ACROSS
www.across-journal.com
Proceedings of the International Conference "Interdisciplinarity and Cooperation in Cross-border Research"
Chisinau, Republic of Moldova, June 2022
Vol. 6. No. 2 – Engineering

OPTIMISATION OF SEVERAL ESTIMATING FUNCTIONS BY MULTICRITERIAL ANALYSIS OF CIVIL ENGINEERING STRUCTURE IN SERVICE STAGE MONITORING

Daniel LEPADATU[1], Dorina ISOPESCU[1], Ion RUSU[2], Loredana JUDELE[1], Gabriel SANDULACHE[1]

[1]Technical University Gheorghe Asachi of Iasi, Iasi (Romania)
[2]Technical University of Moldova, Chisinau (Republic of Moldova)

Abstract

In order to ensure the safety of engineering structures and especially those with special regimen such as the viaducts requiring careful monitoring of spatial displacements, it is necessary to find an optimal combination of criteria that are evaluated by a multi-criteria analysis to avoid major structural degradation and their effects on of the entire structure that can generate catastrophes with major losses of human lives. In this paper we will present an optimization of the estimation functions of the evaluation criteria behaviour for the time monitoring of an engineering structure. In this paper, we are analysing a structure that has 50 years and that has a vital significance for Galati city from Romania. It is a 1.3 km-long viaduct structure connecting the city of Galati with ArcelorMittal steel company. The current legislation requires a plan for permanent monitoring of displacement in order to avoid accidents that can lead to loss of human life. Thus, we will quantify and discuss the effects of the different evaluation criteria behaviour and we will choose those that maximize the user's chances of responding without departing from those values that keep their study credible. In order to obtain the results of the multicriteria analysis, three monitoring cycles with three types of instruments on more than 30 tracking points were designed and performed.

Keywords: Service stage monitoring, structural security, multicriterial analyses, optimization, civil engineering structures

1 Introduction

The multicriterial analysis is a complex way of investigation by which you search in the multidimensional space of definition the combination that satisfies the demands enforced by the user for efficient optimization of a process or phenomenon. Multicriteria analysis (MCA) [1-3], in the literature also known under the names of multiple-criteria decision-making (MCDM) [4], multiple-criteria decision analysis (MCDA) [5-7], multiobjective decision analysis (MODA) [8,9], multiple-attribute decision-making (MADM) [10,11] or multidimensional decision-making (MDDM) [12,13].

Choosing the functions that define the evaluation criteria is difficult in so far as not all the criteria respond certainly to the behaviour that was defined by the corresponding position. Even though they correspond to the multiple problems for which they were imagined, sometimes there is a need for a more comprehensive study to get to the configuration which transposes as closely the behaviour of the estimated criterion. In the long-term monitoring of engineering structures, there is a need to make a compromise between the equipment that we use, financial or human resources, or prioritization of the measurement precision at the expense of the time it takes to complete it.

Multicriteria optimization helps the operator to decide on the possibility of using an optimal solution that simultaneously satisfies criteria that may be contradictory. This method is more and more often utilized in almost all areas [12-21] because it is capable of adapting the criteria of specific problems so that it obtains the best combination of parameters that comply with the growing requirements of society.

Therefore, this paper aims to an evaluation of both the criteria and the functions that describes their behaviour so that we can achieve this compromise and be able to precisely identify the necessary configuration of the efficient optimization of the monitoring process over time, especially of the structures that have special procedures and would produce unwanted effects for the society if they would have structural defects.

2 Methodology

A Multiple Criteria Decision Analysis – MCDA is an analysis method [5-7] based of many approaches, models and methods to handle decision [13] or evaluation problems where include multiple criteria. Originally developed in the United States in the 1970s and known as the Multicriteria Decision Making - MCDM [10,11] it was adopted by the European School in 1996 as the MCDA [5-7]. The functions that will be analysed are those existing in the program library, among which we can mention linear function, constant function or usual, level function or Gaussian function etc. (Figure 1).

