Engenharia Hidráulica e Sanitária

Helenton Carlos da Silva
(Organizador)

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APRESENTAÇÃO

A obra "*Engenharia Hidráulica e Sanitária*" publicada pela Atena Editora apresenta, em seus 18 capítulos, discussões de diversas abordagens acerca da engenharia sanitária e hidráulica brasileira, destacando-se a área ambiental.

Neste contexto, o diagnóstico ambiental pode ser uma importante ferramenta no controle e preservação do meio ambiente, sendo uma caracterização da qualidade ambiental da área estudada, fornecendo informações para identificar e avaliar impactos nos meios físico, biológico e socioeconômico.

É importante que, para que sejam sustentáveis, as áreas urbanas necessitem manter um equilíbrio entre as atividades econômicas, crescimento populacional, infraestrutura e serviços, poluição, desperdício, barulho, entre outros; de modo que o sistema urbano e suas dinâmicas se desenvolvam em harmonia, limitando internamente, tanto quanto possível, os impactos negativos sobre o ambiente natural.

Nesta linha, o saneamento básico pode ser compreendido como um componente necessário para promoção da saúde, principalmente para as populações em condição de vulnerabilidade social, tal qual em bairros populares e periféricos do meio urbano ou comunidades tradicionais do campo brasileiro.

Em razão do crescimento de áreas urbanas, houve um aumento excessivo na geração de resíduos, gerando uma série de problemas de ordem ambiental, econômica e social.

Neste sentido, este livro é dedicado aos trabalhos relacionados à engenharia hidráulica e sanitária brasileira, compreendendo as questões acerca do meio ambiente, como a gestão dos resíduos sólidos gerados, formas de tratamento da água, bem como a análise de políticas de desenvolvimento visando à preocupação com as questões ambientais. A importância dos estudos dessa vertente é notada no cerne da produção do conhecimento, tendo em vista o volume de artigos publicados. Nota-se também uma preocupação dos profissionais de áreas afins em contribuir para o desenvolvimento e disseminação do conhecimento.

Os organizadores da Atena Editora agradecem especialmente os autores dos diversos capítulos apresentados, parabenizam a dedicação e esforço de cada um, os quais viabilizaram a construção dessa obra no viés da temática apresentada.

Por fim, desejamos que esta obra, fruto do esforço de muitos, seja seminal para todos que vierem a utilizá-la.

Helenton Carlos da Silva

SUMÁRIO

CAPÍTULO 18

MULTI-CRITERIA DECISION ANALYSIS (MCDA) FOR DAM'S RISK CLASSIFICATION

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ABSTRACT: This paper purposes the utilization of multi-criteria decision analysis' methods to dam's risk classification, to improve and complement management tools and help entrepreneurs, inspection institutes and professional experts. The developed methodology was applied in dams of watering projects of Formoso and Manuel Alves rivers on Tocantins State. It was used the multi-criterion analysis method ELECTRE-TRI, and it was considered the criteria of multiple risk analysis methodologies. Technical information was raised through in loco visits and the dams were classified in four risk levels: Extreme, Height, Moderate and Low. The results demonstrate the successful use of these methods in designing dam's risks classification.

KEYWORDS: ELECTRE-TRI; Risk management; Dams safety.

1 I INTRODUCTION

For centuries dams provide benefits to society with its diverse uses. They are essential to a country's economic development; dams enable energy production, watering, water supply, among others economic activities.

On the other hand, water or residue accumulation through dams represent risks to the population that live or work near to these constructions, with records of serious accidents worldwide.

That condition concerns society about the exposing level of those risks, mainly when it comes to huge accidents that involve life losses and material damages.

According to Pataki & Cahill (1985), to be considered safe, a dam has to properly be planned, projected, built and sustained. However, to Melo (2014), a high number of recently accidents involving these constructions shows that the safety conditions are not been fully followed.

In spite of Brazil already having the Law nº 12.334, established on 2010 – that settles security and water accumulation polices to any use, the final or temporary tailings disposition and the industrial residue accumulation –, Kochen (2016) asseverates that is essential to improve it. Specially on law inspection. So that regulatory agencies and authorities can acknowledge that security conditions are being effectively minded.

