Applying Verbal Decision Analysis on the Choice of Materials to the Construction Process of Earth Dams

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Abstract. The choice of materials to be used on the construction of earth dams is made in an empirical way, taking into account previous projects and the experience of the involved engineers. An engineer often specifies the materials and their quantities that will be used based on previous projects, on the geotechnical information about the materials available and on common sense. In order to improve this process we propose a multicriterion model to aid in the decisions making concerning the choice of materials on the construction of earth dams with homogeneous and zoned sections. This will be made by means of the Aranaú Tool, a decision support system mainly structured on the ZAPROS method. The case study was applied to the dam Frios project (Ceará, Brazil).

Keywords: Verbal Decision Analysis, Construction of Earth Dams, ZAPROS.

1 Introduction

The search for places where there was plenty of water has always been a constant. In places where water was scarce there was a need to create mechanisms that would guarantee its storage, this gave rise to the need of the construction dams for its purpose (ICOLD, 1999 in [12]). A dam represents a human intervention in nature with the aim of adapting the patterns of natural water flow to the standards demanded by society [2].

In the nineteenth century, around the year 1853, in France, De Sazilly introduces the Engineering of Dams to make its construction something structured in mathematical calculations in order to prove the efficiency of projects [4].

The construction of earth dams is being enhanced every day due to the technological development of machinery of implementation and construction techniques [10]. However, decisions on important aspects such as the type of material to be used, are taken from an empirical and subjective way, without the guarantying its construction with the lowest cost.

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The aim of this paper is to present a modeling process applying a multicriteria method to help in the decision making on the construction of earth dams in order to minimize the materials cost but guarantying a good quality construction.

Multicriteria methodologies help to generate knowledge about the decision context, thus, increasing the confidence of those who make decisions on the results [5]. There are multicriteria methods based either on quantitative ([3,**?**]) or qualitative ([13,**?**]) analysis of the problem, and it is a great challenge to choose the approach that best fits the problem to be solved.

This work focuses on the application of a modification of the ZAPROS method [7], which belongs to the Verbal Decision Analysis framework, in order to solve problems in a more realistic way from the decision maker's point of view, since quantitative methods could lead to loss of information when one tries to assign exact measures to verbal values. The ZAPROS method was chosen among other available methods because it fits the characteristics of the contexts questioned, considering the evaluation of the problem, the decision objects and the available information.

2 The Problem of Choosing the Materials for the Construction of Earth Dams

The materials used in the construction of earth dams' process are usually available in mines either in the place of the dam or nearby [16]. The exploration of these mines is not always accessible, since this will generate additional expenses, such as for deforestation or for renting the area (if it is on private property).

Each mine has one or more materials available [1], and the transportation of these materials to the place where the dam is being constructed may require a high cost even though the materials are in the same mine, because of the extraction difficulty. Besides, the volume of material needed on the construction may vary depending on the type used.

After the extraction and transportation, the soils usually loose part of their moisture. To correct these deviations, it is applied a compression process. There are several types of compression that may be applied to soils, and each soil requires a different amount of water, which is obtained and transported from variable cost sources. For each type of compression, the cost dependent directly on the soil to be compacted, because these have different compression curves, requiring, then, a determined compression effort [8].

An earth dam can be classified as homogeneous or zoned, according to the amount and types of materials used in the massive construction [16]. The decision making about which types of materials and compression will be used, which deposits will be explored and if the dam should be zoned or homogeneous is quite complex. Thus, the problem of the construction of a dam can be stated as follows: "To build an earth dam by selecting the deposits, materials, water sources and types of compression that will lead to a lower-cost construction, considering also the transport costs of the material and of water used in the soil compression, the section type of the dam and the compression process used."

3 An Approach Methodology Based on ZAPROS

A modification to the ZAPROS method [7] is proposed on [14], in order to increase the comparison power of the method. It presents three main stages: Problem Formulation, Elicitation of Preferences and Comparison of Alternatives. An overview of the approach is presented bellow.

