Optimization of asset management process of EDP Distribuição

Multi-criteria Decision Aiding Methodology of reinforced concrete poles performance in power distribution overhead lines in High and Medium voltage

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Abstract

The high competition and the intensive use of assets in the energy industry force companies in this sector to adopt policies to improve their resources management in order to make them more efficient throughout their life time.

Due to that, company EDP Distribuição (EDP D), Distribution Network Operator in Portugal, has tried to find strategies to maintain high quality standards provided to its customers and optimize the assets it has at its disposal.

This paper intends to build and develop a Multi-criteria Decision Aiding Methodology (MCDA) to study the condition of reinforced concrete poles (CP) and its main degradation factors in order to classify the risk related to its performance, and also includes the study of the feasibility of reusing CP, which for various reasons have been removed from service. The work presented a detailed description about the CP. The literature review clarified the importance of asset management in companies, which degradation factors that CP have to lead with and presents the MCDA applied in classification problems describing in particular ELECTRE methods. Subsequently, evaluation criteria are built and a set of parameters are defined to be evaluated by the ELECTRE TRI-nC method. Finally, the model has proven useful on CP classification and indifferent to variations in the parameters.

Keywords: Performance of Reinforced Concrete Pole (CP), EDP Distribuição (EDP D), ELECTRE TRI-nC, Asset Management, Multi-criteria Decision Aiding Methodology (MCDA)

1. Introduction

The operators of the power distribution network perform an intensive use of installed assets, so it's essential to ensure the proper functioning of the equipment and it's sustainability. The high number of installed assets and financial constraints that distribution operators lead with, have been challenging to create a balance between customer demands on the quality of service as well as the appropriate return on capital invested by shareholders (D.E. Nordgård, K. Sand, 2011).

The EDP Group was created in 1976 by merging thirteen companies in electric sector. Currently, it's present in 14 countries which stands out among the major European operators in the energy sector, one of the largest energy operators of the Iberian Peninsula, the largest industrial group operating in Portugal and the 3rd largest producer in the world of wind power.

EDP D is the distribution network operator in Portugal which belongs to EDP Group. The main core business is the distribution of energy and the provision of other supplementary services. EDP D is the holder of the concession for operation of National Distribution Network (RND) of electricity in High Voltage (HV) and Medium Voltage (MV), and municipal concessions in Low Voltage (LV).

This paper intends to focus on CP which play an important role in the proper functioning of power distribution. The main goal is to assess the CP condition when they are in operation and analyse the feasibility of re-using CP removed from service.

2. Contextualization of the problem

2.1. Asset management

The asset management is a set of disciplines, methods, procedures and tools that organizations adopt throughout the lifecycle of the physical asset, in order to optimize asset performance and reduce the impact of costs and exposure to the risk (Woodhouse, 2001).

The implementation of asset management does not only influence the technical and financial areas, also contributes to greater involvement by all departments of the company in the use and information sharing of physical assets in real time. The administrative work is easier since it is automated by information systems (Shahidehpour & Ferrero, 2005).

Asset management is a construction that takes into account all the events that occurred in the past with the best practices that are considered for today, rather than simply be guided by the approaches adopted before (Davies, Dieter & McGrail, 2011).

EDP D launched in 2013 an Asset Management Program, according to a *British Standards Institution* (BSI) PAS 55 which is a publicly available guideline that have the objective to implement good practices in physical asset management, covering all stages of the technical active life cycle (Pinto et al., 2013). An active spends most of the life time at the maintenance/operation stage which brings about 80% of total cost of the asset. Consequently, it’s in this stage that has to work harder to monitor and analyze the performance of technical assets in order to adjust policies and maintenance criteria.

2.2. Reinforced Concrete Poles (CP)

CP are essentially made of cement, sand, water and steel structure. They have different heights, functions and measures according to the specifications that will be required. Its main function is to support the conductor cables (responsible for the transport of electricity). CP is formed by the pole, by their respective foundation and also the components that support the conductor cables. The CP are more frequently used than the metal poles because they are more cheaper and the solid foundation for fixation require smaller dimensions which consequently becomes more beneficial for appropriating less area. However, CP are more difficult to transport because they are one piece, while the metal poles are easily removable, so this type of poles are used in places hard to reach.

The main CP suppliers of EDP D are Cavan and Postejo companies. Cavan also has specialized repair and full recovery of the CP.

