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Multi-Criteria Decision-Making in Construction Using the Software Decision Lab 2000

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ABSTRACT

Decision making is a demanding process, and the consequences of making the wrong decision can have a negative impact on the business. To make successful decisions, a person must be able to predict the outcome of each option and determine which variant is best for a particular situation. In construction, the project manager must be able to decide which combination of construction machines is best for the execution of a job, although many criterions have influence on that decision. Multi-criteria decision-making is a complex process, but with the help of software problems can be quickly and successfully solved and solution can be analyzed. The aim of this paper is to show the support of Decision Lab 2000 software in the decision-making process in construction using the multi-criteria decision-making method PROMETHEE-GAIA.

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1. Introduction

The process of choosing construction machinery starts with a comparative analysis of concrete works and available machines. A wider selection of machines provides insight into their participation in performing certain operations. When choosing machines and their interconnection, it is necessary to take care that mechanized work takes place without downtime. In order to be able to make the right choice of machines for a particular job, it is necessary to know the basic operational and design characteristics of construction machines, which can be applied. In addition, good knowledge of construction technologies is necessary, in order to break down the technological process into parts, operations and procedures, as well as knowledge of the conditions of execution of works (Pamucar and Savin, 2020), (Milosevic et al., 2021).

The following factors especially affect on the choice of construction machinery: location of the facility and weather conditions of construction, condition of existing machinery owned by the contractor, possibility to lease machinery from companies that are in the same corporation (or from the same country, for foreign construction sites). All this indicates that there is no single solution to all the problems of mechanization selection and that a solution is sought for each larger "construction site", taking into account all the specifics of the specific case (Youssef and Webster, 2022).

Therefore, more criterions have influence on the choice of solution. The optimal solution can be determined using multi-criteria optimization, i.e. by evaluating a set of possible solutions or alternatives in relation to a given set of criteria (Alosta et al., 2021). Today, there are many methods for multi-criteria optimization, and one of them is the PROMETHEE - GAIA method, for which there is Decision Lab 2000 software and Visual PROMETHEE software, which can facilitate and speed up the process of determining the most favorable combination of machines.

2. PROMETHEE –GAIA Method

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method is one of the latest in the field of multi-criteria analysis. It consists of a family of methods (1,2,3,4,5,6).

PROMETHEE 1 and PROMETHEE 2 were developed by Professors J. P. Brans, B. Marescha, and P. Vincke (1984). A few years later Brans and Mareschal had developed the PROMETHEE 3 and PROMETHEE 4 methods. In 1988, the same authors proposed a visual interactive modulation of GAIA, which provides a graphical interpretation of the PROMETHEE method in 1992, and in 1992 5 and PROMETHEE 6.

The PROMETHEE - GAIA method is known as the most efficient and easiest method used in multi-criteria decision making, especially with the development of Decision Lab 2000 software.

In PROMETHEE method we use the decision matrix R, for which the names payoff, rating or performance matrix are also common. Each row of the matrix corresponds to one alternative, and each column to one criterion; element r_{ij} represents the rating (performance) of the alternative a_j in relation to the criterion C_i. For I criteria $(C_1, C_2, ..., C_I)$ and J alternative $(a_1, a_2, ..., a_J)$ the matrix R has the form (2.1), and the values $(w_1, w_2, ..., w_I)$ are entered above the matrix represent the weight values of the criteria defined by the decision maker, or otherwise determined. The sum of these weight values is 1.

$$
\begin{array}{cc}
 & \begin{array}{ccccc} C_1 & C_2 & . & . & C_I \\ w_1 & w_2 & . & . & w_I \end{array} \\
R = \begin{array}{c} a_1 \\ a_2 \\ . \\ . \\ a_J \end{array} & \begin{bmatrix} r_{11} & r_{12} & . & . & r_{1I} \\ r_{21} & r_{22} & . & . & r_{2I} \\ . & . & . & . & . \\ . & . & . & . & . \\ r_{J1} & r_{J2} & . & . & r_{JI} \end{bmatrix}
\end{array}
$$

In order to make a good decision, it is necessary to specify alternatives by defining appropriate criteria. It is also necessary to define the weighting coefficients for each criterion, i.e. the importance of each criterion in relation to the others. Weights are usually numbers that are subjectively chosen. In addition, for each criterion, it is determined whether it is necessary to choose an alternative so that the criterion is minimal or maximum, or what is the nature of that criterion. Since each criterion is measured in a specific way, the preference function $Pi\ (a_j, a_m)$ is defined for each, which defines the intensity of the difference between the alternatives a_j and a_m.

