Prioritization of Interventions in EDP Distribuição Assets

João Pedro Trigo Montalvo Rosa

Department of Engineering and Management, Instituto Superior Técnico

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Abstract

This dissertation develops an analysis of EDP Distribution's asset management approach, as well as a review of the methods used for the management of assets in similar cases, with the objective of analyzing the methodological and practical aspects that may be used for the investigation of the problem under study, as well as possible improvements for those methods. These analysis and review are a starting point to identify the methodologies for the development of better analysis of physical assets.

This investigation proposes an approach for the development of an evaluation model in order to prioritize the assets of EDP Distribuição in need for intervention, based on a multicriteria methodology that allows to calculate the overall value associated to the interventions to be carried out, starting from qualitative judgments by the group of decision-makers, taking into account the criteria defined for the developed model. Starting from the global values calculated from the multicriteria model, an intervention priority index is defined, categorizing the assets according to four levels of urgency (Very urgent; Urgent; Medium Priority; Low Priority). Subsequently, taking into account the available budget, a prioritization of the same assets is carried out, but according to the benefit/cost ratio. Next, an analysis of portfolios of assets to intercede was carried out, in order to select the portfolio that presents the best benefit for the available budget.

Finally, a robustness analysis was carried out on the portfolio proposed to the group of decision makers, in order to understand the consistency and robustness of the selected portfolio.

Keywords: Asset Management; Asset Prioritization Model; Multicriteria Decision Analysis; MACBETH; Portfolio Robustness Evaluation; PROBE

1. Introduction

The economic value of a company is the sum of all its assets. Due to the current competitiveness among the operators of the energy distribution market, it is essential to ensure a good functioning of their physical assets. To that end, it is necessary to apply good asset management practices, using mechanisms that lead to a balance between costs, risks and performance, so that the quality of service provided by a company to its consumers could be as good as possible.

Due to the existence of a large number of assets as well as financial constraints faced by operators, it is necessary to change certain policies and actions previously used in order to allow a greater rationalization of costs, since a poor management of these could jeopardize the whole society consumer of energy, resulting for example in the increase of the tariffs, carrying out continuous improvement actions in relation to ongoing processes and operations, such as the re-use of certain materials that constitute the assets.

For EDP Distribuição, asset management allows a detailed and complete analysis of the components of its distribution network, that allows to know the financial impact of each of the assets under analysis, getting to know which to maintain, reduce or, for example, replace. Taking into account the risk to which these assets are subject, and using a valuation factor that allows prioritizing the assets to intervene, considering the benefits, costs and risks, the EDPD seeks to obtain a set of assets and investments that are more profitable as possible. Currently EDP Distribuição intends to provide a model that allows prioritizing interventions in assets, more specifically in medium/low voltage transformers, taking into account several evaluation factors simultaneously. It is expected that the development of such model will allow a greater return on the investment made by EDP Distribuição in its assets, resulting from a more efficient use of its resources.

2. Problem Description

Currently EDP Distribuição has more than 70 thousand medium/low voltage transformers (MT/BT). These are simple assets, but with a significant cost for de company, which have a preponderant role in the company's activity. Every year hundreds of transformers get damaged, many of them before reaching the expected lifetime, leading to significant losses for the company.

For this purpose, fault analysis, the construction of models for evaluating the condition of the transformers as well as predictive models, is something that has been developed by EDP something that has been done by EDP Distribuição, always with the objective of extending the life of these assets, seeking to reduce negative economic impacts and maintain the quality of service provided.

The management of the assets of EDP Distribuição, passes through an act of balance between the following factors:

- **Performance -** related to the state of operation of the asset, as well as the frequency of any interruptions that may occur and their duration. This should be great, not really maximum.
- **Costs -** associated with the operation/maintenance of the assets, such as maintenance, revision, replacement and modification costs. Costs must not be intuitive but justified.
- **Risks -** related to the possible occurrence of external damages and obligations. In order to assess the consequences of each risk, EDP Distribuição chose four business values: sustainability, reputation (image of the company), quality of service and economic factors. The aim is to control risks rather than avoid them.

The physical assets to be analyzed during the present dissertation consist of medium/low voltage transformers (MT / BT), which are tangible fixed assets of enormous importance for the company's activity. This type of power transformer is used to reduce the voltage of the electric current, so that it can be distributed and delivered to EDP Distribuição's final customers (see Figure 1). Currently, EDP Distribution has about 70 000 transformers from different brands.