2.2.1. General characteristics

The characteristics of the AB are associated with its configuration taking into account the purpose of their performance. When it’s designed the placing of a CP is necessary to have knowledge about their length, the size of the head of the CP, the size of foundations, the type of loads applied (longitudinal efforts, vertical efforts or transversal efforts) and the different types of CP. There are six types of CP presented in Figure 1 which performing different functions in OL.

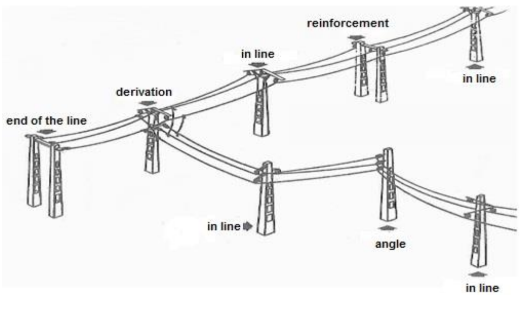


Figure 1 - Different types of CP implemented in OL

At the manufacture time, the CP are marked in relief with an EDP D reference, having also other indications as manufacture date, name or the brand of the manufacturer and in the case of manufacturers having several centers, the number of center. EDP D reference has information about the type of network to which it is intended (high, medium or low voltage), the overall height, the primary and secondary requests and the code reflects the dimension of the CP top.

2.3. Degradation of CP

The performance of CP is entirely related to its durability, with its ability to perform the functions for which they were designed without the need for any pre-planned repair work. The CP have an expected useful life time between 45 and 50 years, although nowadays there are CP in service with 60 years.

The degradation of CP could be related to human error or environmental effects like physical, chemical, biological or mechanical orders (Sarja, A., & Vesikari, 1996). Human errors are relating to the stage of design (calculation errors), project execution and bad maintenance procedures in power distribution overhead lines (OL). The environmental effects are induced by degradation agents such as temperature, wind, water, lightning, microorganisms and bacteria, material resistance to applied loads, among others.

Most of studies that were found in the literature review are about the degradation of wooden poles studies. These studies were used as reference because all poles are subject to the same deterioration agents.

Bogajewski *et al*,. (1982) studied the effects of sustained ground fault current on CP that are in service of OL.

The UK power distribution companies made an analysis in order to verify how the weather has influence on its costs and quality performance (Yu *et al.,* 2009).

Franco & Sanstad (2007) claim that certain climate parameters such as rain, wind, temperature and lightning are correlated with power outages.

Bjamadotti *et al.,*(2014) presented a study based on risk assessing the damage caused to wooden poles of OL by the occurrence of a hurricane, as well as the costs and benefits of different mitigation strategies. Other studie which took into account interruptions in OL originated by the recent hurricanes it was done by Davidson *et al*., (2003).

Kudzys (2006) his work was based in the wind caused by the storms, the ice deposit and rupture events of OL conductors which may put in danger the performance of CP.

To Cerqueira *et al*., (2012) the proximity of the coastline is an important degradation factor to be taken into consideration. They conducted a study in two regions with different climatic characteristics related to humidity, variation of temperature, solar radiation, wind direction, wind speed and precipitation. They were unable to extract relevant conclusions in relation to the concrete structure because the method used was qualitative and did not address the long durability of concrete structures.

2.4. Re-use CP removed from service

CP are removed from OL because of his degradation condition. However, in certain situations as the passage from OL to underground line, changing the route of the OL or LA redimensioning may lead to removing CP in good condition.

Cooper et al. (1996) studied the possibility of reusing or recycling wooden poles or wood parts of the poles. Recycling gave rise to other wood products. An assessment based on the following characteristics was made: age, type of wood, type of conservation treatment, size, state of degradation, damage caused by mechanical stress, deployment location and other specific factors that could affect the performance. Wooden poles were allocated to potential reuse of alternatives based on certain criteria presented in Figure 2. The

Priority or rating	Proposed use	Criteria
1 (highest)	Re-use as is as a pole	Less than 10 years old, good condition, greater than 35 feet (10.7 m) long
2	Cedar roof shakes or shingles	Western red cedar only, top diameter 12 inches (30 cm) or greater, few knots
3	16 foot (4.9 m) saw log	Top diameter 6 inches (15 cm) or greater, sound, minimal hardware
4	8 foot (2.4 m) saw log	Top diameter 6 inches (15 cm) or greater, sound, minimal hardware
5	Round building poles or posts	6 feet (2 m) or longer, sound
6	Firewood	Untreated northern white cedar or western red cedar
7 (lowest)	Landfill disposal	Excessive rot or mechanical damage, excessive hardware, heavy preservative bleeding

Figure 2 - Hierarchy of reuse alternatives of wooden poles removed (Cooper et al., 1996)

study concluded that 8% of the analyzed

support can be reused without using any preservative treatment, 15% can be used in "cedar shakes rood" and 35% in other new products.

