Smart technology optimization by multicriteria analysis of civil engineering structure in service stage through topo-geodetic monitoring

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ABSTRACT

The monitoring of civil engineering structures in service stage that could represent a major risk in case of structural degradation is mandatory. In this context, the methods or techniques used to achieve this objective require primarily human, financial and material means that can generate very high costs. This paper will present a multicriteria optimization of the most advanced technologies for monitoring civil engineering structures in service stage. In this way, modern monitoring instruments of spatial displacements of a viaduct type structure will be analyzed such as - monitoring using 3D Laser Scanner and UAV and 3D Scanner - Robotic Station. It is an engineering structure, viaduct type, over 50 years old, with a length of 1.3 kilometers. The objective is in the North-West part of Galati, Romania and represents an important access road connecting Galati city to the platform of ArcelorMittal steel company requiring regular observation even a permanent monitoring. The compromise solution will be given by the user according to the objectives imposed using the Promethee method. Multicriteria analysis will be performed using Visual Promethee. Monitoring has been done over three cycles with three types of equipments.

Keywords

Smart monitoring technology; Multicriteria optimization; topo-geodetic equipment; civil engineering structures.

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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 (Morariu D.I and Lepadatu D. 2018). The optimization process is very complex in the first place because it depends on many factors, sometimes even unknown (Teodoriu G., Serbanoiu I., 2013). Therefore, any process or phenomenon involves optimization solutions that may vary depending on the user's objectives and their hierarchy is rather heavy. 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 (Matthias E. et all, 2010). The multi-criteria decision provides a systematic methodology that combines these objectives sometimes conflicting and can generate a compromise solution closer to the reality of complex decision-making issues that are almost impossible to solve (Seddiki M., 2016). Multicriteria decision-making methods, among which we can mention the Promethee method (Taillandier P and Serge Stinckwich S. 2010), are a necessary tool, but valuable in the decision-making process (Radulescu C. Z., 2015). Using this method of multicriteria analysis (Zopounidis C and Pardalos P. M, 2010) 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. MATERIAL AND METHOD

2.1 Visual Promethee – multicriterial analysis software

Visual Promethee Gaia is a virtual program that comes to the aid of multicriteria decisions having implemented the concept of the Promethee and Gaia methods (Visual Promethee Manual). The software was developed under the supervision of Professor Mareshal Bertrand from the Economics Solvay School and

Management in Brussels, Belgium. In 1984, the first Promethee program was implemented by Bertrand Mareschal, being different from today's version and being difficult to adapt on computers. Later, the software was ported to IBM computers, providing the basis for PromCalc (Manual Visual Promethee). The software PromCalc was developed around 1990 by Bertrand Mareshal and Jean-Pierre Brans, being the only interactive and graphic program in the field of multi-criteria decision. With the evolution of Windows 95 and 98 in the late 1990s, a new program has emerged in Decision Techniques: Decision Lab 2000 (VP Solutions, 2013). In 2010, D-Sight was created by Yves de Smet from the University of Brussels, being valid for use. Development of Visual Promethee (Figure) began in 2012 to provide a replacement for the Decision Lab program (VP Solutions, 2013). A strong emphasis is placed on the quality and consistency of the user interface, the visualization of aspects and the ease of use of the software, implementing the latest and most advanced developments in multicriteria decisions (VP Solutions, 2013). The program is available in 4 versions: Demo edition, Academic edition, Business and Online edition (VP Solutions, 2013).

PROMETHEE
METHODS

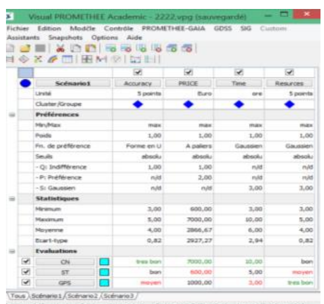


Figure 1. Visual Promethee Gaia software interface

Visual Promethee Gaia is designed for (VP Solutions, 2013):

• evaluating several decisions or elements according to several criteria, sometimes contradictory;

• identifying the best decision;

• classifying decisions from the best to the weakest;

• sorting elements in predefined classes;

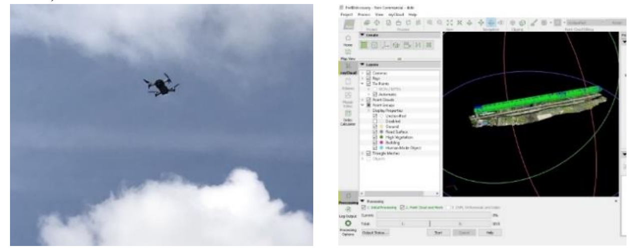
•visualizing decision-making issues to understand the difficulties in choosing the right solutions;

• justification or invalidation of decisions based on objective elements (VPS, 2013).

