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Multicriterial optimization of topo-geodetic techniques for behaviour monitoring in service stage of civil engineering structures

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Abstract. Optimization of civil engineering systems is a complex process that includes both theoretical and practical knowledge of experts from different disciplines. Optimization is defined as a rigorous process by which the methods corresponding to an engineering problem are analyzed and selected. The objective of this scientific paper is to define an optimal system / technique in monitoring the behaviour of civil engineering structures by topographic methods using the multi-criterial decision theory, by analyzing, combining and comparing some topographic methods and techniques used in monitoring the behavior of objectives by identifying decisional criteria (quantitative and qualitative) and applying one-or multi-criteria decisions. Finally, by choosing quantitative and qualitative criteria, we can establish the optimal techniques that correspond to the monitoring activity of the behaviour in service stage of civil engineering structures. The necessity for this optimal system that uses an algorithm is to reduce the risks and uncertainties that may arise from the monitoring process of buildings. Also, the results obtained must fulfil a certain accuracy, time and cost conditions, as well as their extent for other monitoring activities in topographical measurements.

1. Introduction

Specialized civil engineering structures are structures that require at least a scheduled, if not permanent, monitoring to be able to identify in a timely manner structural degradations that may lead to unwanted collapse and implicit loss of human life. Thus, depending on the size and importance of the monitored behavior of the objective in service stage involves significant costs that depend on several factors [1]. Multicriteria analysis is a complex investigation method by which the multidimensional definition space is searched for the combination that satisfies user requirements for efficient optimization of a process or phenomenon [2].

The multi-criteria decision provides a systematic methodology that combines these objectives sometimes conflicting [3] and can generate a compromise solution closer to the reality of complex decision-making issues that are almost impossible to solve [4]. Multicriteria decision-making methods, among which we can mention the Promethee method [5], are a necessary tool, but valuable in the decision-making process [6]. Using this method of multicriteria analysis [7] and optimization in the present paper, we were able to quantify in an intelligent manner and decide according to the scenarios, the method that meets the imposed criteria and constraints, sometimes quite difficult to accomplish.

2. Visual Promethee – multicriterial analysis software

Visual Promethee Gaia is a virtual program to help with multi-criteria decisions that has implemented the Promethee and Gaia concept. The software was developed under the supervision of Professor Mareshal Bertrand of the Solvay School of Economics and Management in Brussels, Belgium. In 1984, Bertrand Mareschal's first Promethee program was implemented differently from today's version and was difficult to adapt to computers.

Later, the software was ported to IBM computers, providing the basis for PromCalc [8]. PromCalc software was developed around 1990 by Bertrand Mareshal and Jean-Pierre Brans, being the only interactive and graphical program in the field of multicriteria decision making. With the development of Windows 95 and 98 at the end of the 90's, a new program emerged in the decision technique: Decision Lab 2000.

In 2010, D-Sight was created by Yves de Smet at the University of Brussels and is available for use. The development of Visual Promethee (figure 1) began in 2012 to provide a replacement for the Decision Lab program. A strong emphasis is placed on the quality and consistency of the user interface, the visualization of the aspects and the ease of use of the software, implementing the latest and most advanced developments in multicriteria decisions. The program is available in 4 versions: Demo Edition, Academic Edition, Business and Online Edition [8].

PROMETHEE
METHODS

Figure 1. Visual Promethee Gaia software interface.

The Visual Promethee Gaia program classifies criterias in two ways: quantitative (economic, technical, time) and qualitative (numerical value scale).

The advantages of using Visual Promethee Gaia software are: the easy use of the program and its applicability in vast areas, the setting of scenarios according to the importance of the group of criterias, the graphical representation of the criteria in the multicriteria decision that can provide clarity on choosing the most optimal solution.

3. Results and discussions

The case study in this scientific paper uses multicriteria analysis based on concrete data. The information on which the three scenarios were based on come from monitoring through topographic methods different types of civil engineering structures. Moreover, the tools presented in the scenarios below contain details from the observations the authors had made during topographic activity. Knowing the particularity of each topographic instrument is essential when the operator wants to obtain an optimized system. The multicriteria analysis in this part of the paper was organized on two sets of criteria: technical and qualitative.