The evaluation of alternatives consists in determining the index of multi-criteria preference $\Pi(a_j, a_m)$. The ranking of alternatives is done according to the decreasing values of the preference index. $\Pi(a_j, a_m)$ shows how much the alternative a_j is better (more favorable) than the alternative a_m, considering all the criteria. The value of the preference index ranges from 0 to 1. If $\Pi(a_j, a_m) = 0$, then alternative a_j is not better (no difference) than alternative a_m by all criteria. If $\Pi(a_j, a_m) = 1$, then the alternative a_j is much better (complete dominance) than the alternative a_m by all criteria.

Ranking of alternatives is done based on preference flows. The positive flow of preference $\Phi^+{}_j\ (a_j)$ shows that alternative a_j is better (more favorable) compared to other alternatives. The best alternative has the highest value of the positive flow of preference Φ^+. The negative flow of preference $\Phi^-{}_j\ (a_j)$ shows that all other alternatives are better (more favorable) compared to alternative aj. The best alternative has the lowest value of the negative flow of preference Φ^-. The net flow of preference Φ represents the difference between the positive and negative flow of preference and the higher its value, the better (more favorable) the alternative.

3. Application of PROMETHEE – GAIA Method on a Practical Example

The paper presents an example of the application of multi-criteria optimization in the choice of construction machinery for concrete works, where the optimal compromise solution is obtained using the PROMETHEE-GAIA method, using the software *Decision Lab 2000*.

The phase of performing concrete works on the business facility was taken as an illustrative example, which is located in the village of Turjak, municipality of Gradiška (Šmitran, 2009).

When we are solving the problem of choosing mechanization for concrete work on the construction site, we should solved the mechanization of the following work operations:

- concrete management,

- external transport of concrete from concrete factory to the construction site,
- transshipment on the construction site,
- internal transport of concrete on the construction site,
- compacting concrete,
- internal transport of formwork (shuttering) and steel reinforcement on the construction site,
- concrete care.

Five combinations of machines (alternatives) have been formed as possible variants of mechanization for performing concrete works on a certain business facility (Šmitran, 2009).

A set of 4 criterion functions has been adopted for multi-criteria optimization:

1. **The actual cost** of operating the system per effective hour, which includes the cost of labor, machinery and materials,
2. **The total duration** of the works is determined from the network plan, summarizing the times from the critical path for performing the designed works (Šmitran, 2009). For each alternative, the total duration of the works is shown in Table 1,
3. **Total expected time** of machine repairs,
4. **Total number of workers** (machinists).

The values of the criterion functions are shown in Table 1, and are taken from the thesis (Šmitran, 2009).

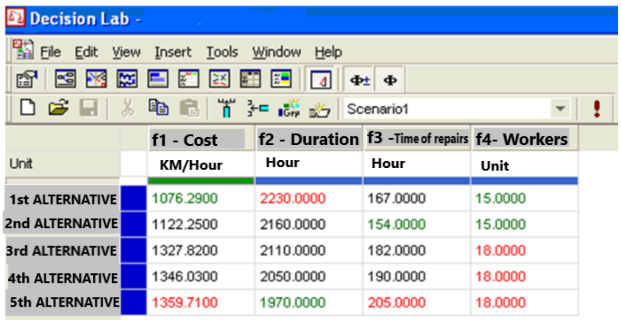
Table 1. Criterion functions (Šmitran, 2009)

	Criterion functions			
Name	f_1 - Cost	f_2 - Duration	f_3 – “Time of repairs“	f_4 – Workers
Unit	KM/ Hour	Hour	Hour	Unit
Ekst.	min	min	min	min
w_i	0,30	0,35	0,20	0,15
Alternatives A1	1076,29	2230	167	15
A2	1122,25	2160	154	15
A3	1327,82	2110	182	18
A4	1346,03	2050	190	18
A5	1359,71	1970	205	18

For each criterion function, a simple preference function is adopted, i.e. Type I ("simple criterion").

4. Problem Solving Using Decision Lab 2000 Software

Figure 1 shows a table with the data obtained after entering the data from Table 1 into the Decision Lab 2000 software.



	f1 - Cost	f2 - Duration	f3 - Time of repairs	f4- Workers
Unit	KM/Hour	Hour	Hour	Unit
1st ALTERNATIVE	1076.2900	2230.0000	167.0000	15.0000
2nd ALTERNATIVE	1122.2500	2160.0000	154.0000	15.0000
3rd ALTERNATIVE	1327.8200	2110.0000	182.0000	18.0000
4th ALTERNATIVE	1346.0300	2050.0000	190.0000	18.0000
5th ALTERNATIVE	1359.7100	1970.0000	205.0000	18.0000

Figure 1.

