P_{ij}, i = \overline{1,n}$$

The relative importance (w_i) of each criterion is obtained when the value d_i is divided by the number of criteria n. The total sum of the relative importance of the criteria should be equal to 1.

$$w_i = \frac{d_i}{n}, i = \overline{1,n}; \quad \sum_{i=1}^{n} w_i = 1$$

2.2. VIKOR method

The VIKOR method goes through the next steps (Nikolic et al., 2010; Opricovic & Tzeng, 2004; Opricovic & Tzeng, 2007; Chatterjee & Chakraborty, 2016):

Step 1: taking into consideration the criteria requirement, determine f^* and f^- for each criterion, whereby the following applies (Opricovic & Tzeng, 2007; Opricovic, 2016):

$$f_j^* = max_i f_{ij}, f_j^- = min_i f_{ij}$$

if the observed criterion has a maximization requirement,

$$f_j^* = \min_i f_{ij}, f_j^- = max_i f_{ij}$$

if the observed criterion has a minimization requirement.

Step 2: determination of values S_i and R_i using the following formulas:

$$S_i = \sum_{j=1}^{n} w_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}, i = \overline{1,m}$$

$$d_{ij} = \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}$$

$$R_i = \max_j w_i \cdot d_{ij}, i = \overline{1,m}$$

where: m - number of alternatives, n - number of criteria.

Step 3: determination of values S^*, R^*, S^- and R^- whereby the following rules apply:

$$S^* = \min_i S_i, S^- = \max_i S_i$$

$$R^* = \min_i R_i, R^- = \max_i R_i$$

Step 4: determination of values QS_i, QR_i, and Q_i using the formula:

$$Q_i = v \cdot QS_i + (1 - v) \cdot QR_i$$

$$QS_i = \frac{S_i - S^*}{S^- - S^*}$$

$$QR_i = \frac{R_i - R^*}{R^- - R^*}$$

where value v = 0.5 (Opricovic & Tzeng, 2004; Aleksić et al., 2024).

Ranking of the alternatives is based on values Q_i from lowest to highest.

According to Nikolic (Nikolic et al., 2010), for an alternative to be the most favorable, it must meet the following conditions:

1. is ranked first according to value Q_i from lowest to highest
2. the difference between the second-placed and the first-placed value must be greater than or equal to 0.25 if it is a small number of alternatives (m) or the DQ value if it is a large number of alternatives

$$Q(a'') - Q(a') \geq DQ$$

$$DQ = \min(0.25; \frac{1}{m-1})$$

3. the alternative must be first ranked according to values QS_i and QR_i and value Q_i when v = 0.25 and v = 0.75.

According to Opricovic (Opricovic & Tzeng, 2004), for an alternative to be the most favorable, it must meet the following conditions:

1. first ranked on the compromise rank list, i.e., value Q_i for that alternative is the lowest
2. the difference between the second-placed and the first-placed value must be greater than or equal to DQ=1/(m-1).
3. the alternative is first ranked according to values S_i and/or R_i.

3. Data analysis and findings

The problem of decision-making is the selection of a machine for the needs of the printing process in a small Serbian printing company.

The first part will explain the criteria that will be used when making a decision. Using the AHP method, the weight of each criterion will be determined. Finally, the ranking of the observed alternatives will be shown with the help of the VIKOR method.

3.1. Defining the criteria

The decision matrix is shown in

Table **2**. The criteria that will be used for selection are: price of the machine (C1); user experience (C2); technical support (C3); print quality (C4); printing speed (C5); price of paint (C6) and machine dimensions (C7).

The alternatives that will be considered are: HP Latex R2000 Plus Printer (A-1), Durst Rho P10 200/250 HS (A-2), and LiYu

Platinum Q2 Hybrid (A-3).

Criteria C2 and C3 are defined on a scale from 1 to 5, where 1 represents the lowest value and 5 represents the highest value. Values for each alternative are based on the conducted interview.

Table 2. Decision matrix

	C1 [€]	C2 [No.]	C3 [No.]	C4 [dpi]	C5 [m^2/h]	C6 [€ / 1L]	C7 [m^3]
A-1	300 000	3	4	1200	86	85	32.487
A-2	250 000	4	3	1000	127	50	48.157
A-3	120 000	4	5	2400	100	65	29.6

3.2. Application of the AHP method

The pairwise comparison matrix is shown in Table **3**. Following steps 2 (Table **4**) and 3 (Table **5**), the relative importance of the criteria is determined.