3.1 Formal Statement of the Problem

The methodology follows the same problem formulation proposed in [7]:

Given:

1) K = 1, 2,..., N, representing a set of N criteria;

2) n_q represents the number of possible values on the scale of q-th criterion, $(q \in K)$; for the ill-structured problems, as in this case, usually $n_q \leq 4$;

3) $X_q = x_{iq}$ represents a set of values to the q-th criterion, which is this criterion scale; $|X_q| = n_q(q \in K)$; where the values of the scale are ranked from best to worst, and this order does not depend on the values of other scales;

4) $Y = X_1 * X_2 * ... * X_n$ represents a set of vectors y_i, in such a way that: $y_i = (y_{i1}, y_{i2}, ..., y_{iN})$, and $y_i \in Y$, $y_{iq} \in X_q$ and $P = |Y|$, where $|Y| = \prod_{i=1}^{i=N} n_i$.

5) $A = \{a_i\} \in Y$, i=1,2,...,t, where the set of t vectors represents the description of the real alternatives.

Required: The multicriteria alternatives classification based on the decision maker's preferences.

3.2 Elicitation of Preferences

In this stage, the scale of preferences for quality variations (Joint Scale of Quality Variations - JSQV) is constructed. The elicitation of preferences follows the order of steps shown in Fig. 1 [14]. This structure is the same proposed in [7]; however, substages 2 and 3 (numbered on the left side of the figure) were put together in just one substage.

Instead of setting the decision maker's preferences based on the first reference situation and, then, establishing another scale of preferences using the second reference situation, we propose that the two substages be transformed in one. The questions made considering the first reference situation are the same as the ones made considering the second reference situation. So, both situations will be presented and must be considered in the answer to the question, in order not to cause dependence of criteria. The alteration reflects on an optimization of the process: instead of making 2n questions, only n will be made. The questions to Quality Variations (QV) belonging to just one criteria will be made as follows: supposing a criterion A having $X_A = A_1, A_2, A_3$, the decision maker will be asked about his preferences between the QV $a_1 - a_2$, $a_1 - a_3$ and $a_2 - a_3$. Thus, there is a maximum of three questions to a criterion with three values ($n_q = 3$).

The question will be formulated dividing the QV into two items on the preferences elicitation for two criteria, because there were difficulties in understanding and delay in the decision maker's answers when exposing the QV of different criteria.

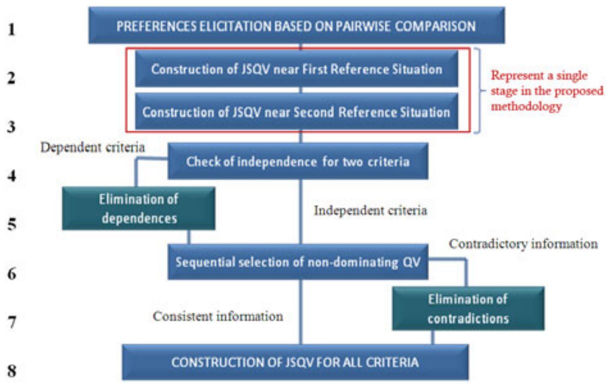

Fig. 1. Elicitation of preferences process

3.3 Comparison of Alternatives

With the aim of reducing the number of incomparability cases, we apply the same structure proposed in [7], but modifying the comparison of pairs of the alternatives' substage according to the one proposed in [9]. Figure 2 shows the structure of the comparison of the alternatives' process.

Each alternative has a function of quality - V(y) [7], depending on the evaluations of the criteria that it represents. In [9], it is proposed that the vectors of ranks of the criteria values, which represent the function of quality, are rearranged in an ascending order. Then, the values will be compared to the corresponding position of another alternative's vector of values based on Pareto's dominance rule. Meanwhile, this procedure was modified for implementation because it was originally proposed to scales of preferences of criteria values, not for quality variation scales.