Analyzing and classifying methods applied in risks associated to dam's management are important tools, which use has been increasing; it could help in the development of detecting and preventing accidents techniques. Methods used by CEMIG, COGERH, SABESP, the Global Risk Index and the nº 143 CNRH Resolution (instrument of the nº 12.334/2010 Law) can be highlighted.

On this context, this paper demonstrates an effective multi-criterion methodology that contributes to the improvement and completion of classification, analysis and management practices of dams risks. And, consequently, provide to managers, inspectors and experts a new tool that can make classifications to any dam and that also considers each dam specificities according to the risks it presents.

2 I SAFETY OF DAMS

The first watering dam's projects date from more than 6.000 years ago, in Persia. Embankment dams were the first to be built. Afterward the first millennium A.D., significative progresses in embankment dams with more than 15 m high took place on Asia; and in Europe with masonry dams constructions (NEVES et al., 2015).

In Brazil, the most ancient dam known is in a Dutch map from 1577. It was built where today is the urban area of Recife, possibly, even before the Dutch invasion. Today, this dam is known as Apipucos dam. The original dam was widened and reinforced to allow the construction of an important access road to Recife's downtown (MELLO, 2011).

Consonant to the increasing number of dams is also an increasing concern about these constructions safety, mainly the ones in downstream areas.

In what concerns dams, safety is a very important aspect worldwide.

According to Moraes (2013), when more qualitative approaches, based on experience, are used, it is normal to express the risk as a direct result of the occurring probability of an event, and its consequence. The risk associated to a specific activity is evaluated by the probability estimative, through the frequency and the consequence in relative terms, such as "low", "medium" or "high"; and by the combination of both, using some principles previously settled.

However, to Oliveira et al. (2014), the probability estimative process demonstrates itself as too arduous, once to make estimations it is necessary to search a most appropriate alternative through settled criterion.

In this regard the experience and the knowledge about certain risks factors that are determinant to the evaluation of the involved risks.

A dam risk can change through time: by the alteration of the dam vulnerability, or by the alteration of the soil occupation or by the protection measures adopted (ARAÚJO et al., 2015). Therefore, due to the complexity demonstrated in measure dam risks, a consensual concept was spread: there is no zero risk.

To assure safety conditions to the involved society it is truthfully necessary to develop risk management actions. One of the most important tool is the risks checklist, based on accumulated experience in dam's safety.

3 I MULTI-CRITERIA CRITERIA DECISION ANALYSIS

The multi-criteria decision analysis method aims to help decision making before multiple criteria, incompatible many times, through the application of elaborated techniques and methods (LIMA et al., 2015).

Several authors, Dias et al., (2018), Marinakis et al. (2017), Tervonen et al. (2018), supported that Multi-Criteria Decision Analysis (MCDA) methods are especially well-suited to address strategic decision problems.

These methods deal with three kinds of mainly issues: choice, organization and classification. With a limited set of alternatives, the issue in choice consists in pick an even more limited set of the best alternatives among the considered. The issue in organization consists in characterize all the evaluated alternatives from the best to the worst. And, the issue in classification consists in allocate each alternative in predefined categories (CORRENTE et al., 2016).

With the issue clearly defined, alternatives are risen for its solution, jointly a set of decision makers and with the alternative's criteria evaluation list. Afterward identifying all these elements, it is possible to apply the quantitative procedure of multicriterion analysis (JANNUZZI et al., 2009).

To better understand MCDA methods it is necessary to know the fundamental components of decision making process. This process is realized by people who are immersed in the decision making circumstances, have common interests on the decision results, and have influence on decisions making and their particularities.

Roy & Vanderpooten (1996) demonstrate that the decision maker role can be assumed by one person or by a group in charge of the decision making. To Mello et al. (2003) decision makers could act in self-interest or in benefit of a group, where they can make choices and have preferences according to their opinion.