The ranking of alternatives is done based on the values of the preference flows Φ^+ and Φ^- and the net preference flow Φ. The best alternative has the highest value of the positive flow of preference Φ^+, the lowest value of the negative flow of preference Φ^- and the highest value of the net flow of preference Φ.

We can see in the Figure 2. that the best solution is the 2nd alternative.

Preference Flows

	Φ+	Φ−	Φ
1st ALTERNATIVE	0.5625	0.4000	0.1625
2nd ALTERNATIVE	0.6250	0.3375	0.2875
3rd ALTERNATIVE	0.4250	0.5000	-0.0750
4th ALTERNATIVE	0.3875	0.5375	-0.1500
5th ALTERNATIVE	0.3500	0.5750	-0.2250

Figure 2.

The Decision Lab 2000 software graphically displays the results of ranking alternatives.

Figure 3 shows the ranking of alternatives by the PROMETHEE 1 method. This method performs a partial evaluation of the positive negative flows (deviations) of the preference functions Φ^+ and Φ^- , on a set of criteria for each alternative. As a result, not all alternatives need to be ranked one after the other. In this case, all alternatives are ranked one after the other, as we can see in the Figure 3.

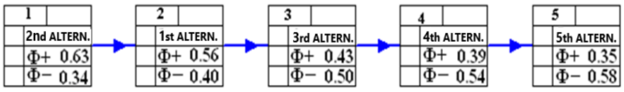


Figure 3.

Figure 4 shows the ranking of the alternative according to the PROMETHEE 2 method. This method realizes a complete evaluation of the alternatives, using the net flow (deviation) of the preference function Φ. All alternatives are ranked one after the other, from the best to the worst.

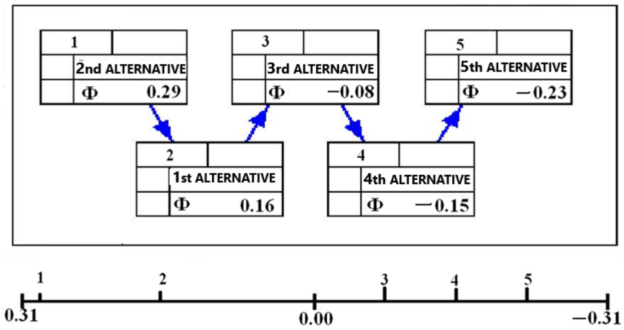


Figure 4.

It is obvious, that the ranking of alternatives using the methods PROMETHEE 1 and PROMETHEE 2 was done according to the coefficients of weight of the criteria. A special feature of the software called "THE WALKING WEIGHTS" allows the initial weights of the criteria to be modified, i.e. changes and to display the results of the modification graphically using the PROMETHEE 2 method, which is shown in Figure 5.

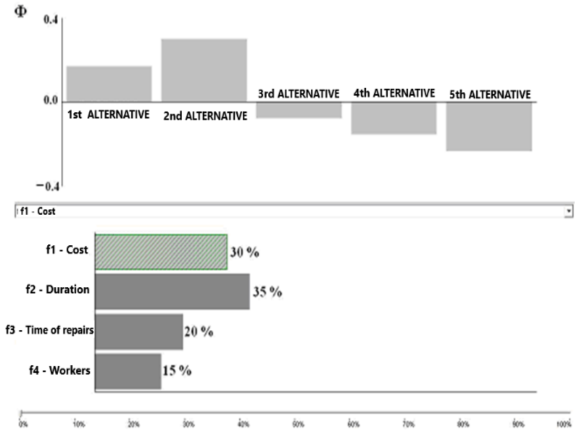


Figure 5.

The results can also be graphically displayed, as shown in Figure 6.

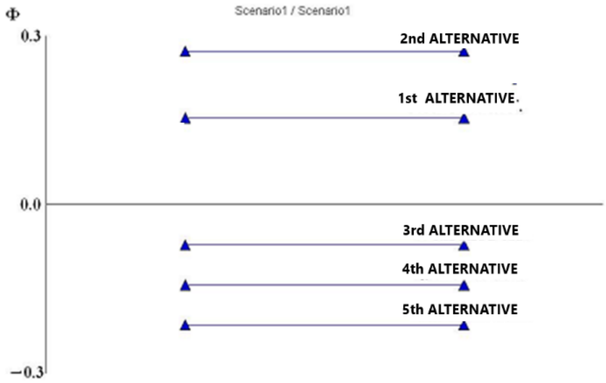


Figure 6.