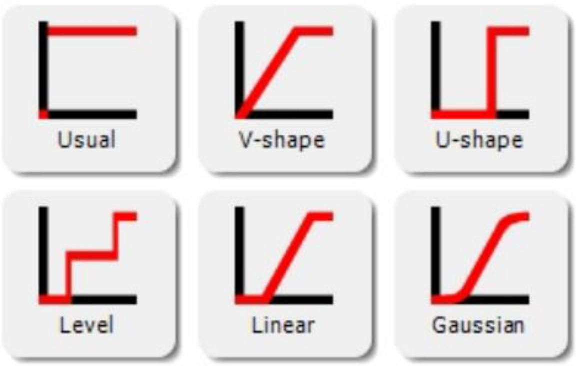


Figure 1. Preference function using in Visual Promethee program [22].

The mathematical equations that define the approximation functions are given for example for the usual criterion (Equation 1) and for the Gaussian criterion (Equation 2).

$$f_1(x) = \begin{cases} 0, \wedge\, x < 0 \\ 1, \wedge\, x \geq 0 \end{cases} \qquad (1)$$

$$f_2(x) = \begin{cases} 0, \wedge\, x \leq 0 \\ 1 - e^{\frac{-x^2}{2\times\sigma^2}}, \wedge\, x > 0 \end{cases} \qquad (2)$$

Generally speaking, the criteria that can be taken into account for a laborious study in the process of monitoring the civil engineering structure can be of two types:

1. Quantitative

   a. Time
   b. Price
   c. Number of operators
   d. Number of landmarks
   e. Frequency of observations
2. Qualitative
   a. Precision
   b. Used equipment
   c. Importance class of the monitored objective
   d. Choosing the topographic method
   e. Diminution of Errors
   f. Processing of observations
   g. Interpretation of results

Another way of ranking and defining these criteria in service stage monitoring process can be given by:

- The way it is used (importance classification of the object, choosing the topographic approach, the number of operators, the number of references);
- Technical performances (cost, precision, time, the equipment that was used, internal memory, duration of usage);
- Duration of execution (processing of the comments, interpretation of the results, the reduction of mistakes).

The PROMETHEE methods [1,2,23], represent a multicriteria approach that for several actions can manage multiple individual criteria and they propose a compromise solution by optimizing them. This can be expressed mathematically as follows:

$$max\{f_1(x), f_1(x) \cdots, f_j(x) \cdots f_k(x) \mid x \epsilon A\} \qquad (3)$$

where *A* is a finite set of *n* actions; f_1 to f_k are *k* criteria; $f_j(x)$ is the evaluation of action *n* on criterion f_j.

There is no objection to consider some criteria to be maximized and others to be minimized, but for the sake of simplicity we will suppose here that all criteria have to be maximized.

The mathematical approach from two-way multicriteria formulation can be write like this:

$$max\{f_1(x), f_1(x) \cdots, f_j(x) \cdots f_k(x) \mid x \epsilon A\} \qquad (4)$$

	$f_1 f_2 \cdots f_j \cdots f_k$
x_1	$f_1(x_1), f_2(x_1), \cdots, f_j(x_1), \cdots f_k($
x_2	$f_1(x_2), f_2(x_2), \cdots, f_j(x_2), \cdots f_k$

$$\begin{array}{c|c} \vdots & \vdots\vdots\vdots\vdots \\ x_i & f_1(x_i), f_2(x_i), \cdots, f_j(x_i), \cdots f_k(\\ \vdots & \vdots\vdots\vdots\vdots \\ x_n & f_1(x_n), f_2(x_n), \cdots, f_j(x_n), \cdots f_k \end{array} \quad (5)$$

The purpose of using this method is to find the best combination of parameters that meet all the criteria at the same time, criteria that are usually contradictory. The user's art is to choose the function that best describes the behaviour of each criterion, considered so that it is as close as possible to reality. The main objective of MCDA is thus to identify the best compromise decisions.

3 Results and discussion

3.1 Introduction

The data collected for this study were recorded from the process of monitoring space movements for a structure of major importance. In this paper, we are analysing a structure that has 50 years and that has a vital significance for Galati city from Romania. It is a 1.3 km-long viaduct structure (Figure 2) connecting the city of Galati with ArcelorMittal steel company. The process of monitoring these types of structures is vital for maintaining the designed and traffic safety parameters. Thus, it is important to optimize the costs related to this permanent monitoring of these objectives as well as the accuracy of the data obtained, which must relate to the accuracy of the instruments used but also to their evolution over time.