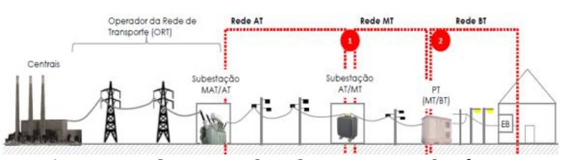


Figure 1 - Electricity distribution network of EDP Distribuição (EDP, 2016)

Analyzing the distribution of the 70 000 MT/BT transformers in the 18 districts of Continental Portugal shown in Figure 2, it is possible to observe that there is a greater quantity of transformers in operation in the districts of Lisbon and Porto with, when compared to the other districts.

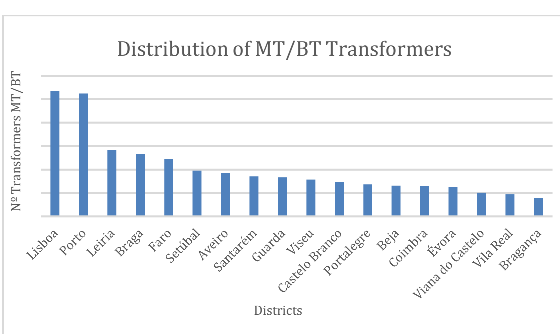
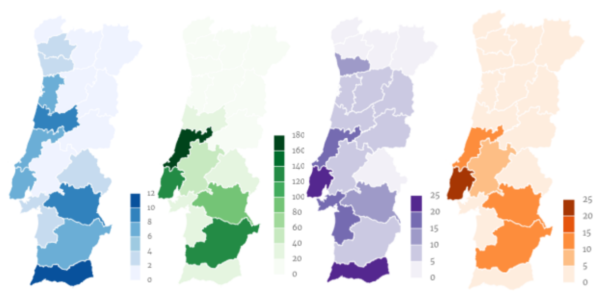


Figure 2 - Distribution of MT/BT transformers in mainland Portugal

Of the approximately 70 000 MT/BT transformers in existence, about 1 100 were operated with a total cost of about € 1 600 000. The interventions were of four types:

- **Post mortem analysis:** this type of analysis consists of a check made to transformers that have reached the end of their life, in order to understand the reasons that led to their failure.
- **Beneficiation:** intervention carried out with the objective of improving certain characteristics of the asset.
- **Rehabilitation:** actions aimed at recovering the condition of the asset, incorporating the increase in useful life and/or increase of its productive capacity.
- **Conservation:** Lighter intervention, used when the transformer is in good operating conditions.

Analyzing the four types of intervention by district (see Figure 3), it is possible to draw some conclusions: the district with the highest number of intervention on assets is Leiria, although it is only the third district with the largest number of transformers in operation, with about half of the transformers in Lisbon and Porto. Porto is the second district with the largest number of transformers in operation, but it is the district with the lowest number of asset intervention. Similar case for the district of Braga. The districts with the highest number of post mortem analyzes, associated to the end of life of the transformers, correspond to Faro followed by Évora, although this last district is one of the districts with the smaller number of transformers, this is the second district with the highest number of post mortem analyzes. The districts with the highest number of beneficiation interventions are Leiria followed by Beja. Regarding rehabilitations, the districts with a higher number are Faro, followed by Lisbon. Faro is thus the district with the highest number of post-mortem interventions as well as rehabilitation.



(a) (b) (c) (d)

Figure 3 - Graphical representation of: a) Post Mortem analyzes, b) Beneficiations, c) Rehabilitations, d) Conservations

In the analysis of the current situation in EDP Distribuição, the following shortcomings were detected:

- Difficulty in comparing the level of intervention needed for the assets under study, leading to inefficient management.
- The need for a mechanism to classify asset's performance, allowing the identification of the state of operation of the asset.
- Difficulty in prioritizing assets according to a certain level of need.

3. Literature Review

3.1 Causal Maps

A cognitive map corresponds to the representation of thinking in relation to a problem, which results from the mapping process of the problem in question, which is the reason for the attributed denomination (Eden, 2004). This type of maps seeks to represent both the beliefs and values of an individual (Nutt and Wilson, 2010). The maps are constituted by a network of knots and arrows that unite them, in which the direction of the arrows represents causal relations (Harary et al., 1965; Harary, 1972), reason why often these types of maps also are denominated causal maps, particularly when they are performed by a group, and can not be related to the cognition of only one individual (Eden, 2004).