2.5. Maintenance of OL

The Maintenance Department of EDP D monitors the technical condition of the entire OL in High and medium voltage by performing visual inspections, thermographic and measuring distances of lines using a laser to obstacles such as trees, buildings, among others. This supervision is carried out using helicopters by Labelec, one of EDP Group companies.

Labelec must ensure inspection of the entire High voltage OL within about 3 years, and Medium voltage OL in 5 years. With the resources currently available, the company has run the inspection of more than 20 000 km of line per year.

3. ELECTRE TRI-nC method

The ELECTRE TRI-nC method belongs to a group of methods called ELECTRE ("Elimination Et Choix Traduisant la réalité") derived from the first ELECTRE I method presented by Bernard Roy in 1968.

The ELECTRE TRI-nC method is designed to associate a set of actions (alternatives) $A = \{a_1, a_2, \dots, a_m\}$ to ordered classes (categories). Let $C = \{C_1, C_2, .., C_k\}$ a set of k ordered classes in order of preference in which it is assumed C_1 is the worst and C_k is the best. The method allocates each action a_k from A to certain C_k class. This classification is a comparison between a_k and reference action corresponding to the upper and lower bounds of the class represented by $B = \{b_0, b_1, \dots, b_k\}$. The evaluation consider a set of criteria $F = (g_1, g_2, \dots, g_j)$ and define a set of performance $\{g_j(b_0, \dots, g_j(b_n)\}, \forall j = 1, \dots, n$, limiting classes (see Figure 3).

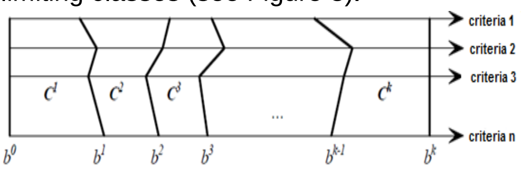


Figure 3 - Class boundaries in ELECTRE TRI-nC method (Dias, 2000)

ELECTRE methods are based on outranking relations to aggregate different evaluation criteria. Outranking relations are constructed to make a comparison of an alternative a_k with actions reference b_i, where $K = 1, \dots, m$ and $i = 1, \dots, n$. The outranking relation $a_k S\, b_k$ whose meaning is *"at least as good as"*. Building an outranking relations is based on two conditions (Mousseau & Slowinski, 1998):

- *Concordance:* for an outranking $a_k S\, b_i$ (or $a_k S\, b_i$) to be validated most of the criteria have to be in favor of this assertion.
- *Non-discordance*. When the the concordance condition is verified, none of the criteria which is in minority must be opposed against to the assertion $a_k S\, b_i$.

According to concordance and non-discordance conditions it is calculated an index $\sigma(a_k, b_i) \in [0{,}1]$, which represent a degree of credibility of an outranking relation. The assertion is valid if $a_k S\, b_i \geq \lambda$, where $\lambda \in [0.5{,}1]$ is a cutting level or credibility level, which is the lowest lowest value of the degree of credibility σ can have. When increasing the value of λ increases the credibility level but the occurrence of incompatibilities is more frequent. If there is a reduction in λ value, there is lower exigence and are increased indifference situations (Figueira et al., 2005).

The allocation of action a_k to a class C_k, taking into account the comparison with reference actions, can be performed by two different processes (Figueira et al., 2005):

- Pseudo-conjunctive (an action a_k will be assigned to the highest class C_k, such that a_k outranks its lower limit b_{h-1});
- Pseudo-disjunctive (an action a_k will be assigned to the worst class C_k,such that superior limit b_k outranks a_k).