According to Bana and Costa (1992), the facilitator must enlighten the evaluation/ negotiation process inherent to the decision making, enabling the dialog and the understanding between the actors; and build a model that considers the actors' points of view and values judgment.

The Stakholder could be any individual or group that have some connection with the problem or could be affected by it. They are interested in the problem solution; however, they do not participate actively in the decision process.

3.1 ELECTRE-TRI

The ELECTRE-TRI method belongs to the ELECTRE methods family. It was originally demonstrated by Bernard Roy and Wei Yu (1992). The original method was designed for classifying evaluated alternatives in multiple criteria of organized and defined categories by limiting profiles (BOUYSSOU & MARCHANT, 2015).

So far, ELECTRE TRI has been extensively applied in a wide on decisional classification problems related to risk areas (Antonella et al., 2017; Takougang et al., 2015; Brito et al., 2010).

According to Costa et al. (2007) this method presents tools that help the decision maker in the process choice, reducing the cognitive effort required on the structuring phase and in classifying alternatives based on a subordination relation that determinates how the alternatives are compared to the categories limits.

Given a finite alternatives/actions set (A), valuated by a family/vector of criteria (F), the ELECTRE-TRI will build a subordinated relation that represents the preferences established by the decision maker. The highly use of this relation aims to help the decision maker to resolve the problem. Given the set A of alternatives, specific sub-sets or organized categories can be classified A1, A2,... An (LAURINDO et al., 2005).

According to Yu (1992), the structuring method process of the ELECTRE-TRI has 5 steps:

(i) Determination of set A of viable alternatives, A = {A1, A2, a3, ..., An};

(ii) Determination of the criteria set F = {g1, g2, g3, ..., gm} and their weight (k1, k2, k3, ..., kj);

(iii) Limits of preference definition (pj(bh)), indifference (qj(bh)) and veto (vj(bh)), to each criterion;

(iv) A generic class Ch is delimitated by an inferior limit bh and a superior limit bh – 1.

(v) Performance of the alternatives on the basis of criteria.

Figure 1 presents a set formed by h+1 class. The classes limit ae h, considering the criteria set F = {g1, g2, g3, ..., gm}:

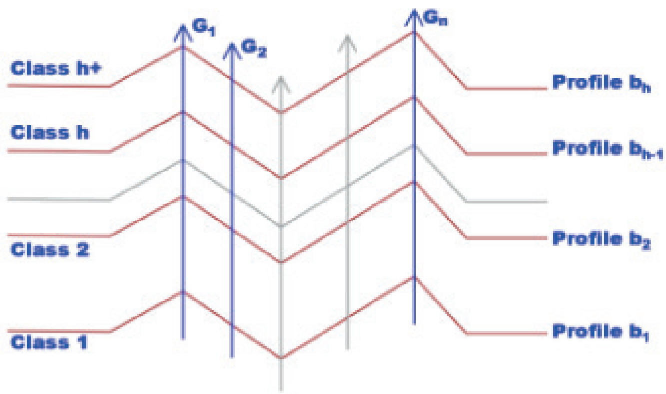

Figure 1 – Categories and limits ELECTRE-TRI method. Source: Adapted from Costa et al. (2007)

According to Szajubok et al. (2006), ELECTRE-TRI broaches problems shaped by a family of pseudocriteria, where the threshold of preference, indifference and veto pj(bh), qj(bh) e vj(bh) compose the intracriteria elements.

The threshold of indifference (qj) corresponds to a bigger difference in performance, where the indifference situation is validated, i.e., qj(b) it is the bigger difference between gj(a) – gj(b) that guarantees the indifference between a and b in relation to a criterion.

The threshold of preference (pj) is the value above the decision maker demonstrates a clear preference for one alternative to another, i.e., pj(b) it is the smaller difference between gj(a) – gj(b) compatible with the preference for the alternative a, in relation to a criterion.

The threshold of veto (vj) is the value above the decision maker will deny any possibility of a preference relation indicated by another criterion. The threshold of veto is used on the discordance test and represents the smaller difference between gj (b) – gj (a) incompatible with the preference a in relation to ab.