So, supposing the comparison between alternatives $Alt1 = A_2, B_2, C_1$ and $Alt2 = A_3, B_1, C_2$, considering a scale of preferences: $a_1 \prec b_1 \prec c_1 \prec a_2 \prec b_2 \prec c_2 \prec a_3 \prec b_3 \prec c_3$, we have the following functions of quality: V(Alt1) = (0, 0, 2) and V(Alt2) = (0, 3, 4), which represents the ranks of, respectively, b_1 and c_1, a_2. Comparing the ranks presented, we can say that Alt1 is preferable to Alt2.

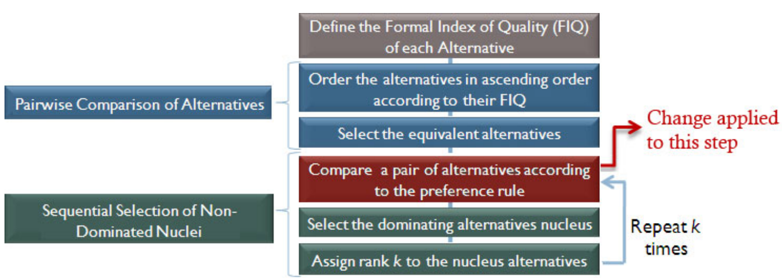

Fig. 2. Alternatives comparison process

However, there are cases in which the incomparability of real alternatives will not allow the presentation of a complete result. These problems require further comparison. In such cases, we can evaluate all possible alternatives to the problem in order to rank the real alternatives indirectly.

3.4 A Tool to the Approach Methodology

In order to facilitate the decision process and perform it consistently, observing its complexity and with the aim of making it accessible, a tool was implemented in Java and it is presented by the following sequence of actions:

- Criteria Definition: The definition of the criteria presented by the problem;
- Preferences Elicitation: Occurring in two stages: the elicitation of preferences for quality variation on the same criteria and the elicitation of preferences between pairs of criteria;
- Alternatives Definition: The alternatives can be defined only after the construction of the scale of preferences;
- Alternatives Classification: After the problem formulation, the user can verify the solution obtained to the problem. The result is presented to the decision maker so that it can be evaluated. The comparison based on all possible alternatives for the problem is possible, but it should be performed only when it is necessary for the problem resolution (for being an elevated cost solution).

4 A Multicriteria Model to Aid in the Choice of Materials to the Construction of Earth Dams

A multicriteria model aiming to define a rank order of the materials that will be used in the dam's construction is presented. The materials and their quantities are determined by an engineer, based on another projects with geotechnical characteristics similar to the ones of the available materials, and their experience in previous projects. Then, the choice of materials and quantities will be facilitated by the ordering obtained after applying the multicriteria model.

The criteria were defined based on the following geometrical characteristics [12]:

1. Compressibility: the capability presented by the soil to decrease its volume when subjected to certain pressure. The criteria values to the compressibility vary from "Very Low" (C1) to "High" (C4);
2. Shear Strength: the capability of soil to resist to shear stress. Due to the frictional nature, the rupture occurs preferentially by shear, becoming an important feature to be observed to guarantee the slope stability. The possible values for this criterion vary from "Very High" (RC1) to "Low" (RC4);
3. Permeability: the facility with which the water flows through the soil. The water may cause unfavorable conditions, affecting the dam's security and

performance when it penetrates in the soil used on the dam. The possible values for this criterion vary from "Very Impermeable" (P1) to "Permeable" (P4);

4. Workability: the convenience of handling and using the material in the construction. It varies from "Very Good" (T1) to "Bad" (T4);

5. Piping Strength: Phenomenon that causes the removal of the soil's particles due to the water flowing through the structure, creating canals that may evolve in an opposite direction to the water flow and it may cause a collapse of the structure. It varies from "High" (RP1) to "Very Low" (P4);

The increasing concern with the environment makes the impact caused by the engineering construction an important criterion. The use of a material that has good geotechnical characteristics may cause a great impact on nature, making its use less interesting than another one with similar characteristics, but causing a minor impact. This way, it was also considered as criteria the features related to the material and the effect of its use:

6. Material Quality, that varies from "Very Good" (QM1) to "Bad" (QM4);

7. Extraction Difficulty: represents the difficulties found in the extraction process considering all material deposits available. The criteria values to the extraction difficulty vary from "Low" (D1) to "Very High" (D4);

8. Environmental Impact: represents the impact caused to the environment when a determined material is used in the construction. It varies from "None" (I1) to "High" (I4).