Information about the problem of multi-criteria decision-making, which has *i*-criteria, can be displayed in *i*-dimensional space.

A GAIA plan is a plan obtained by projecting all information into two-dimensional space. In the GAIA plan, alternatives are represented by triangles, and criteria by axes. The conflicting characteristics of the criterion are clearly shown in the diagram, the conflicting criterion is oriented in opposite directions (directions), while the criterion that has a similar preference (advantage) is oriented in the same direction. In Figure 7, we can see that the price and duration criteria are shown as opposing criteria. It is also possible to clearly classify the qualities of alternatives according to the given criteria. It is obvious then that the 2nd alternative is especially good in relation to the 3rd and 4th criterion (duration of repairs and number of workers), while the 1st alternative is in relation to the 1st criterion (price), and the 5th alternative in relation to 2nd criterion (duration).

In addition to the presented alternatives and criteria, in the GAIA plan we also have the vector π, which represents the projection of the weight vector w_i. The vector π shows the direction of the compromise solution. In this way, the decision maker can decide for himself which solution is the best.

If π vector is longer, then the decision axis (s) is richer with the number of solutions that can make it easier for the program user to decide which solution is best. If π vector is shorter, then the decision axis (s) is poorer with the number of solutions and then it is difficult for the program user to decide which solution is best because he thinks the criteria are very conflicting.

According to the position of the vector π in the GAIA plan (Figure 7), it can be concluded that the best compromise solution is the 2nd alternative. The same was obtained by the methods of PROMETHEE 1 and PROMETHEE 2.

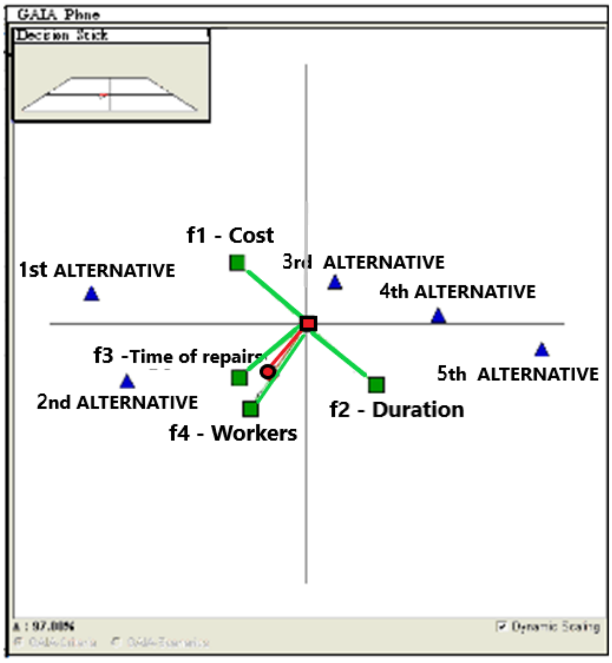


Figure 7.

The ranking list of alternatives obtained by both PROMETHEE 1 and PROMETHEE 2 methods is the same and looks like this:

A2 , A1 , A3 , A4 , A5.

If the weight coefficients of the criterion change, the configuration of the alternatives and the criteria remains stay the same, while the direction of the π axis of the vector changes.

Using the WALKING WEIGHTS option, the weight coefficients of the criteria were equalized for each criterion and based on that new values of preference flows Φ^{+} and Φ^{-} and net preference flows Φ were obtained, and the 2nd alternative (2nd machine combination) was shown as the most favorable compromise solution.).

The ranking of alternatives obtained by both PROMETHEE 1 and PROMETHEE 2 methods has stayed the same and looks like this:

A2 , A1 , A3 , A4 , A5.

5. Conclusion

Methods of multi-criteria analysis are being developed in the direction of enabling greater, creative, systematic involvement of decision makers in the process of making optimal decisions, using computers. Using a computer and the appropriate computer software gives more reliable results, makes work easier and saves time.

The application of the above-mentioned method is significantly facilitated by the use of *Decision Lab 2000* software and *Visual PROMETHEE* software, which in a very simple and fast way propose the final solution and clearly show the obtained results, using a graphical representation

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