The method calculates a credibility index σ(bh,a) that is obtained from the construction and exploitation of an over-classification relation S, validating or not validating from two conditions:

- Asserting that aSbh demonstrates that “a has not an inferior performance as defined by the limit bh”.
- On the other hand, the asserting that bhSa, demonstrates that “the limit bh has not an inferior performance than the alternative a”.

In order to asseverate that a has a performance as good as bh – considering the criterion –, gj can be validated by calculating the partial agreement index cj (a, bh). When gj presents the preference sense in an increasing direction, it is computed from the following expression:

- If $g_j(a) \leq g_j(b_h) - p_j\ (b_h)$, then $c_j(a,\ b_h) = 0ƒ$

- If $g_j(b_h) – q_j (b_h) < g_j(a)$, then $c_j(a, b_h) = 1$
- If $g_j(b_h) – p_j (b_h) < g_j(a) \leq g_j(b_h) – qj (b_h)$, then:

$$c_j(a, b_h) = \frac{g_j(a) - g_j(b_h) + p_j(b_h)}{p_j(b_h) - q_j(b_h)} \quad (1)$$

However, when a criterion gj presents the sense of preference in a decreasing direction it is computed from the following expression:

- If $g_j(a) \leq g_j(b_h) – p_j (b_h)$, then $c_j(a, b_h) = 0$ƒ
- If $g_j(b_h) + q_j (b_h) > g_j (a)$, then $c_j(a, b_h) = 1$
- If $g_j(b_h) + q_j (b_h) \leq g_j (a) \leq g_j(bh) + p_j (b_h)$, then:ƒ

$$c_j(a, b_h) = \frac{g_j(b_h) - g_j(a) + p_j(b_h)}{p_j(b_h) - q_j(b_h)} \quad (2)$$

According to Luarindo et al. (2005) the global concordance index Cj(bh, a) expresses, in all the criteria, how far the evaluations a and bh are favorable to the assertiveness that “a subordinates bh“:

$$C_j(b_h, a) = \frac{\Sigma_{j \in G}.c_j(a, b_h)}{\Sigma_{j \in G}.k_j} \quad (3)$$

The partial discordance index dj (a, bh), that determinates how far the criterion gj opposes to the assertiveness a, presents a performance as good as bh. Costa et al. (2007) say that, when veto concept is not adopted to an alternative, the discordance effect is annulled, and credibility is equalized to concordance.

- If $g_j(b_h) – g_j(a) \leq p_j(b_h)$, then $d_j(a, b_h) = 0$ ƒ
- If $g_j(b_h) – q_j (b_h) < g_j(a)$, then $c_j(a, b_h) = 1$

$$d_j(a, b_h) = \frac{g_j(b_h) + g_j(a) - p_j(b_h)}{v_j(b_h) - p_j(b_h)} \quad (4)$$

The value ofσ(a,b_h) is calculated just as $\sigma(b_h,a)$, from the expression:

$$\sigma(a, b_h) = c(a, b_h). \prod \frac{1 - d_j(a, b_h)}{1 - c(a, b_h)}, \text{ where:}$$

$G = \{j \in G: d_j(a, b_h) > c(a, b_h)\}$

3.2 Analytic Hierarchy Process (AHP – Classic)

This is a method of matched comparisons, develop by Saaty (1980). The AHP aims to represent the decision making process and help in obtaining the best judgments for the hierarchization and selection of the best alternative among a finite number of alternatives through calculation of their utility functions (FRANEK & KRESTA, 2014).

The criteria are demonstrated by “g1, g2, ...,gn”, their real weight by “w1, w2, ..., wn” and the matrix of relations “W =[wi/w j]”. The weight vector is the eigenvector correspondent to the maximum eigenvalue “λmax” of the matrix A (SÁNCHEZ-LOZANO et al., 2016).