Table 3. Pairwise comparison matrix

	C1	C2	C3	C4	C5	C6	C7
C1	/	7	7	5	5	2	4
C2	/	/	1	1/2	1/2	1/5	1/3
C3	/	/	/	1/2	1/2	1/5	1/3
C4	/	/	/	/	1	1/3	1/2
C5	/	/	/	/	/	1/3	1/2
C6	/	/	/	/	/	/	3
C7	/	/	/	/	/	/	/

Table 4. Normalization matrix

	C1	C2	C3	C4	C5	C6	C7
C1	1	7	7	5	5	2	4
C2	0.143	1	1	0.5	0.5	0.2	0.333
C3	0.143	1	1	0.5	0.5	0.2	0.333
C4	0.2	2	2	1	1	0.333	0.5
C5	0.2	2	2	1	1	0.333	0.5
C6	0.5	5	5	3	3	1	3
C7	0.25	3	3	2	2	0.333	1
β_i	2.436	21	21	13	13	4.399	9.666

Table 5. Eigenvectors matrix

	C1	C2	C3	C4	C5	C6	C7	d_i	w_i
C1	0.411	0.333	0.333	0.385	0.385	0.455	0.414	2.716	0.388
C2	0.059	0.048	0.048	0.038	0.038	0.045	0.034	0.31	0.044
C3	0.059	0.048	0.048	0.038	0.038	0.045	0.034	0.31	0.044
C4	0.082	0.095	0.095	0.077	0.077	0.076	0.052	0.554	0.079
C5	0.082	0.095	0.095	0.077	0.077	0.076	0.052	0.554	0.079
C6	0.205	0.238	0.238	0.231	0.231	0.227	0.31	1.68	0.24
C7	0.103	0.143	0.143	0.154	0.154	0.076	0.103	0.876	0.125
								Σ	1

3.3. Application of VIKOR method

The first step of the VIKOR method is to determine values f^* and f^- (Table 6). Based on previously mentioned formulas, for easier calculation of values S_i and R_i, a value d_{ij} is

used (
Table **7**).

In Table 8, the calculation of values S_i and R_i is shown, while in Table 9 are shown values QS_i, QR_i, and Q_i.

Table 6. Determination of values f^* and f^-

	C1	C2	C3	C4	C5	C6	C7
Criteria requirement	min	max	max	max	max	min	min
w_i	0.388	0.044	0.044	0.079	0.079	0.24	0.125
A-1	300000	3	4	1200	86	85	32.487
A-2	250000	4	3	1000	127	50	48.157
A-3	120000	4	5	2400	100	65	29.6
f^*	120000	4	5	2400	127	50	29.6
f^-	300000	3	3	1000	86	85	48.157

Table 7. Value d_{ij}

	C1	C2	C3	C4	C5	C6	C7
A-1	1	1	0.5	0.857	1	1	0.156
A-2	0.722	0	1	1	0	0	1
A-3	0	0	0	0	0.659	0.429	0

Table 8. Values S_i and R_i

	C1	C2	C3	C4	C5	C6	C7	S_i	R_i
A-1	0.388	0.044	0.022	0.068	0.079	0.24	0.019	0.86	0.388
A-2	0.28	0	0.044	0.079	0	0	0.125	0.528	0.28
A-3	0	0	0	0	0.052	0.103	0	0.155	0.103

Table 9. Values QS_i, QR_i and Q_i

	QS_i	QR_i	Q_i	Rank
A-1	1	1	1	3.
A-2	0.529	0.621	0.575	2.
A-3	0	0	0	1.

Table 10. Value Q_i when v=0.25 and v=0.75

	Q_i (v = 0.25)	Q_i (v = 0.75)	Rank
A-1	1	1	3.
A-2	0.598	0.552	2.
A-3	0	0	1.

From Table 9, it can be seen that alternative A-3 is ranked first according to Q_i.

In order for the alternative to be considered the most favorable, the value DQ needs to be greater than or equal to 0.25. It can be seen that alternative A-3 fulfills that requirement (0.575 - 0 = 0.575 ≥ 0.25).