According to Eden (1992), this type of map represents subjective information in a more meaningful and concise way, compared to other models, functioning as a tool to facilitate the process of decision making, problem solving and negotiation in organizational contexts. Cognitive maps are usually obtained through an interview, with the objective of representing the entire subjective component of the interviewee (Eden, 2004). In general terms, a phrase at the origin of an arrow (of which the arrow points) has a causal or influential relationship to the phrase at the other end of the arrow, ie where the arrow points (Eden, 2004).

The main expressions above correspond to goals to be achieved or avoided, the other side of the arrow corresponding to options for achieving those goals (Eden, 2004).

3.2 Multi-Criteria Decision Analysis (MCDA)

This type of methodology allows the accomplishment of an analysis with multiple criteria in order to facilitate the decision making process either by a single individual or decision group (Linkov et al., 2004).

The use of this type of decision support methodology is very common within the decision-making process, since it provides an organized and rational approach capable of integrating several important requirements for the process as well as the presence of the various stakeholders involved, each one with its objectives, vision and requirements (Mendoza and Martins, 2006).

According to Mendoza and Martins (2006), one of the characteristics of multicriteria decision support models is that these are composed by four properties that make it interesting in structuring a problem: it takes into account multiple criteria; facilitates the process of structuring the problem; it has a rational, perceptible and explanatory process of the model; provides a problem analysis model capable of serving as an object of discussion. The MCDA models allow the creation of a list of options, ordered according to the preference of the decision maker, based on three main processes, (Bana e Costa et al., 2005):

- **Structuring -** formulation of the problem, identification of the decision maker and all stakeholders, identification of acceptance/rejection criteria, evaluation criteria and alternatives.
- **Evaluation -** the performance revealed by the different alternatives for each of the considered criteria is transformed into value and the weights of the criteria are defined by the decision maker. The value of each alternative in each of the criteria is aggregated in order to obtain its overall value, after which sensitivity and robustness analyzes are performed on the results.
- **Selection of the best alternative -** more attractive hypothesis considering the analysis made to the obtained results of the model, taking into account the sensitivity and robustness analyzes previously performed.

There are several methods that produce a quantitative measure that aims to represent performance attractiveness, for example: AHP, MAUT, MAVT, UTA (Figueira et al., 2005). The best method for the problem described was the MAVT (Multi-Attribute Value Theory), since it consists of an aggregation of value obtained through the evaluation of the different alternatives, using for that purpose, functions of value (partial) in each of the criteria, in order to define a global value function. The global value function can be determined additive or multiplicative, depending on the conditions (Figueira et al., 2005). One of the MAVT methods is MACBETH, that only requires qualitative judgments from the decision maker to assess value scales and to weigh the criteria (Bana e Costa et al., 2005).

Given that MACBETH also has a companion software tool "M-MACBETH" (Bana e Costa et al. 2012) that validates the consistency of decision-maker's answers, this was the chosen approach for the problem.

3.2.1 The MACBETH Approach

MACBETH (Measuring Attractivess by a Category-Based Evaluation Technique) is a methodology that addresses the decision-making process for multicriteria evaluation problems (Bana and Costa et al., 2012). The objective behind its operation is to measure the attractiveness or the different value among the alternatives considered, through a non-numerical comparison questionnaire based on seven distinct qualitative categories in terms of attractiveness: there is no difference (indifferent), the difference is very weak, weak, moderate, strong, very strong or extreme (Bana e Costa et al., 2012).

This methodology is based on a humanistic and interactive approach of the problem, whose quantitative model is based on qualitative judgments, which allows modeling from ordinal to cardinal preference without the possible loss of rigor and consistency (Bana e Costa et al., 2008). This is also widely used in problems of evaluation, prioritization and selection of investment projects, strategy and policies as well as allocation of resources (Bana and Costa et al., 2010).

The weighting coefficient of each criterion is calculated from the M-MACBETH, using qualitative judgments of differences in attractiveness between alternatives provided by the decision maker. Usually in the MACBETH approach two distinct levels of reference performances are defined: a level called "Neutral" (level that is neither attractive nor repulsive to the decision maker, 0), and a "Good" level (attractive level, 100) (Bana e Costa et al. al., 2012). From the definition of these two levels, the judgment process of the decision maker becomes easier due to the two references established (Bana and Costa et al., 2012). Subsequently, the MACBETH decision support process evolves towards the development of a quantitative evaluation model (Bana e Costa et al., 2005 and 2012).