This method uses the traditional eigenvector to estimate weight, measuring the consistence of the decision makers preferences on the comparison matrix from the Consistence Index, which can be obtained by equation 5.

$$IC = \frac{(\lambda\, max - n)}{(n-1)} \quad (5)$$

The evaluations of the AHP are based on the assumption that the decision makers is rational, therefore, if A is preferable to B and B is preferable to C, then A is preferable to C. For that to happen, the Consistence Ratio (CR) is verified, and it can be higher than 0,1 (10%), otherwise the judgments are not trustful and the obtained results does not present consistent values (LIMA et al., 2015). The CR is acquired by the equation 6.

$$RC = \frac{IC}{IR} \quad (6)$$

To the matched comparisons, Saaty (2005) defined a scale of values (1, 3, 5, 7 and 9) that cannot exceed 9 factors, so the consisted matrix can be maintained.

4 I METHODOLOGY

According to Belton & Stewart (2002) the MCDA process is developed in three steps: the first one consists in identifying the problem; the second one is the structuration of the problem; and the third one is the construction of a model that, finally, will be used to inform and do the analysis. These steps can be observed in Figure 2.

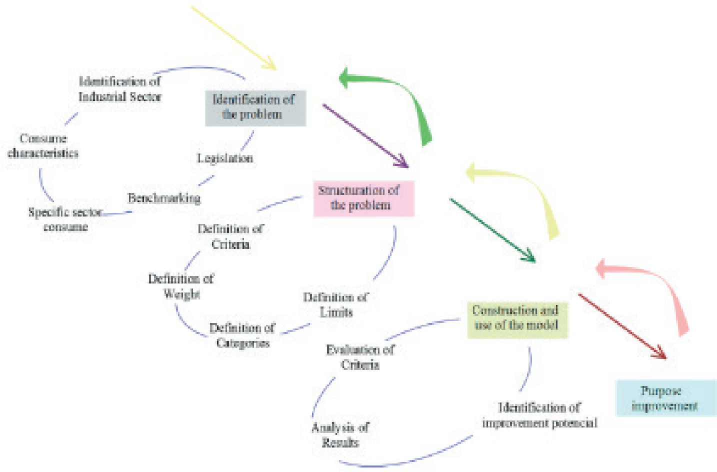

Figure 2 – MCDA process steps. Source: Adapted from Belton & Stewart (2002).

4.1 Structuration of the problem

The structuration step corresponds to the formation of the decisional environment. Interviews were made with five decision makers about the decision making, identifying the risk factors from his knowledge and experiences in dam's safety, which is the MCDA principle.

The authors intermediated, clarified and organized the opinions presented by the decision makers and the facilitator for the structuration of the method.

The group of Stakeholders was formed by riverside population, downstream community, agricultures, experts and the Catchment area of Rio Formoso Commitee.

Three dam of watering accumulation were chosen for testing the method proposed.

They are huge dams and have great importance to the communities that live in their proximities: Manuel Alves and Formoso rivers project

4.2 Dam of Manuel Alves river project

The dam in the Rio Manuel Alves river, built in 2003, provides the Hydro-agricultural Utilization System, located in the cities of Porto Alegre do Tocantins and Dianópolis.

Table 1 presents the materials that composes the dam masonry construction of Manuel Alves river project.

Dam	Maximum High	Length	Coronation breadth	Kind of the dam	Reservoir total volume
Manuel Alves	30,00 m	1.470 m	7,00 m	Homogeneous land	214.000.000 m3

Table 1 – Mainly characteristics of the Manuel Alves river dams project

Source: SEAGRO (2005).

The dam of Manuel Alves river project has an inundated area of 23,12 km². The dam was built with homogeneous land and an internal drainage system. The inclination of the upstream slope is 1:3; and of the downstream is 1:2. It has a 120 m length underflow the dam's left side to maximum discharge of a 379 m³/s ten thousand-year project. It also has a water diversion gallery to 32m³/s (SEAGRO, 2005).

4.3 Dams of Formoso river project

Located in the city of Formoso do Araguaia, the Formoso river project is in operation since the 70's. Its mainly purpose is to make good use of the floodplain area in the Araguaia river valley for grains production.