The results to be analysed actually include 3 series of measurement, which are performed in order to monitor the mentioned objective – the including of three different new technologies: Mavic Air UAVs, Leica P50 Laser Scanner and Leica Total Station TS 12 [18].

The purpose of this analysis is in fact the multicriteria optimization in order to obtain the best compromise for the different criteria in the realization of the measurements of time monitoring of the structures in civil engineering.

Figure 2. Study case – Viaduct in City of Galati, Romania.

3.2 Visual Promethee – multicriterial analysis software

The multicriterial analysis will be carried out using the Visual Promethee Gaia program (Figure 3), based on the PROMETHEE - Preference Ranking Organization Method for Enrichment Evaluation [19,22]. Being a method of classification according to qualitative or quantitative criteria, the role of the operator is to correctly define the field of research for each criterion with functions adapted to their variation in these fields. This software can help with multicriteria decisions that has implemented the Promethee and Gaia concepts [22]. Published in the '60s the multicriterial analysis is a powerful decision-making tool, which is capable to sometimes combine the conflicting criteria, but also of ranking complex scenarios with meeting several requirements at the same time which considerably improves the final decision of the user.

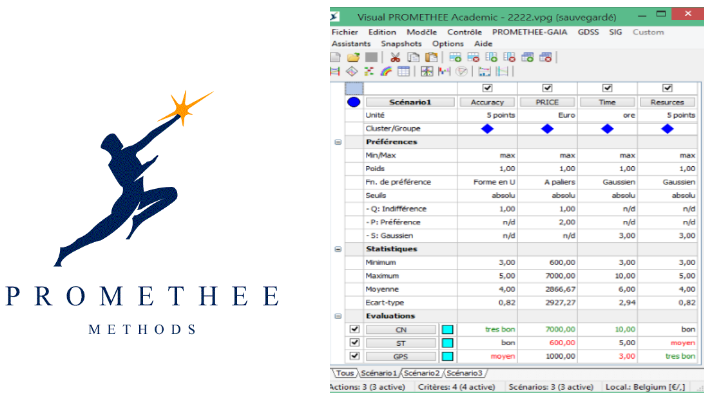


Figure 3. The Visual Promethee Gaia software.

The Visual Promethee Gaia is designed for [22]:

- Multicriteria analysis and implementation of decisions based on contradictory criteria;
- Finding the best solution;
- Classification of decision;
- Clear graphic representation.

The advantage of this program is that the scenarios are ordered and influenced by multiple criteria and the intuitive graphical representation helps the user on choosing the optimal solution.

3.3 Smart monitoring equipment

For the monitoring of the structure the following devices as Mavic Air UAV, Laser Scanner P50 and Leica Total Station TS 12 were used (Figure 4a-c) [19].

a) Mavic Air UAV

b) Laser Scanner

c) Leica Total Station TS 12

Figure 4. Smart tools.

The general parameters of the used equipment can be found in Table 1 [19].

Table 1. Parameters for multicriteria optimization.

Smart Technology	Accuracy (mm)	Time (hours)	Measurement distance (m)	Internal Memory (points)	Price (RON)	Resources (Operator)	Autonomy (hours)
Robotic Total Station	15	1	1000	30000	1500	2	5
Laser Scanner	20	2	200	250000	3000	1	6
UAV	30	1	80	300000	3000	1	1

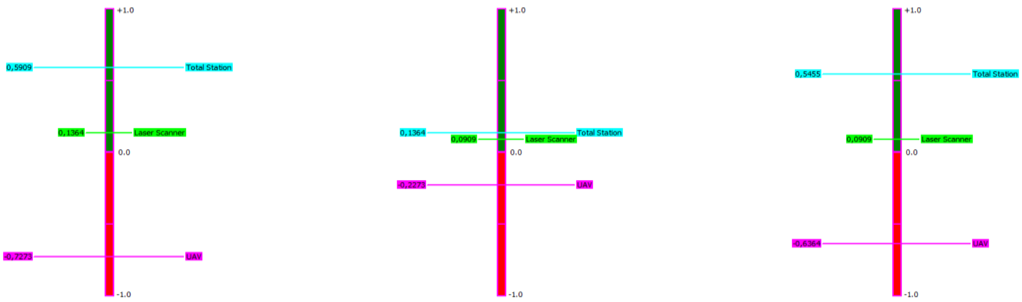
In this study, three scenarios presented in the table below (Table 2) will be analysed and optimized [18,19]. During the monitoring process of vital structures, the use of the top technologies from which we cannot exclude the Unnamed Aerial Vehicle - UAV, Laser Scanner or Total Robotic Station, and the necessary precision for such observations is required. Instead, multicriterial optimization helps us to make a choice according to several criteria and scenarios that converge to the user’s convenient solution.