4. Methodology

The objective of this work is to develop a MCDA to characterize the CP condition and its storage in order to check if their reuse is feasible. These two problems will be studied separately but using the same methodology. To do this work and since it will adopt an ELECTRE method the methodology implemented was the following:

i. Criteria construction. It was defined the criteria to be considered in assessing the condition and storage of CP. Bana e Costa (1992) considers fundamental points of view (FPV) is a perspective that the decision maker uses to analyze the problem. For characterization of CP condition were created FPV_1 that includes aspects of a technical nature which can be obtained by visual inspection and FPV_2 deal with the negative impact of the environment on the CP. To evaluate the possible storage of CP, to be reused have set FPV_3 which is associated with all transport costs and disassemble CP tasks as the own CP costs and FPV_4 relates to technical aspects relating to condition and important storage characteristics.

ii. **Specify the scale of the criteria performances.** The scales are set to characterize the different CP in criteria.

iii. **Determining the weights of each criteria.** Revised Simos procedure (Figueira & Roy, 2002) was used to define the weights of criteria. The method can be divided into two phases. The first one is to obtain data with decision maker help and the second phase is carried out calculations that allow us to assign weights to each criterion.

iv. **Define the CP performance in each criterion to be evaluated by ELECTRE TRI-nC method.** With the help of decision-makers will be analyse a set of CP.

v. **Identifying the classes with their reference actions.** Set up the classes will be used to classify the CP problems described.

vi. **Establish the preference thresholds (*p*) and indifference thresholds (*q*) for each criterion.** ELECTRE TRI method uses the indifference threshold and preference threshold to model the imperfect nature of the data collected, as well as the performance of the alternatives for each criterion and arbitrariness in the construction of each of criteria.

vii. **Definition of veto thresholds (*v*).** The introduction of veto thresholds to a criteria means that this criteria in particular can disagree with the allocation of a given action to a particular category.

viii. **Execution of ELETRE TRI-nC method algorithm's and results analysis**. In this step it will obtain the classification of CP. It will use the MCDA Ulaval software which implements several ELECTRE methods.

ix. **Sensitivity analysis.** Model susceptibility evaluation to change certain parameters (value of credibility level, value of Z and the number of white cards in Revised Simos procedure). When a parameter varies the other are equal.

5. Application of proposed methodology

The development of this methodology will have the collaboration of two decision makers from Maintenance Department and other from Loures operating area.

i. **Criteria construction.** FPV_1 will be evaluated by criteria g_1, g_2, g_3, g_4, FPV_2 will be evaluated by criteria g_5, g_6, g_7, g_8, FPV_3 will be evaluated by criteria g_9, g_{10}, and FPV_4 will be evaluated by criteria g_{11}, g_{12}, and g_{13}. The following criteria were considered:

- **g_1**: Age of CP - years since CP manufacture. Acquired by reading the markings recorded in CP.
- **g_2**: CP cracking level - The cracks are openings which occur on the CP surface due to various tensions that CP are subject.
- **g_3**: Covering of CP armor - Measures exposure level of armor. Throughout CP lifetime covering will be affected by degradation agents. In general the coverage is 20mm.
- **g_4**: Changing the CP Linearity - Related to some deformation in terms of bending or torsion. When applied overstressing in abnormal directions CP tend to get bent or crooked.
- **g_5**: Number of storms per year per region - Failures in electricity supply is often due to the impact of lightning on OL. The occurrence of this phenomenon has great influence on functioning of all elements of the OL.
- **g_6**: Proximity to coastal zone – CP degradation emphasized with the proximity to more acidic and saline environments. The penetration of various chlorides from sea water or exposure to air that carries sea salts are crucial in accelerating CP degradation process.

- **g_7**: Wind speed by geographic zone - The wind is a major atmospheric degradation agents responsible for CP. The higher the wind speed more vibrations on OL and higher stress will be experienced in CP. The wind can also cause impacts of objects in OL or even in AB.