The project – at the time, accomplished by Goiás government – has 20.550 hectares to plantation and embraces 61.000 hectares in the Javaés river tributary (RIMA, 1998).

These dams were built in the 70's. Therefore, they need restoration work to make them safe and efficient in their duties performance.

The total area of useful agricultural surface is, nearly, of 27.787 hectares. Its hydric demand is supplied by three dams in the Formoso river catchment. Taboca, Calumbi I and Calumbi II, and the own Formoso rever (TOCANTINS, 2016). Table 2 presents the mainly characteristics of their dam.

Dam	Maximum High	Length	Coronation breadth	Kind of the dam	Reservoir total volume
Calumbi I	7,00 m	17.200 m	7,00 m	Homogeneous land	110.190.000 m3
Calumbi I	7,00 m	12.700 m	12,00 m	Homogeneous land	93.520.000 m³
Taboca	20,60 m	10.300 m	7,00 m	Homogeneous land	141.900.000 m³

Table 2 – Mainly characteristics of the dams of Formoso river project

Source: ANA (2015).

The Calumbi I dam broke in 1985. After this dam was recovered, an operationalization with 40% of the capacity was adopted.

4.4 Identification of Risk Factors

The decision makers – based on his technical knowledge and experiences – choose the most significant criteria to compose the dam's classification table for MCDA methodology.

With the defined criteria, relative values were attributed in the construction of the matrix for the 15 criteria previously defined; the Saaty scale (1, 3, 5, 7 and 9) was used to determinate the weight, using the AHP method.

From the matched evaluation, the AHP gave the normalized eigenvalue that corresponds to the criteria weight, hierarchized according to his relevance and risks potential to the dam safety.

The AHP method was only used to obtain the relation on criteria weight. The risk analysis was defined by the ELECTRE-TRI method. And finally, the decision makers divided the criteria in five groups described in Table 3. It was verified that the Consistence Ratio was inferior to 0,1 (10%), what validates the judgements as consistent results.

In accomplishing matched comparisons between the determined levels in each criterion (g1, g2,..., gm), it was verified that has not occurred indifference situations with null indifference threshold (q=0). On the other hand, preference threshold (pj) was defined as the minor difference in performance where the strict preference situation occurred p=min(gn). The veto power (vj) was used for the levels that presented great performance differences between alternatives in none of the criteria.

Criteria		**Code**	**Weight**	**Preference threshold (pj)**	**Indifference threshold (qj)**
External or environmental	Actions of nature	g1	0,009	15	0
Project experts	Dam's extension	g2	0,129	15	0
	Kind of the dam	g3	0,027	15	0
	Kind of the foundation	g4	0,056	15	0
	Age of the dam	g5	0,009	15	0
	Discharge of the project	g6	0,056	25	0
	Reservoir total volume	g7	0,129	15	0
Conservation	Trustworthiness of the extravasating structure	g8	0,056	25	0
	Trustworthiness of the adduction structure	g9	0,056	15	0
	Percolation	g10	0,129	25	0
	Deformation	g11	0,129	25	0
	Deterioration of the slopes	g12	0,056	25	0
Documentation	Projects	g13	0,015	15	0
	Dam management	g14	0,015	25	0
Downstream impacts	Downstream impacts	g15	0,129	15	0

Table 3 – Criteria of the method

The MCDA process requires that criteria qualitative organization were transformed in numerical values, accomplishing a codification that respects the decision maker preferences. For this process, risk levels were defined: Low, Moderate, Height and Extreme.

According to the decision makers, the **extreme risk** category embraces great dams that presents anomalies in advanced levels. In the absence of these anomalies, the dams will conform in the inferior risks classification.

In a scale that varies from 0 to 100, the decision makers defined the classification frontiers (bh). The dams that stayed between 0 and 25 were classified as Low risk; from 25 to 50, as Moderate risk; from 50 to 75, as Height risk; and from 75 to 100, as Extreme risk. It can be observed in Table 4.