According to Opricovic (Opricovic & Tzeng, 2004), one of the conditions that the alternative should fulfill is to be ranked first according to values S_i and/or R_i. In Table 8, it can be seen that alternative A-3 fulfills this condition (S^* = 0.155, R^* = 0.103).

According to Nikolic (Nikolic et al., 2010), one of the conditions that the most favorable alternative should fulfil is to be ranked first according to Q_i when the value v = 0.25 and v = 0.75. In Table 10, it can be seen that alternative A-3 meets the given condition.

4. Conclusion

Using the AHP method, the weight of the criteria can be determined, as well as the criteria ranking. In the given example, it can be seen that the most important criterion for the decision-maker when making the decision was C1, which is the price of the machine. Of course, this outcome was expected given that the company is a small printing business.

Using the VIKOR method, the ranking of the alternatives can be seen. The most favorable alternative according to all criteria is alternative A-3, i.e., LiYu Platinum Q2 Hybrid.

It should be noted that these methods provide assistance to the decision-maker in choosing an alternative. When making a decision, the decision-maker does not have to choose the most favorable alternatives according to the method used.

References:

Aleksić, A. R., Delibašić, B. V., Jokić, Ž. M., & Radovanović, M. R. (2024). Application of the AHP and VIKOR methods of individual decision making and the Borda method of group decision making when choosing the most efficient way of performing preparatory shooting at serial number one from a 12.7 mm long range rifle M-93. *Vojnotehnički glasnik/Military Technical Courier*, *72*(3), 1147-1170. doi: 10.5937/vojtehg72-52204

Azizi, M., & Azizpour, M. (2012). A BOCR structure for privatisation effective criteria of Iran newsprint paper industry. *International Journal of Production Research*, *50*(17), 4867–4876. doi: 10.1080/00207543.2012.657973

Chakraborty, S., Chatterjee, P., Protim Das, P. (2024). *Multi-Criteria Decision-Making Methods in Manufacturing Environments : Models and Applications*. United States of America: Apple Academic Press. ISBN: 978-1-00337-703-0

Chatterjee, P., & Chakraborty, S. (2016). A comparative analysis of VIKOR method and its variants. *Decision Science Letters*, *5*(4), 469-486. doi: 10.5267/j.dsl.2016.5.004

Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2009). Selection of materials using compromise ranking and outranking methods. *Materials & Design*, *30*(10), 4043-4053. doi: 10.1016/j.matdes.2009.05.016

de Freitas, A., Gomes Salgado, E., & Sousa Lira, J. M. (2020). Selection of suppliers in the green supply chain: case study with multi-criteria decision. *International Journal for Quality Research*, *14*(1), 51-64. doi: 10.24874/IJQR14.01-04; UDC: 005.6

Fu, H.-P., Chu, K.-K., Chao, P., Lee, H.-H., & Liao, Y.-C. (2011). Using fuzzy AHP and VIKOR for benchmarking analysis in the hotel industry. *Service Industries Journal*, *31*(14), 2373–2389. doi: 10.1080/02642069.2010.503874

Huang, J. J., Tzeng, G. H., & Liu, H. H. (2009). A revised VIKOR model for multiple criteria decision making-The perspective of regret theory. *Cutting-Edge Research Topics on Multiple Criteria Decision Making: 20th International Conference, MCDM 2009*, 761-768. doi: 10.1007/978-3-642-02298-2_112

Hwang, C.L., Yoon, K. (1981). *Multiple Attribute Decision Making: methods and applications*. doi: 10.1007/978-3-642-48318-9

İç, Y. T., Çelik, B., Kavak, S., & Baki, B. (2022). An integrated AHP-modified VIKOR model for financial performance modeling in retail and wholesale trade companies. *Decision Analytics Journal*, *3*, 100077. doi: 10.1016/j.dajour.2022.100077

Jing, S., Niu, Z., & Chang, P. C. (2019). The application of VIKOR for the tool selection in lean management. *Journal of Intelligent Manufacturing*, *30*(8), 2901-2912. doi: 10.1007/s10845-015-1152-3

Jovanovic, J., Shah, H., Vujovic, A., & Krivokapic, Z. (2014). Application of MCDM methods in evaluation of environmental impacts. *International Journal for Quality Research*, *8*(4), 517-532.