- **g_8**: Temperature extremes by geographic zone - The temperature has an influence on the chlorides penetration process. Low temperatures may trigger the formation of ice in OL, contributing to increase its weight, diameter and wind impact area causing greater tensions in CP. Temperature variations cause expansion and contraction in OL by changing the length and traction in CP.
- **g_9**: Transport cost of CP - This criteria refers to the cost associated with CP disassembly and transport activities to storage location. The transport cost is dependent on certain characteristics of CP, including its total height, your weight, whether or not massive and the distance to storage location.
- **g_{10}**: CP cost - For storage it is important to know CP cost in order to store the most expensive CP.
- **g_{11}**: CP base condition - In order to reuse a CP is required CP base is in good condition after being removed from its foundation.
- **g_{12}:** CP condition **-** The CP condition to be reused is the criteria most important in the storage process. The evaluation of this criteria is carried out a set of previously defined criteria (g_1, g_2, g_3, g_4, g_5, g_6, g_7, g_8).
- **g_{13}:** Storage indicator (SI) - This criteria takes into account the frequency of use and number of CP with the same features that have in stock. This criteria will be assessed taking into account historical data for the annual consumption and the quantities that are available in the database. Storage indicator is given by the expression (1):

$$SI = \frac{CP\ number\ available\ in\ stock}{CP\ number\ consumed\ annually} \quad (1)$$

Storage indicator it is better as nearest 1, since stock meet required needs and thus it is not necessary to incur unnecessary costs.

ii. Specify the scale of the criteria performances. In qualitative scales the different levels are encoded by numbers in brackets.

- **g_1**: S_1=[0,50] is the number of years in which 50 years is the expected useful lifetime of the CP.
- **g_2**: S_2={very low (1), low (2), medium (3), high (4), very high (5)} corresponding to the number and severity of cracks that CP presents.
- **g_3**: S_3={good coverage(1), moderate delamination (2), high delamination (3), moderate exposure (4), high exposure (5)}
- **g_4**: Table 1 shows the scale to characterize criterion g_4.

Table 1 – g_4 scale criteria

Scale	Description
Low (1)	No visible changes
Moderate (2)	Small visible signs of bending and / or torsion
Medium (3)	Visible signs of bending and / or torsion
High (4)	Severe visible signs of bending and / or torsion
Critical (5)	Very serious visible signs of bending and / or torsion

- **g_5**: S_5=[3,24] based on the map that indicates the number of storms per year in each region of Portugal.
- **g_6**: S_7=[0,10] It is wind speed in m/s based on the spatial distribution wind speed map in Portugal (www.prociv.pt).
- **g_7**: Based on the risk of heat waves and cold waves in Portugal in each region (www.prociv.pt). The criteria will be performed before the worst case of extreme temperature. Table 2 shows the scale to characterize criterion g_7.

Table 2 - g_7 scale criteria

Scale	Description
Minimum (1)	Risk of heat waves and cold waves is minimal
Reduced (2)	Worst scenario between risk of heat waves and cold waves is reduced
Moderate (3)	Worst scenario between risk of heat waves and cold waves is moderate
High (4)	Worst scenario between risk of heat waves and cold waves is high
Maximum (5)	Worst scenario between risk of heat waves and cold waves is maximum

- **g_8**: S_9={low (1),moderate (2), medium (3), high (4), very high (5)}
- **g_{10}**: S_{10}={very high (1), high (2), medium (3), moderate (4), low (5)}

• **g_{11}**: Table 3 shows the scale to characterize criterion g_{11}.

Tabela 3 – g_{11} scale criteria

Scale	Description
Good conditions (1)	CP presents its base in good condition to be reused
Damaged (2)	CP presents its base totally or partially destroyed

• **g_{12}:** Table 4 shows the scale to characterize criterion g_{12}.

Table 4 – g12 scale criteria

Scale	Description
Very good (1)	Low/no risk for the OL operation
Moderate (2)	Moderate risk for the OL operation
Median (3)	Medium risk for the OL operation
Critical (4)	High risk for the OL operation
Critical (5)	Very high risk for the OL operation

• **g_{13}:** The scale for g_{13} criterion is given by the absolute value of the expression (2). Smaller value of (2) more closer to 1 is the SI and more beneficial to the company that has lower costs.

$$S_{13} = |1 - SI| \tag{2}$$

Criteria always have a preference meaning, to maximize or minimize. In this work all the criteria are to minimize.

iii. Determining the weights of each criterion (Revised Simos procedure). Revised Simos procedure enables decision makers to easily express their opinion even if they are not very familiar with MCDA. This approach consists of associating a ‘‘playing card’’ with each criterion.

In the first phase, using a set of cards where each card corresponds to a criteria than decision-makers need to prioritize the cards in order to rank the levels in ascending order of importance. The first criteria in ranking is the least important and the last is the most important. If decision-makers comes to an understanding that the criteria have the same level of importance than others, they should group them together (a subset of *ex aequo* cards).