Frontiers	Risk Classification	Frontiers Values Of Each Criterion														
		g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12	g13	g14	g15
	Extreme															
b3		75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
	Height															
b2		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Moderate															
b1		25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Low															

Table 4 – Frontiers for Criteria of the method purposed by this research

4.5 Dams evaluation phase

As the model has been structured, information of the dams jointing was raised. The project data, the organizational structure, the manual and inspection reports, as well as an in situ visit, were considerate when the verification of the parameters defined by the decision makers for the risk classification.

With that data, a classification was made from the software ELECTRI-TRI, version 2.0a, developed by LAMSADE – Laboratoire D'Analyse et Modélation de Systèmes Pour l'aide à la Décision, of Dauphine University, Paris – France (MOUSSEAU et al., 1999).

At the following, the stages for generating classifications using the software ELECTRI-TRI version 2.0a:

1st - Introduction of the criteria and their respective weight;

2nd - Introduction of the profiles that composes the categories frontiers: extreme risk, height risk, moderate risk and low risk;

3rd - The introduction of all criteria levels were made, as well as their respective values;

4th - The indifference threshold values were inserted (qj), preference (pj) and, if necessary, veto (vj);

5th - As the software classifies the classification alternatives in Optimist (less demanding) and Pessimist (more demanding), the option that better fits to the research has to be chosen. In this case, as it is a risk analysis study, the pessimist option – more conservative – was chosen;

6th - Other alternatives were inserted in the defined categories: Dam of Manuel Alves project and Taboca, Calumbi I and Calumbi II dams;

7th - The cutting level λ – that should be between 0,5 and 1,0 – was obtained. This index indicates how many criteria have to be accomplished, in order to classify an alternative for one of the defined risk categories.

8th - At last, it was calculated the credibility indexes that expresses for which extension (σ(A, bh) "A overcomes bh") and (σ(bh, A) "bh overcomes A"), according to the global index of agreement C (A, bn), and for the disagreement indexes d(A, bh). This process validates the classification.

5 I ARGUMENTATION AND RESULTS

The dam's classification obtained by the ELECTRE-TRI 2.0 can be observed in Table 5.

Barragem	Classificação Pessimista	Classificação Otimista
Manuel Alves	Risco Baixo	Risco Baixo
Taboca	Risco Extremo	Risco Extremo
Calumbi I	Risco Alto	Risco Alto
Calumbi II	Risco Alto	Risco Alto

Table 5 – Risk classification of the method purposed by the ELECTRE-TRI study.

The classification cutting level presented in Table 5 was low, i.e., near to 0,5, because the dam of *Manuel Alves* project does not present matched comparabilities in higher levels. As this value increased, incomparabilities appeared where the credibility index was not compatible to the asserting that a presents a performance as good as the frontier bh. Therefore, the classification loses credibility.

Doing a new classification, without the dam of Manuel Alves project – remaining with the *Calumbi I, Calumbi II* and *Taboca* dams –, it was verified that the cutting level increased to λ= 0,791. With this value, it can be noticed that, the higher the cutting level is, the most rigorous and trustful is the asserting that a presents a performance as good as the frontier *bh*.

The dam of *Manuel Alves* project is in good conditions because of the maintenance procedures taken by a team that was responsible for its management

This dam has basic and executive projects, as well as manuals of utilization, operation and conservation. And the result is that it has structures in good functioning and operation.

The classification in Extreme risk level in the dam of *Taboca* on *Formoso* river project represents the lack of conservation actions. Because of the nonexistence of professional experts to do maintenance, correction and inspection works, these dams present countless anomalies.

The *Taboca* dam presents downstream water leaking, located where is – according to the project's irrigation expert – the riverbed of *Calumbi* river. This leaking is, approximately, 21m from crest elevation, located in the dam's foundation.

This model prescribes that the dams classified in that level needs urgent intervention, as they can break in any moment.

All *Formoso* river dams presents damage in its riprap layers because of the constantly waves and the land slipping from the slopes, plus the damages at the extravasating structures and at the floodgates.

The *Taboca* dam reflects a condition that can be found in countless Brazilian dams, as a result of the lack of interest of entrepreneurs and managers.