Table 2. Scenarios for multicriteria optimization.

	Scenario 1 – Maximum accuracy			**Scenario 2 – Minimum time**			**Scenario 3 – Global Cost**		
Devices	Total Station	Laser Scanner	UAV	Total Station	Laser Scanner	UAV	Total Station	Laser Scanner	UAV
Accuracy (mm)	15	20	30	4	5	5	5	5	15
Time (hours)	1	2	1	1	1	1	2	1	1
Measurement Distance (m)	1000	200	80	1000	100	50	1500	150	50
Internal memory (points)	30000	250000	100000	20000	50000	50000	20000	50000	60000
Price (RON)	1500	3000	5000	1500	2000	2500	2000	5000	2500
Resources (operators)	2	1	1	2	1	1	2	1	1
Autonomy (hours)	5	6	1	6	6	1	6	6	1

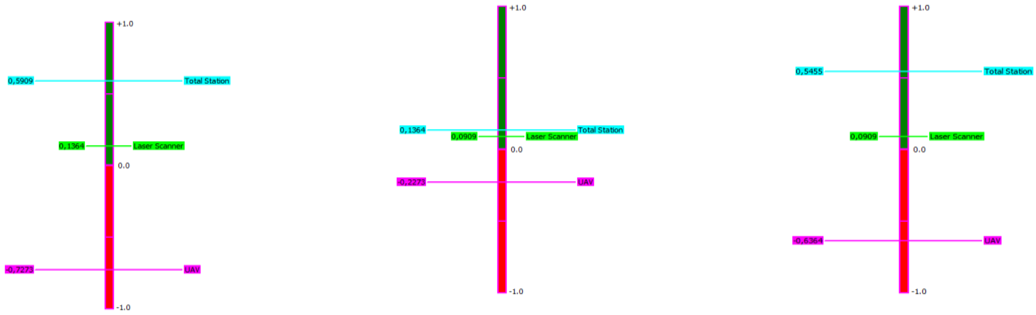
3.4 Optimization of several estimation functions

In order to highlight the importance of choosing the functions for estimating the different parameters used for multicriteria optimization, we proposed the use of the same function for each criterion in the three scenarios. Thus, we will have to analyse 6 cases for the 6 functions in the program library (usual, linear, V-shape, U-shape, Gaussian, constant or step function), which we will compare with those chosen by the user depending on the proposed criteria.



a) Scenario I *b) Scenario II* *c) Scenario III*

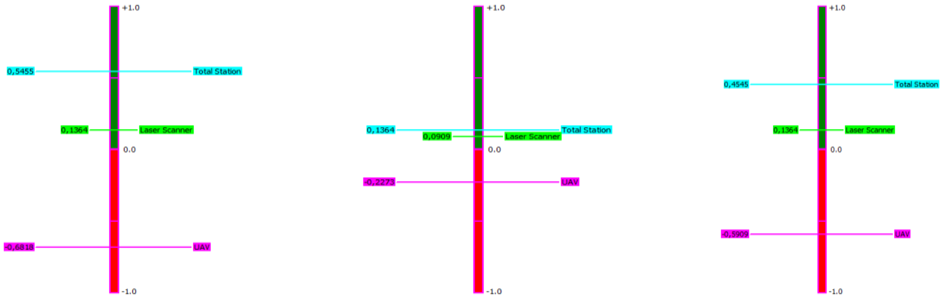
Figure 5. Ranking of linear function for multicriterial analysis.