The Visual Promethee Gaia program classifies the criteria in two modess: quantitative (economic, technical, duration) and qualitative (numerical value scale) (VP Solutions, 2013).
The advantages of using the Visual Promethee Gaia software are: the simplicity of the use of the program and its applicability in wide areas, the setting of scenarios according to the importance of the criteria group, the graphical representation of the criteria in the multicriteria decision that can provide clarity on the choice of the optimal solution.

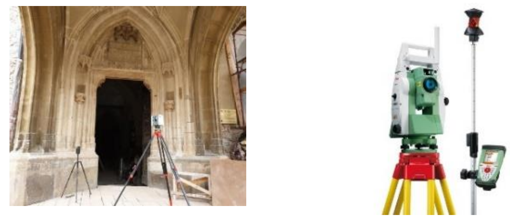
2.2 Smart monitoring equipment

For structure monitoring, three topo-geodic devices cutting-edge were used. So, we used a UAV Mavic Air, Laser scanner Leica P50 and Leica TS 12 total station.



a. UAV Mavic Air b. Point cloud-UAV Pix4d

Figure 2. Unmanned Aerial Vehicle and results



a) Laser scanner b) Total Station Leica TS 12

Figure 3. Smart tools

The parameters of the equipment used can be found in the following table.

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	150 0	2	5
Laser Scanner	20	2	200	250000	300 0	1	6
UAV	30	1	80	300000	300 0	1	1

For multicriteria optimization three scenarios were proposed to be presented and analyzed below. The use of smart technologies when monitoring vital civil engineering structures is necessary because the value of the accuracy in the results is an important issue due to obtaining the spatial displacements faster and more precise. Other authors (Alizadeh 2017, Alizadeh et all. 2018), such as Scaioni (Scaioni et all, 2018), used optimization methods for monitoring special civil engineering structures such as dams with smart technologies: robotic total station and Global Navigation Satellite System, for measuring the spatial displacements. Also, optimizing the methods in the monitoring process can help the operators to choose the best instrument that will provide best results concerning time, costs and accuracy.

3. RESULTS AND DISCUSSIONS

3.1 Introduction

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.

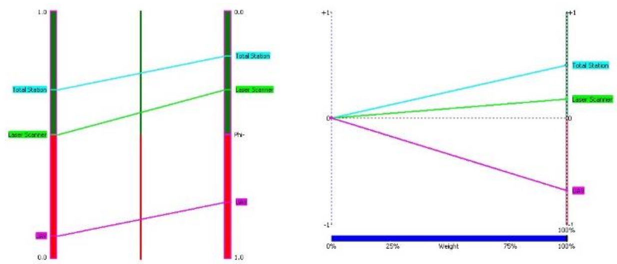
3.2 Scenario I

Scenario 1 was performed taking into account the absolute value of the accuracy compared to the other criteria listed above. Accuracy directly influences the results of the monitoring. The better the observations of space travel will have improved accuracy.

Table 2. Scenario 1-Accuracy

Scenario 1	Total Station	Laser scanner	UAV
Accuracy (mm)	15	20	30
Time (Hours)	1	2	1
Meas. Distanc (m)	1000	200	80
Int. memory (Pts)	30000	250000	100000
Price (RON)	1500	3000	5000
Res. (operators)	2	1	1
Auton. (Hours)	5	6	1

The modern intelligent techniques presented in the Figure 4 with which we can monitor engineering structures over time are: the robotic total station, the laser scanner and the UAV. The data was introduces in the Visual Promethee Gaia program, where we obtained the following results (Figure 5):