The preferences' elicitation process was performed by means of interviews with experienced engineers. The information obtained was transformed into the scale of preferences that follows: $rc_1 \prec p_1 \prec c_1 \prec rp_1 \prec rc_2 \prec p_2 \prec rp_2 \prec c_2 \prec q_1 \prec t_1 \prec i_1 \prec d_1 \prec rc_3 \prec p_3 \prec rp_3 \prec c_3 \prec q_2 \prec t_2 \prec i_2 \prec d_2 \prec rc_4 \prec p_4 \prec rp_4 \prec c_4 \prec q_3 \prec t_3 \prec i_3 \prec d_3 \prec rc_5 \prec p_5 \prec rp_5 \prec c_5 \prec q_4 \prec t_4 \prec i_4 \prec d_4 \prec rc_6 \prec p_6 \prec rp_6 \prec c_6 \prec q_5 \prec t_5 \prec i_5 \prec d_5 \prec q_6 \prec t_6 \prec i_6 \prec d_6$.

The case study was applied in the design of zoned dams of Frios reservoir, situated in the same name river, county of Umirim, Ceará, Brazil.

According to the Unified Soil Classification in Araújo (1990 in [12]), the approached dam has zoned section and consists of material from massive type SC (Sand-Clay), SM (Sand-Silt) and residual soil, being these available in eight mines (from J1 to J8). It was included three other types of materials in order to better illustrate the application of the model: M4 (CL - Clay-Low soil), M5 (ML-SC soil) and M6 (ML - Mo-Low soil); also available in the same mines.

The material types were analyzed considering their characteristics based on the criteria previously defined. The values of criteria for the six types of materials, the original classification and the one obtained by the application of the Aranaú tool to the problem are presented in Table 1.

By the application of the proposed methodology, a complete ranking was achieved without being necessary to perform a comparison between all possible alternatives of the problem. Figure 3 shows the graph obtained by the application of the Aranaú Tool to the problem.

Table 1. Material classification for the construction of earth dams

Material	Values of Criteria	Rank
SC (Sand-Clay)	C2 RC2 P2 RP1 T2 Q2 D4 I1	1
SM (Sand-Silt)	C2 RC2 P3 RP2 T3 Q2 D4 I2	3
SM-SC	C2 RC3 P3 RP2 T3 Q2 D4 I2	4
CL (Clay-Low)	C1 RC3 P2 RP1 T2 Q1 D4 I2	2
ML (Mo-Low)	C1 RC4 P2 RP3 T4 Q2 D4 I1	5
ML-CS	C3 RC3 P2 RP2 T3 Q3 D4 I3	6

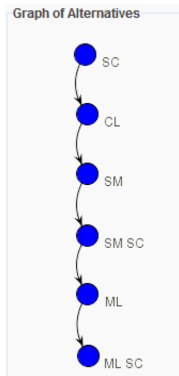

Fig. 3. The graph obtained by the application of the Aranaú Tool to the problem

5 Conclusions

The construction of dams involves a lot of variables, which makes its modeling complex. This work considered some of these variables in order to propose a modeling process, involving multicriteria, with the aim of improving the decision making in the construction of earth dams by observing the lowest cost.

The application of the multicriteria methodology, by means of the Aranaú Tool, aims to facilitate the choice of materials that can be used in the construction of the dam, defining, at the end of the modeling process, a range of minimum and maximum quantities of each material. This way, it was obtained that the best material to be used in the construction is the SC (Sand-Clay).