Kumar, P., & Sodhi, R. S. (2024). Literature review on implementation of intuitionistic fuzzy set using Analytical Hierarchy Process (AHP) for food manufacturing industry based on multi-factors. *Proceedings on Engineering*, *6*(1), 207-214. doi: 10.24874/PES.SI.24.02.003;

Nikolic, M., Radovanović, Lj., Desnica, E., i Pekez,. J. (2010). Primena metode VIKOR za izbor strategije održavanja [The application of VIKOR method for selection of maintenance strategies]. *Tehnička dijagnostika*, *9*(4), 25-32.

Opricovic, S. (2016). A comparative analysis of the DEA-CCR model and the VIKOR method. *Yugoslav Journal of Operations Research*, *18*(2), 187-203. doi: 10.2298/YUJOR0802187O

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European journal of operational research*, *156*(2), 445-455. doi:10.1016/S0377-2217(03)00020-1

Opricovic, S., & Tzeng, G. H. (2007). Extended VIKOR method in comparison with outranking methods. *European journal of operational research*, *178*(2), 514-529. doi:10.1016/j.ejor.2006.01.020

Rao, R.V. (2007). *Decision Making in the Manufacturing Environment using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods.* London: Springer-Verlag. ISBN: 978-1-84628-819-7

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical modelling*, *9*(3-5), 161-176. doi: 10.1016/0270-0255(87)090473-8

Saaty, T. L. (1980). *The Analytic Hierarchy Process – Planning, Priority Setting, Resource Allocation*. United States of America: McGraw-Hill Inc. ISBN 0-07-054371-2

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83-98. doi: 10.1504/IJSSCI.2008.017590

Samanlioglu, F., Ayağ, Z., & Kahraman, C. (2020). An intelligent approach for the evaluation of innovation projects. *Journal of Intelligent & Fuzzy Systems*, *38*(1), 905–915. doi: 10.3233/JIFS-179458

Sharma, P., Thakar, G., & Gupta, R. C. (2013). Evaluation of assembly line balancing methods using an Analytical Hierarchy Process (AHP) and Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) based approach. *International Journal for Quality Research*, *7*(4), 523-544.

Sharma, P., Thakar, G., & Gupta, R. C. (2014). Evaluation of multi criteria assembly line balancing by MCDM approaches: A conceptual review. *International Journal for Quality Research*, *8*(1), 87-106.

Soota, T. (2014). Integrated approach to multi-criteria decision making for sustainable product development. *International Journal for Quality Research*, *8*(4), 543-556.

Surange, V. G., & Bokade, S. U. (2024). A Comparative Study of the Severity Ranking of Risks in the Indian Automobile Manufacturing Supply Chain Using PROMETHEE, VIKOR and TOPSIS. *Vikalpa: The Journal for Decision Makers*, *49*(4), 327–348. doi: 10.1177/02560909241302201

Štilić, A. & Njeguš, A. (2019). Primena metoda višekriterijumske analize u odabiru kandidata za rad u turističkoj privredi [Application of multi-criteria analysis methods in the selection of candidates for work in the tourism industry]. *Sinteza 2019 - International Scientific Conference on Information Technology and Data Related Research*, 505-510. doi: 10.15308/Sinteza-2019-505-510

Tavakkoli, M.R., Mousavi, S. M., & Heydar, M. (2011). An Integrated AHP-VIKOR methodology For Plant Location Selection. *International Journal of Engineering*, *24*(2), 127-137.

Tong, L. I., Chen, C. C., & Wang, C. H. (2007). Optimization of multi-response processes using the VIKOR method. *The International Journal of Advanced Manufacturing Technology*, *31*, 1049-1057. doi: 10.1007/s00170-005-0284-6

Jelena Jovanovic
University of Kragujevac,
Faculty of Technical Sciences,
Cacak,
Serbia
jelena.jovanovic@ftn.kg.ac.rs
ORCID 0000-0001-7418-6061

Dragana Perisic
University of Kragujevac,
Faculty of Technical Sciences,
Cacak,
Serbia
dragana.perisic@ftn.kg.ac.rs
ORCID 0009-0005-3584-8428