Ranching Stability
Figure 5. Scenario I – Maximum accuracy

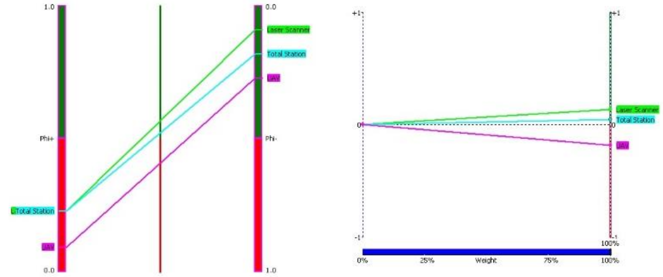
3.3 Scenario II

Scenario 2 is played by the influence of the times value. The time depends on several factors: the distance of measurement, the storage space, resources and the autonomy of the topographic instruments. The total robotic station, the laser scanner and the UAV have as values of the time allotted to the process of tracking the structures at least one hour. This also depends on the size of the objective pursued, the visibility to all landmarks and the weather conditions (wind, rain, excessive heat). In the case of unmanned aerial vehicle flying, these factors are important because the process can only take place under circumstances that are beneficial to this type of technique.

Table 3. Scenario II – Minimum time

Scenario 2	Total Station	Laser scanner	UAV
Accuracy (mm)	4	5	5
Time (Hours)	1	1	1
Meas. Distance (m)	1000	100	50
Internal memory (Pts)	20000	50000	50000
Price (RON)	1500	2000	2500
Resources (operators)	2	1	1
Autonomy (Hours)	6	6	1

Also, the number of resources for laser scanning and UAVs is at least one operator, and the maximum autonomy is 6 hours, during the time of spatial displacements of the engineering structure can be recorded using the total station and laser scanning. The data processed using the Promethee method were materialized in graphical form (Figure 7).



Ranching Stability
Figure 7. Results processed with Promethee method for Scenario II

Compared to Scenario 1, where the accuracy of the results of vertical space shifts was taken into account, Scenario 2 was based on the time value. 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 in the first place, followed by the small difference of the robotic total station.

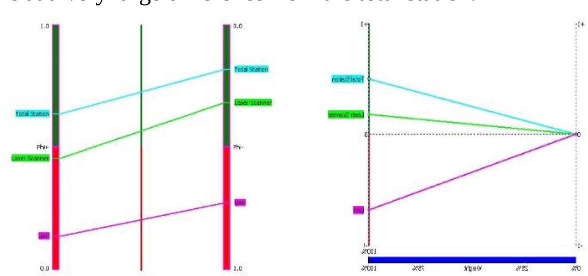
3.4 Scenario III

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 4. Scenario III – Global Cost

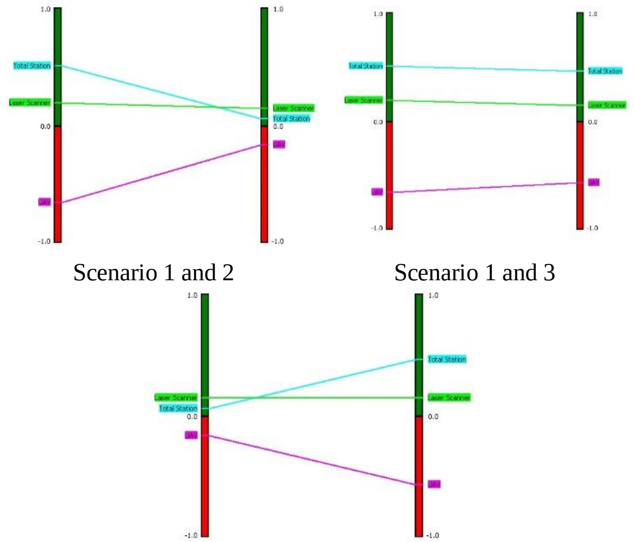
Scenario 2	Total Station	Laser scanner	UAV
Accuracy (mm)	5	5	15
Time (Hours)	2	1	1
Measurement Distance (m)	1500	150	50
Internal memory (Points)	20000	50000	60000
Price (RON)	2000	5000	2500
Resources (operators)	2	1	1
Autonomy (Hours)	6	6	1

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 9. 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.



Scenario 1 and 2 Scenario 1 and 3

Scenario 2 and 3

Figure 10. 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, laser scanning can be used to monitor a civil engineering structure over time, depending on the purpose of the building, its size and the comparison of several profiles made up of point clouds. 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.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 is the most efficient tool in user-defined conditions and level of precision.

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