a) Scenario I *b) Scenario II* *c) Scenario III*

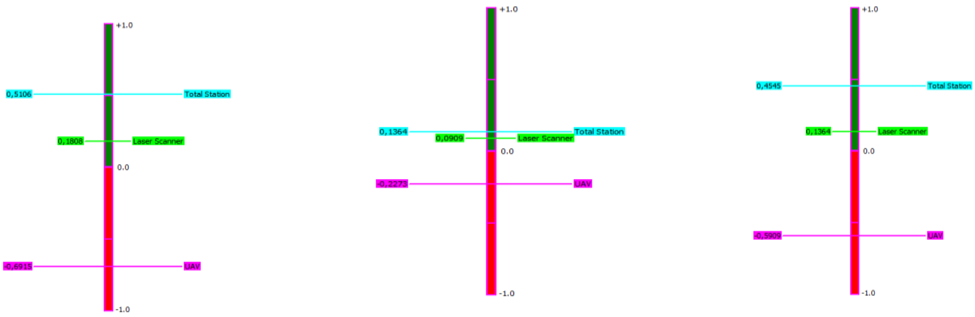
Figure 6. Ranking of U-function for multicriterial analysis.

Figures 5 and 6 show the influence of linear function – Figure 5 and U-function – Figure 6 on the classification of the three-smart equipment in the three presented scenarios. We notice that there is no difference between the two functions and the classification of the three scenarios remains unchanged.



a) Scenario I *b) Scenario II* *c) Scenario III*

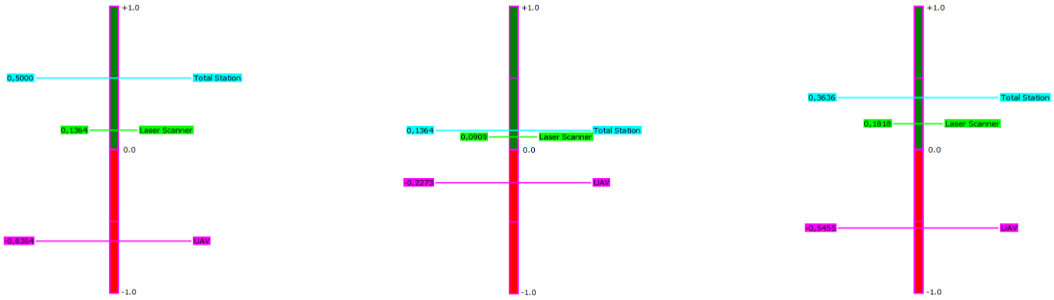
Figure 7. Ranking of V-function for multicriterial analysis.



a) Scenario I b) Scenario II c) Scenario III

Figure 8. Ranking of Gaussian function for multicriterial analysis.

Figures 7 and 8 show the influences of V-function – Figure 7 and Gaussian function – Figure 8. We can see that although there are variations between the different values specific to these classifications, this time, the order of priority of this equipment does not change.

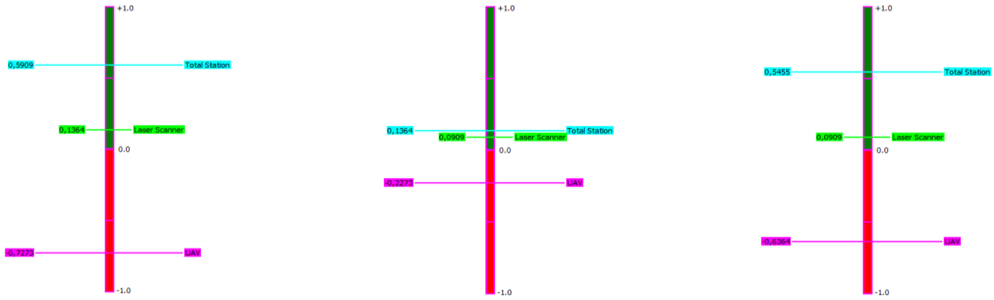


a) Scenario I b) Scenario II c) Scenario III

Figure 9. Ranking of constant function for multicriterial analysis.

Figures 9 and 10 show the classification of smart equipment using constant function – Figure 9, respectively step function – Figure 10. And this time, we can highlight that there are significant differences between the behaviours of classification criteria using these functions in 2 of the 3 scenarios. Priority remains unchanged, this being the optimal one, namely:

1. Total Station – rank 1,
2. Laser Scanner – rank 2,
3. UAV – rank 3.



a) Scenario I b) Scenario II c) Scenario III

Figure 10. Ranking of step function for multicriterial analysis.