Technical criteria include: precision, measurement distance, memory space and time. On the other hand, qualitative criteria are represented by: price, resources and autonomy. Thus, we have drawn up three selection scenarios on the optimal method / technique that meets the requirements of the structure's monitoring process. Each group of criteria introduced into the Visual Promethee Gaia processing program has been assigned ratios of importance.

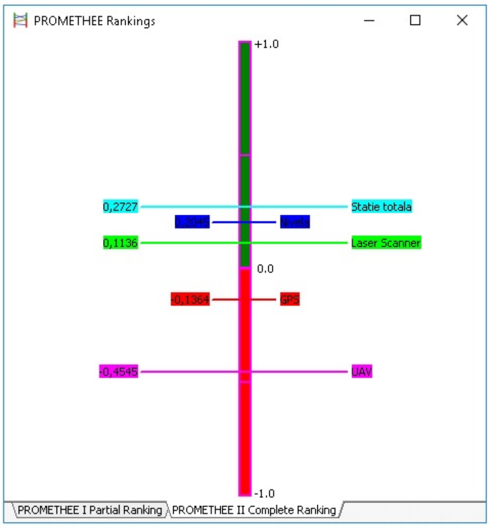
3.1. Scenario I

Scenario 1 was performed taking into account the absolute value of precision against the other criteria listed above. Accuracy influences directly the results of the monitoring, the better the observations of spatial displacements will have improved accuracy.

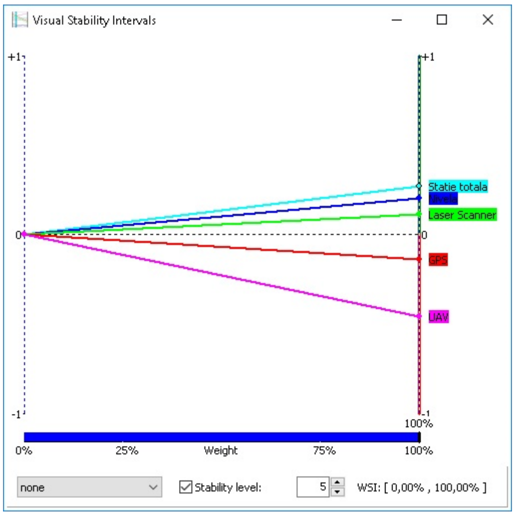
Table 1. Scenario 1-Accuracy.

Scenario 1	Level	Total Station	GPS	Laser scanner	UAV
Accuracy (mm)	7	15	30	20	30
Time (Hours)	4	2	1	2	1
Meas. Distanc (m)	100	1000	2000	200	50
Int. memory (Pts)	1000	17000	25000	50000	70000
Price (RON)	1000	1500	2000	3000	5000
Res. (operators)	3	2	1	1	1
Auton. (Hours)	4	5	6	6	1

The modern intelligent techniques presented in the figure 2 with which we can monitor engineering structures over time are: the level, the robotic total station, Global Positioning System (GPS), the laser scanner and the UAV. The data was introducing in the Visual Promethee Gaia program, where we obtained the following results (figure 2):



Ranching



Stability

Figure 2. Scenario I – Maximum accuracy.

3.2. Scenario II

Scenario 2 is rendered by the influence of time value. Time depends on several factors: measurement distance, storage space, resources and autonomy of topographic tools. The robotic total station, laser scanner and UAV have time values assigned to the process of the monitored structure for at least one hour. This also depends on the size of the target, visibility to all landmarks and weather conditions (wind, rain, excessive heat). In the case of unmanned aerial vehicle flight, these factors are important because the process can only take place in circumstances beneficial to this type of technique.