The decision maker should use white cards if the difference in importance between two cards (or subset of *ex aequo* cards) should be higher. It can be added the number of white cards that the decision maker find it necessary. Tables 5 and 6 present the criteria hierarchy of the two issues under study, ranking the subsets of *ex aequo* from the least to the best.

Table 5 - Hierarchy of criteria relating to the CP condition

Rank	Subset of *ex aequo*	Number of cards
1	g_7, g_8	2
2	g_6	1
3	g_5	1
4	g_1	1
	White card	1
5	g_2	1
6	g_3, g_4	2

Table 6 - Hierarchy of criteria relating to the CP storage

Rank	Subset of *ex aequo*	Number of cards
1	g_9	1
	White card	1
2	g_{10}	1
3	g_{13}	1
	White card	2
4	g_{11}, g_{12}	2

In the second phase we used the SRF software to calculate the weights of the criteria. This software is an implementation of the revised Simos’ procedure.

For weighting process be more accurate, there is a parameter Z which SRF software let us define associated with the number of times that the criteria in first place of hierarchy it is more important than the latter criteria.

Tables 7 and 8 are the weights of criteria for the two problems studied using value of Z = 10. This value means that the criteria g_3 and g_4 are 10 times more important than the criteria g_7 and g_8. The same can be said about the g_{11} and g_{12} criteria against the g_9 criteria.

Table 7 – Weights of CP condition criteria

Criteria	Normalized weights
g_1	0,129
g_2	0,20
g_3	0,235
g_4	0,235
g_5	0,094
g_6	0,059
g_7	0,024
g_8	0,024

Table 8 - Weights of CP storage criteria

Criteria	Normalized weights
g_9	0,033
g_{10}	0,131
g_{11}	0,328
g_{12}	0,328
g_{13}	0,18

iv. Define the CP performance in each criterion to be evaluated by ELECTRE TRI-nC method. It was analyzed twenty two CP in order to characterize their condition (see Figure4). The CP a_1 to a_5 are in exploration of OL. The a_6 to a_{10} are stored. The remaining are fictitious CP. It was used fictitious CP to simulate different characteristics and test the allocation of CP to different classes. The a_{11} a a_{14} are located in north of the country, a_{15} a a_{18} are located in center of the country and a_{19} a a_{22} are located in south of the country.

CP	Criteria g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
a_1	18	1	1	1	10	1	5,5	1
a_2	21	2	1	1	10	1	5,5	1
a_3	10	2	1	1	10	2	6	1
a_4	16	1	2	1	10	2	6	1
a_5	22	2	2	1	10	1	5,5	1
a_6	3	1	1	1	10	1	5,5	1
a_7	13	2	1	1	10	1	5,5	1
a_8	7	1	1	1	10	1	5,5	1
a_9	5	1	1	1	10	1	5,5	1
a_{10}	15	2	2	1	10	1	5,5	1
a_{11}	15	3	2	1	18	1	6,5	5
a_{12}	30	3	3	3	22	2	5	1
a_{13}	25	2	2	1	16	1	7	4
a_{14}	16	2	1	1	10	1	5,5	1
a_{15}	10	1	1	1	14	3	6,5	5
a_{16}	20	3	3	1	12	2	5	1
a_{17}	32	3	5	2	9	2	5	4
a_{18}	39	4	3	2	10	1	5	3
a_{19}	6	1	1	1	5	3	5,5	4
a_{20}	12	3	2	1	11	1	5	4
a_{21}	18	2	2	1	15	1	6	5
a_{22}	45	5	4	3	10	1	5	4

Figure 4 - Performance criteria of different CP (condition criteria)

It was analysed CP a_6 to a_{10} which were stored because it's needed to know the CP base condition (g_{11}) and CP condition (g_{12}) to make storage evaluation.