In classifying the dams using the Global Risk Modified Index – purposed by ICOLD in 1982, one of the firsts dam's risks checklist methods –, it was verified that the *Calumbi* and *Taboca* dams reached the Class A (height risk or unacceptable risk). The Manuel Alves project and *Calumbi* II dams were classified as Class B (controlled anomalies, but with risks to downstream).

Using the USACE (United States Army Corps of Engineers) method, developed by Andersen et al. – that aims to define priorities to evaluation and application of emergency measures in dams –, it was verified that the *Manuel Alves, Calumbi I* and *Calumbi II* dams present reasonable Condition Index and have to be watched. The Taboca dam presented Marginal Index and demands more attention than the others.

Through the *Companhia de Gestão dos Recursos Hídricos of Ceará* (COGERH) methodology, created and developed by Menescal (2005), the *Manuel Alves* project dam was classified as Normal risk and the *Formoso* river project dam as Medium risk.

After Brazil has adopted the risk classification of the *Conselho Nacional de Recursos Hídricos* (Resolution nº 143 of 2012) – that presents the matrix concept of risk and of associated potential damage –, all the dams passed to Class A, i.e., present height risk.

Analyzing different classifications made with different methods, it was noticed that in spite of the divergences in classification, ELECTRE-TRI is applicable for risk classifications in dams. It can also be used as a decision support tool in dam's risk management.

Comparing to the CNRH Resolution nº 143 – used, currently, in classifications made by Brazilian inspection institutions –, it has occurred two divergences in classifications because the Conservation state team presented bigger weights. Hence, it is justifiable that *Taboca* dam presents extreme risk, since it received the highest grades on these criteria. On the other hand, the dam of *Manuel Alves* river project, that is in a good state of conservation, was considered of low risk.

The ELECTRE-TRI method allows the risks classifications to be build based on the judgment of decision makers that has the experiences and technical knowledge. It was the case employed in this study.

However, this dependence on these experts' subjective analysis can always lead to a discrepancy of results. Nevertheless, it is possible to notice that the experts have an inclination to agree with each other.

Because of the high amount of required information for classifications, the chances for the decision maker of being subjective, is also high. Maybe, having a lower number of criteria, or gathering more than a criterion in one, could help decreasing this subjectivity.

The ELECTRE-TRI method also allows the manipulation of the data inserted by adjustments, letting the decision maker guides the classification process to a desirable, or as desirable as possible, result. This flexibility can be seen in the definition of weights and criteria, that can be changed and, consequently, act on the final product. That helps the decision maker to better express his preferences. On the other hand, there is a chance of achieving a result that not necessarily is the most reliable. The weight definition from the AHP method could decrease this possibility.

CONCLUSION

The study presented in this paper uses a multicriterion method for decision making support; purposed a classification method of risk in dams in parallel to other methods, and also aims to cooperate with risk management processes.

With this evaluation is possible to consider all risks and to define the accep' level of risk in a dam. With this information, it is easier to make better decisions related with the security of downstream areas.

Because of the complexity of these constructions, the management process is indispensable for the localization and solution of these risks. In this way, all these prevention tools could help in the evolution of dam's policies field.

The use of multi-criterion support method on ELECTRE-TRI decision proved to be effective in reaching positive results of dams risks classification.

One of the method's biggest difficulty is the agreement between the facilitator and the decision makers in listing the preference criteria. Even if these criteria could be interpreted, it would hardly give results that could faithfully express the decision makers preferences.

The criteria amount can also interfere in the classification quality. The higher the number of evaluated criteria, the bigger will be the probability in obtaining a lower cutting level, i.e., far from 1. And that generates less credibility in the classification.

One of the advantages of ELECTRE-TRI is the flexibility in choosing the criteria to build the dams' risks classification methodology. These criteria can change according to local characteristics, the final used of the reservoir or to adjust into specific values of institutions that manage these structures.

It can be concluded that MCDA achieved its main goal. Has successfully created a dam's risk classification that can be used as a support to management decision.

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