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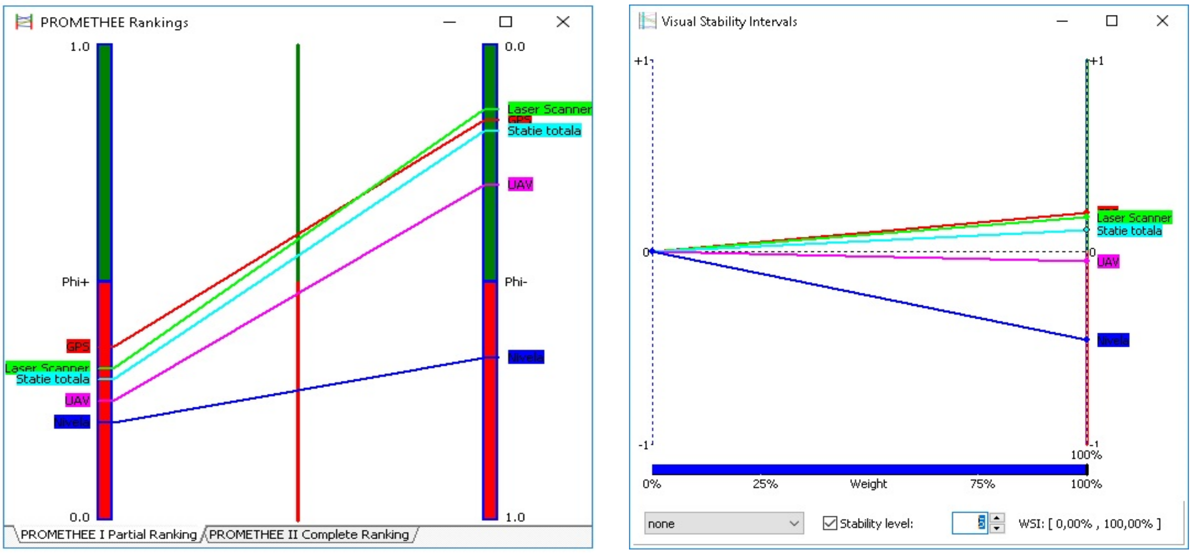
Table 2. Scenario 2-Minimum time.

Scenario 2	Level	Total Station	GPS	Laser scanner	UAV
Accuracy (mm)	3	4	10	5	5
Time (Hours)	4	1	1	1	1
Meas. Distanc (m)	100	1000	2000	100	50
Int. memory (Pts)	1000	20000	30000	30000	50000
Price (RON)	1000	1500	1500	2000	2500
Res. (operators)	2	2	1	1	1
Auton. (Hours)	5	6	6	6	1

Also, the number of resources for laser scanning and UAV is minimum an operator and the autonomy is maximum of 6 hours, during which the spatial of the engineering structure can be recorded with the total station and laser scanning. The data processed using the Promethee method were materialized in graphical form (figure 3).



Ranching Stability

Figure 3. Results processed with Promethee method for Scenario II.

As against Scenario 1, the results of the vertical spatial displacements, where the accuracy was taken into account, Scenario 2 was based on the value of time. Thus, the laser scanner is the optimal technique to monitor the behavior of a civil engineering structures in service stage according to the time criterion. The values obtained in both charts: Promethee I Partial Ranking and Visual Stability Intervals classify the method on the first place, followed by the small difference of the robotic total station.

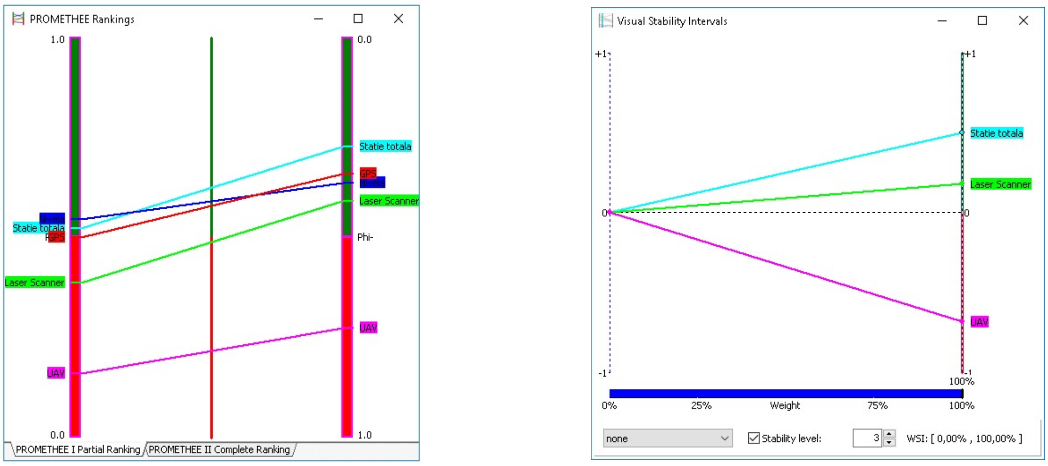
3.3. *Scenario III*

Scenario 3 was based on the introduction of the seven quantitative and qualitative criteria, but the results were obtained on the basis of the Global Cost criterion. This includes: the number of operators, the precision of the equipment and the time allocated to the determination of the spatial displacements. Following the latest software analysis we have obtained the following results:

Table 3. Scenario 3-Global Cost.