CP	Criteria g_9	g_{10}	g_{11}	g_{12}	g_{13}
a_6	1	3	1	1	0,8
a_7	2	4	1	2	0,9
a_8	1	3	1	1	0,9
a_9	1	3	1	1	0,75
a_{10}	3	2	1	2	0,5
a_{23}	3	3	2	3	0,5
a_{24}	1	2	1	4	0,25
a_{25}	4	4	1	1	0,25
a_{26}	2	2	1	2	0,9
a_{27}	1	3	2	1	0
a_{28}	1	5	1	3	0,7

Figure 5 - Performance criteria of different CP (storage criteria)

v. Identifying the classes with their reference actions. To characterize CP condition is considered a set of four classes associated with the risk which CP performance may endanger the proper functioning of OL presented in Figure 6. In order to characterize the viability of CP storage, with the objective of their reuse, it was considered three categories presented in Figure 7. All classes are ordered from worst class (C_1) to the best class (C_3 or C_4). Note that ELECTRE TRI-C method can be used one or more reference actions in classes definition.

Classes	Risk level	Reference actions	Criteria g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
C_1 – very critical	Very high	b_1^1	45	5	4	4	21	3	7	5
C_2 – critical	High	b_2^1	35	4	3	3	18	3	6,5	4
C_3 – moderate/ good	Medium	b_3^1	25	3	2	2	15	2	6	3
		b_3^2	20	2	2	1	15	1	5,5	3
C_4 – very good	Low/without risk	b_4^1	12	2	1	1	12	1	5	2
		b_4^2	6	1	1	1	6	1	4,5	1

Figure 6 - Performance of reference actions of classes that characterize CP condition

Classes	Storage	Reference actions	Criteria g_9	g_{10}	g_{11}	g_{12}	g_{13}
C_1	Not feasible	b_1^1	4	5	2	4	1
C_2	Questionable	b_2^1	2	3	1	3	0,8
C_3	Feasible	b_3^1	1	2	1	2	0,5

Figure 7 - Performance of reference actions of classes that characterize CP storage

vi. Establish the preference thresholds (*p*) and indifference thresholds (*q*) for each criterion. It was defined constant indifference thresholds and constant preference thresholds for all criteria (see Figure 8).

vii. Definition of veto thresholds (*v*). The veto thresholds are presented in Figure 8.

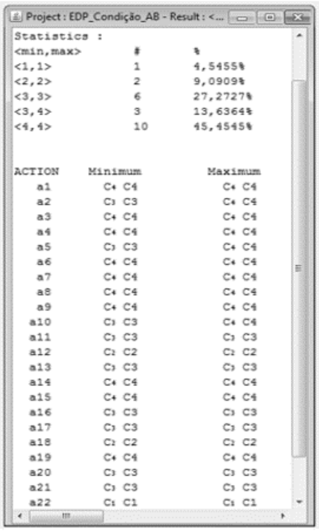
Thresholds	Criteria g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}	g_{12}	g_{13}
q	-	-	-	-	2	-	1	-	-	-	-	-	0,1
p	-	-	-	-	5	-	2	-	-	-	-	-	0,2
v	30	4	4	4	15	-	6	4	4	4	-	4	0,7

Figure 8 - Indifference thresholds, preference thresholds and veto thresholds for all criteria

viii. Execution of ELETRE TRI-nC method algorithm's and results analysis. Once all information inserted on the MCDA ULAVAL software and considering the two issues being studied, the results were obtained for a level of credibility of λ = 0,6 (see Figures 9 and 10).

By being applied two allocation process in simultaneous (pseudo-conjunctive and pseudo-disjunctive process) a minimum and maximum class are obtained to the same

CP. When minimum and maximum classes are not equal to same CP means there is no information necessary to allocate a CP to only one class. In these cases it is important the cooperation of decision makers to assign the CP to the class that is considered to be the most appropriate.



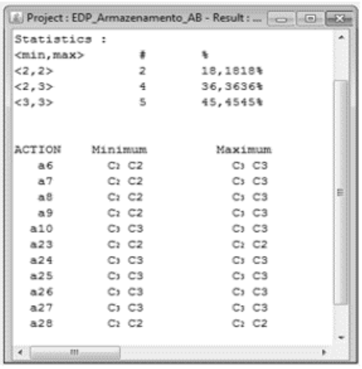
Project : EDP_Condição_AB - Result : <...