The work [12] presents an extension to this work, applying non-linear programming in order to determine the best usage of the materials for the construction, the types of compression for the selected materials, the mines of which materials would be extracted and the sources with the volumes of water needed.

As future works, we suggest an improvement of the model, such that the most indicated place to construct a dam, the slope angle and the optimal session would be defined including more evaluation variables. This way, a complete modeling of the problem would be presented.

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References

1. Bordeaux, G.H.M.: Barragens de terra e enrocamento, projeto e construção. Clube de Engenharia, Salvador (1980)
2. Campos, N.B.: Dimensionamento De Reservatórios: O Método Do Diagrama Triangular De Regularização, 51p. Edições UFC, Fortaleza (1996)
3. de Castro, A.K.A., Pinheiro, P.R., Pinheiro, M.C.D.: An Approach for the Neuropsychological Diagnosis of Alzheimer's Disease: A Hybrid Model in Decision Making. In: Wen, P., Li, Y., Polkowski, L., Yao, Y., Tsumoto, S., Wang, G. (eds.) RSKT 2009. LNCS, vol. 5589, pp. 216–223. Springer, Heidelberg (2009)
4. Esteves, V.P.: Barragens de terra. Campina Grande: Escola Politécnica da USP (1964)
5. Evangelou, C., Karacapilidis, N., Khaled, O.A.: Interweaving knowledge management, argumentation and decision making in a collaborative setting: the KAD ontology model. International Journal of Knowledge and Learning 1(1/2), 130–145 (2005)
6. Larichev, O., Moshkovich, H.M.: Verbal decision analysis for unstructured problems. Kluwer Academic Publishers, Boston (1997)
7. Larichev, O.: Ranking Multicriteria Alternatives: The Method ZAPROS III. European Journal of Operational Research 131(3), 550–558 (2001)
8. Machado, S.L., Machado, M.F.C.: Mecânica dos Solos I - Conceitos introdutórios (1997)
9. Moshkovich, H., Mechitov, A., Olson, D.: Ordinal Judgments in Multiattribute Decision Analysis. European Journal of Operational Research 137(3), 625–641 (2002)
10. Narita, K.: Design and Construction of Embankment Dams, Dept. of Civil Eng., Aichi Institute of Technology (2000)
11. Pinheiro, P.R., de Souza, G.G.C., de Castro, A.K.A.: Structuring problem newspaper multicriteria for production. Operational research. Pesqui. Oper., Rio de Janeiro 28(2) (2008), doi:10.1590/S0101-74382008000200002
12. Reis Filho, M.A.M.: A Modeling Process to Optimize the Construction of Earth Dams. In: Master Program in Applied Informatics. University of Fortaleza (2005)
13. Tamanini, I., Machado, T.C.S., Mendes, M.S., Carvalho, A.L., Furtado, M.E.S., Pinheiro, P.R.: A Model for Mobile Television Applications Based on Verbal Decision Analysis. In: Sobh, T. (Org.) Advances in Computer Innovations in Informations Sciences and Engineering, vol. 1, pp. 399–404. Springer, Heidelberg (2008), doi:10.1007/978-1-4020-8741-7_72
14. Tamanini, I., Pinheiro, P.R.: Challenging the Incomparability Problem: An Approach Methodology Based on ZAPROS. Modeling, Computation and Optimization in Information Systems and Management Sciences. Communications in Computer and Information Science 14(1), 344–353 (2008)
15. Tamanini, I., Carvalho, A.L., Castro, A.K.A., Pinheiro, P.R.: A Novel Multicriteria Model Applied to Cashew Chestnut Industrialization Process. Advances in Soft Computing 58(1), 243–252 (2009)
16. Vieira, V.P.P.B., et al.: Roteiro para projeto de pequenos açudes, 160 p. Universidade Federal do Ceará, Fortaleza (1996)