Scenario 3	Level	Total Station	GPS	Laser scanner	UAV
Accuracy (mm)	4	5	10	5	15
Time (Hours)	3	2	1	1	1
Meas. Distanc (m)	100	1500	2000	150	50
Int. memory (Pts)	1000	20000	30000	50000	60000
Price (RON)	1000	2000	3000	5000	6000
Res. (operators)	2	2	1	1	1
Auton. (Hours)	4	6	6	6	1

Following study 3 of the global cost of time monitoring of spatial displacements, we can see that the total robotic station corresponds to the minimum process cost criterion. The other two techniques are at a very large difference from the total station.



Ranching Stability

Figure 4. Results processed with Promethee method for Scenario III.

Finally, we compared the three scenarios to be able to apply the decision criteria for the optimal technique for monitoring engineering structures. Each scenario had the same criteria introduced, but the values differed in the precision, time and total costs. Also, the results were influenced by the measure distance, number of operators, autonomy and memory space.

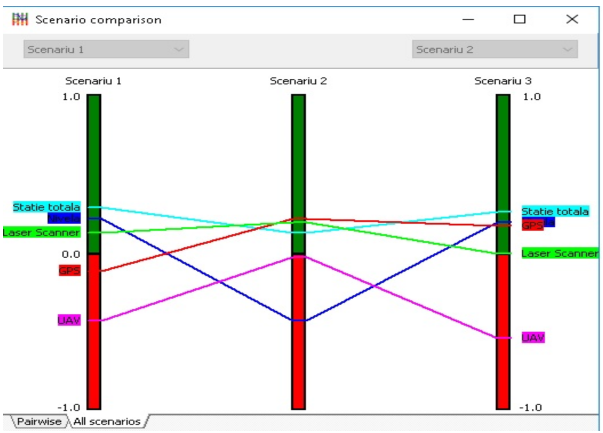


Figure 5. Comparative analyses for the three scenarios.

Thus, after analyzing the three situations, it is noticed that the total robotic station corresponds to the criteria: precision, time and cost. On the other hand, level can be used to monitor a civil engineering structure over time, depending on the purpose of the building and its size. Also, operator experience and professional software is required to achieve high accuracy results. The tools used in the process of monitoring are what we call smart technology optimization as being the latest generation instruments and definitely contribute to increasing the efficiency and accuracy of the monitoring process in time of civil engineering structures in service stage. We can add that this process is a mandatory one for the structures of the type presented (vital importance class) and also the precision and accuracy of the results can contribute in a significant manner to the disaster prevention caused by the loss of structural stability due to the undesirable appearance of some structural displacements that are not admissible.

4. Conclusions

Multicriteria optimization is an advanced analysis and optimization method that allows the user to obtain the desired response while taking into account several parameters that ultimately lead to a compromise between conditions or criteria that may be antagonistic, making it difficult to establish an alternative technique efficient to solve such problems. Thus, with this method several objective functions have to be optimized at the same time, and it is possible to determine the combination of control parameters of a process or phenomenon that simultaneously maximizes one and minimizes others. The process is based on two types of information: the partial importance of the criteria and the characteristics of the decision when the user compares the yield offered by each criterion.

In this paper we performed a multicriteria optimization using the Promethee method and Visual Promethee Gaia program through which we managed to rank in a professional manner a complex problem that allowed us to take into account the control parameters of the topo-geodetic monitoring process in the process of studying the behavior of civil structures in service stage and constraints that we could not quantify with other optimization methods. The final comparison showed that the robotic total station and the level are the most efficient tool in user-defined conditions and level of precision.

Within the monitoring in time of a civil engineering structure in service stage, the system will be optimized according to the accuracy, that is an important condition for the precision of the results, the time allotted to the operations necessary to obtain the results, but also their costs. The method comprises several objective functions that must be optimized at the same time and the combination of the control parameters of a process or phenomenon can be determined which simultaneously maximizes one and minimizes the other.

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