Following this analysis, it is found that although in the chosen fields there are similarities between the behaviours of different estimation functions, there are scenarios with user-chosen functions depending on the used criteria in multicriteria optimization and which give different results in the final classification. Therefore, the idea is that it is very important that the estimation functions are in accordance with both the used criterion and the behaviour in the chosen field.

4 Conclusions

Monitoring structures of major importance to society is more than mandatory due to the detection of any form of space travel can save lives and especially an intervention on it to extend the operating life in the parameters designed to lead to safety and confidence in current operation. Given the evolution of monitoring equipment, which has recently gained huge attention, especially in terms of the use of real-time tracking resources that are able to anticipate an imminent disaster and its optimal prevention, we have chosen to use the multicriteria analysis. Therefore, we get the best ratio between different criteria - such as - accuracy of determination, time and price, which can lead to relatively high costs if used cyclically throughout the service stage. The purpose of using this method is to find the best combination of parameters that are satisfying all the criteria at the same time, criteria that are usually contradictory. The art of the user is to choose the function that describes the best behaviour of every criterion considered so that it could get closer to reality. The data collected for this study was registered from the monitoring process of spatial displacement of a major importance structure. The monitoring process of this kind on structures is vital for keeping it in the projected parameters and for the safety of the traffic. Therefore, the optimization of the costs related to permanent monitoring of these objectives, as well as the obtained data accuracy, which have to report to the precision of the used instruments, but also at their evolution in time are important.

ACKNOWLEDGEMENTS

This paper was realized with the support of project EFECON – ECO-INNOVATIVE PRODUCTS AND TECHNOLOGIES FOR ENERGY EFFICIENCY IN CONSTRUCTION, POC/71/1/4 - Knowledge Transfer Partnership, Cod MySMIS: 105524, ID: P_40_295, Project co-financed by the European Regional Development Fund.

References

[1] Azzabi, L., Azzabi, D., Kobi, A. (2020) Multi-Criteria Approach to Classification Systems of Control Aircraft Flight: Application PROMETHEE Method. In: *International Series in Operations Research & Management Science - The Multi-Criteria Approach for Decision Support*, 49–60, Switzerland: Springer International Publishing.
[2] Azzabi, L., Azzabi, D., Kobi, A. (2020) The Multi-Criteria Approach Assessment Human Risks: Application the Analytical Hierarchy Process and PROMETHEE Methods. In: *International Series in Operations Research & Management Science - The Multi-Criteria Approach for Decision Support*, 61–84, Switzerland: Springer International Publishing.
[3] Azzabi, L., Azzabi, D., Kobi, A. (2020) The Multi-Criteria Approach Decision. In: *International Series in Operations Research & Management Science - The Multi-Criteria Approach for Decision Support*, Switzerland: Springer International Publishing, 1–23.
[4] Wang, C.N., Dang, T.T., Nguyen, N.A.T., Wang, J.W. (2022) A combined Data Envelopment Analysis (DEA) and Grey Based Multiple Criteria Decision Making (G-MCDM) for solar PV power plants site selection: A case study in Vietnam. *Energy Reports*, 8, 1124–1142. https://doi.org/10.1016/j.egyr.2021.12.045
[5] Matthias, E., Figueira, J.R., Salvatore, G. (2010) Trends in Multiple Criteria Decision Analysis. In: *International Series in Operations Research & Management Science*. E. Matthias, J.R. Figueira, and G. Salvatore (eds). New York: Springer.
[6] Mateu, A.V. (2002) *ClusDM: A Multiple Criteria Decision-Making Method for Heterogeneous Data Sets*. PhD thesis. Universitat Politècnica de Catalunya.