Statistics :

<min,max>	#	%
<1,1>	1	4,5455%
<2,2>	2	9,0909%
<3,3>	6	27,2727%
<3,4>	3	13,6364%
<4,4>	10	45,4545%

ACTION	Minimum	Maximum
a1	C4 C4	C4 C4
a2	C3 C3	C4 C4
a3	C4 C4	C4 C4
a4	C4 C4	C4 C4
a5	C3 C3	C4 C4
a6	C4 C4	C4 C4
a7	C4 C4	C4 C4
a8	C4 C4	C4 C4
a9	C4 C4	C4 C4
a10	C3 C3	C4 C4
a11	C3 C3	C3 C3
a12	C2 C2	C2 C2
a13	C3 C3	C3 C3
a14	C4 C4	C4 C4
a15	C4 C4	C4 C4
a16	C3 C3	C3 C3
a17	C3 C3	C3 C3
a18	C2 C2	C2 C2
a19	C4 C4	C4 C4
a20	C3 C3	C3 C3
a21	C3 C3	C3 C3
a22	C1 C1	C1 C1

Figure 9 - Results of the MCDA ULAVAL software (CP condition)



Project : EDP_Armazenamento_AB - Result : ...

Statistics :

<min,max>	#	%
<2,2>	2	18,1818%
<2,3>	4	36,3636%
<3,3>	5	45,4545%

ACTION	Minimum	Maximum
a6	C2 C2	C3 C3
a7	C2 C2	C3 C3
a8	C2 C2	C3 C3
a9	C2 C2	C3 C3
a10	C3 C3	C3 C3
a23	C2 C2	C2 C2
a24	C3 C3	C3 C3
a25	C3 C3	C3 C3
a26	C3 C3	C3 C3
a27	C3 C3	C3 C3
a28	C2 C2	C2 C2

Figure 10 - Results of the MCDA ULAVAL software (CP storage)

ix. Sensitivity analysis.

a) Credibility level variation (λ): it was tested the value of **λ=0,7** (more exigence). The new results compared to Figure 9 were the actions a_2, a_5 and a_{10} allocated only to one class, C_4, C_3 and C_3 respectively. Compared to Figure 10, in new results a_{24} and a_{27} are now allocated to two classes (C_2 and C_3) but a_6, a_7, a_8 e a_9 are now allocated to the same minimum and maximum class (C_3, C_2, C_3 and C_3 precisely). It was tested the value of **λ=0,5** (less exigence). It occurred more indifference situations in terms of assigned classes. a_3, a_4, a_{13}, a_{14} e a_{20} are now allocated to different minimum and maximum classes (compared to Figure 9) and a_{24} e a_{26} also are now allocated to different minimum and maximum classes (compared to Figure 10).

b) Z value variation: the change in value of Z changes the criteria weight. In CP condition criteria there were no changes in results between the interval **[7,20]**. It was found that from **Z=6**, a_{12} changed its classification of C_2 to C_3. In CP storage criteria there were no changes in results between the interval **[4,12]**. It was found that from **Z=3**, a_7 changed its classification to C_2 and **Z=13**, a_7 changed its classification to C_3.

c) Number of white cards: the change in number of white cards also changes the criteria weight. The introduction one more white card between $\boldsymbol{g_1}$ **and** $\boldsymbol{g_5}$ did not change the previous results. Placing another white card between $\boldsymbol{g_2}$ **and** $\boldsymbol{g_1}$, we are going to have two white cards in this interval, also did not change the results. So, it was tested in simultaneous the introduction one more white card between $\boldsymbol{g_1}$ **and** $\boldsymbol{g_5}$ with the introduction of another white card between $\boldsymbol{g_2}$ **and** $\boldsymbol{g_1}$. Again, the change of the number of white cards had no impact on the results.

It was decided to examine the introduction of a white card between $\boldsymbol{g_{11}}/\boldsymbol{g_{12}}$ **and** $\boldsymbol{g_{13}}$, we are going to have three white cards in this interval. The possibility of adding two more white cards between the same criteria was also considered. The results of these changes were the same. CP a_{24} has to be allocated to minimum class C_2 and maximum class C_3.

6. Conclusions

ELECTRE TRI-C method was shown to have great potential as applied to risk classification problems. The collaboration of the decision-makers of the way the model takes into account their preferences and be more appropriate to the problems under study.

The results showed no surprise and through sensitivity analysis it was concluded that model is robust and indifferent to changes in parameters.

It was decided that the construction of an easy analysis criteria for specialist or non-specialist people can make CP evaluation.

In the future to contribute for this work, the methodology can be applied to Low Voltage CP and articulated metal poles by changing some criteria. The parameterization supported by experts may be discussed.

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