[7] Hichem, A., Mohyeddine, S., Abdessamed, K. (2021) Benchmarking framework for sustainable manufacturing based MCDM techniques. *Benchmarking: An International Journal*, 29(1), 87–117. DOI:10.1108/BIJ-08-2020-0452

[8] Yajie, D., Pengle, Z., Jiang, J., Kewei, Y., Yingwu, C. (2014) Comparisons of Hybrid Multi-Objective Programming Algorithms with Grey Target and PCA for Weapon System Portfolio Selection Yajie Dou. *Applied Mathematics & Information Sciences*, 8(3), 1389–1399. DOI:10.12785/amis/080356

[9] Yu, Y., Zhang, J.B., Cheng, G., Schell, M.C., Okunieff, P. (2020) Multi-objective optimization in radiotherapy: applications to stereotactic radiosurgery and prostate brachytherapy. *Artificial intelligence in medicine*, 19(1), 39–51. https://doi.org/10.1016/S0933-3657(99)00049-4

[10] Zolfani, S.H., Maknoon, R., Zavadskas, E.K. (2016) Multiple attribute decision making (MADM) based scenarios. *International Journal of Strategic Property Management*, 20(1), 101–111. https://doi.org/10.3846/1648715X.2015.1132487

[11] Yucheng, D., Yating, L., Haiming, L., Francisco, C., Herrera-Viedma, E. (2018) Strategic weight manipulation in multiple attribute decision making. *Omega*, 75, 154–164. https://doi.org/10.1016/j.omega.2017.02.008

[12] Dean, M. (2020) Multi-criteria analysis. In: *Advances in Transport Policy and Planning*. N. Mouter (ed), Cambridge: Academic Press-Elsevier, 165–224. DOI:10.1016/j.ijar.2020.11.003

[13] Shuwei, C., Jun, L., Yang, X. (2021) A logical reasoning based decision making method for handling qualitative knowledge. *International Journal of Approximate Reasoning*, 129, 49–63. DOI:10.1016/j.ijar.2020.11.003

[14] Malczewski J., Jankowski, P. (2020) Emerging trends and research frontiers in spatial multicriteria analysis. *International Journal of Geographical Information Science*, 34(7), 1257–1282. https://doi.org/10.1080/13658816.2020.1712403

[15] Doorga, J.R.S., Hall, J.W., Eyre, N. (2022) Geospatial multi-criteria analysis for identifying optimum wind and solar sites in Africa: Towards effective power sector decarbonization. *Renewable and Sustainable Energy Reviews*, 158, 112107. https://doi.org/10.1016/j.rser.2022.112107

[16] Liu. H.C., Li, Z., Song, W., Su, Q. (2017) Failure Mode and Effect Analysis Using Cloud Model Theory and PROMETHEE Method. *IEEE Transactions on Reliability*, 66(4), 1058–1072. DOI:10.1109/TR.2017.2754642

[17] Maadi, M., Javidnia, M., Khatami, M. (2016) Business intelligence evaluation model in enterprise systems using fuzzy PROMETHEE. *Journal of Intelligence Studies in Business*, 6(3), 39–50. https://doi.org/10.37380/jisib.v6i3.195

[18] Morariu, D.I., Lepadatu, D., Serbanoiu, I. (2020) Multicriterial optimization of topo-geodetic techniques for behavior monitoring in service stage of civil engineering structures. *IOP Conference Series: Materials Science and Engineering*, 789(1), 012041. DOI:10.1088/1757-899X/789/1/012041

[19] Lepadatu, D., Morariu, D.I., Cherradi, T., Rotaru, A., Judele, L. (2019) ‘Smart technology optimization by multicriteria analysis of civil engineering structure in service stage through topo-geodetic monitoring’. In: *Proceedings of the 4th International Conference on Smart City Applications*, 71, 1–4. https://doi.org/10.1145/3368756.3369055

[20] Munn K., Dragićević, S. (2021) Spatial multi-criteria evaluation in 3D context: suitability analysis of urban vertical development. *Cartography and Geographic Information Science,* 48(2), 105–123. https://doi.org/10.1080/15230406.2020.1845981

[21] Hamurcu M., Eren, T. (2020) Selection of Unmanned Aerial Vehicles by Using Multicriteria Decision-Making for Defence. *Journal of Mathematics*, 4, 4308756, 1–11. https://doi.org/10.1155/2020/4308756

[22] Visual PROMETHEE Software Academic 2022. Retrieved from: http://en.promethee-gaia.net/academic-edition.html (Accessed on 14 December, 2021)

[23] Visual Promethee 1.4, Manual 2013. Retrieved from: http://en.promethee-gaia.net/assets/vpmanual.pdf (Accessed on 20 December, 2021)