Based on the judgments made by the decision maker and using the functionalities present in the M-MACBETH software, each criteria's score as well as the relative weights for them are gradually suggested and discussed (Bana and Costa et al. al., 2005). Then, an overall score for each of the alternatives is calculated by a weighted sum of the scores obtained by the multiple criteria (Bana and Costa et al., 2005).

The simplest and most common form used in aggregation of value is the additive model, represented in the next equation (Bana and Costa et al., 2012):

$$V(A) = \sum_{i=1}^{n} w_i v_i(A_i) \; with \; \sum_{i=1}^{n} w_i = 1, w_i > 0$$

where,

- $V(A)$ is the overall performance value of alternative A;
- A_i is the performance of the alternative A in the criterion i (i=1, …, n);
- $v_i(A_i)$ is the partial value of the performance of the alternative A in the criterion$i$ (i=1, …, n);

- w_i corresponds to the weighting coefficients or relative weights of the criteria, which allow to transform the partial value units, v_i, in units of global value V.

After this formulation of the problem, it is possible to carry out sensitivity and robustness analyzes of the results obtained by the model, in order to understand the problem more deeply, to adjust the model as well as to create convictions about the priorities to be established or options to select, in context of individual or group decision-making. The M-MACBETH software allows several graphical representations, facilitating the elaboration of a final report justifying the elaborated recommendations (Bana and Costa et al., 2005).

3.3 Portfolio Analysis

Companies and organizations face a number of investment projects that exceed their availability in terms of resources, seeking to find the set of projects (portfolio) that maximizes their created value (Lourenço et al., 2017). Given the existing constraints, a manager intends to select the portfolio of projects that provides the organization with the highest possible benefit value (Lourenço et al., 2012). An exhaustive analysis of the total possible range of portfolios would be unthinkable even for a small number of projects, since, for example, for a small number of 20 projects, the final result would be approximately one million portfolios ($2^{20} =$ 1,048,576) (Lourenço et al., 2012)

The selection of multiple projects on budget constraints can also be performed according to a prioritization approach (Lourenço et al., 2017), with projects prioritized according to a benefit/cost ratio, and selected until the available budget is reached (Phillips et al. Bana and Costa, 2007).

From the approaches used to form efficient project portfolios, the following stand out (Lourenço et al., 2017):

- **Benefit/Cost prioritization:** consists of a decreasing ordering of projects according to the benefit/cost ratio. The list is covered, choosing projects to include in the portfolio until the available budget is reached. It allows only convexly efficient portfolios to be formed. This method is simpler to apply relative to optimization since optimization requires the use of a solver. The prioritization also allows a large number of projects to be dealt with, which is difficult to apply in optimization, due to the fact that the problem, also called "knapsack", is much more difficult to solve (in fact, the knapsack problem is classified as NP-difficult (Garey and Johnson 1979). The selected portfolio through the benefit/cost ratio approach produces the greatest benefit for the money spent, but not necessarily the maximum benefit for the money available (Lourenço et al. 2012).
- **Optimization:** the efficient project portfolio is the optimum solution of a binary programming problem {0,1} (BIP), known as a knapsack problem, in which the benefits of the projects are maximized taking into account the constraint that the sum of project costs can not exceed the available budget. This approach allows us to deal with a greater number of constraints than prioritization, and to consider synergies and/or other types of interaction between projects, as well as budget constraints over different time periods, while prioritization is limited to problems with a single budgetary constraint. This approach forms any type of portfolios, convexly or not convexly efficient.

The mathematical formulation behind this approach is presented in the follow equation:

$$Maximize: \sum_{j=1}^{m} v_j\, x_j \qquad Subject\ to: \sum_{j=1}^{m} c_j x_j \leq B,$$

$$x_j \in \{0,1\}, j = 1, \dots, m$$

Where,

- x_j is a binary variable such that $x_j = 1$ if the project j is found in the optimal portfolio, e $x_j = 0$ otherwise.
- B is the available budget.
- c_j represents the cost of the project j.
- v_j represents the value of the project's benefit j.

3.4.1 PROBE (Portfolio Robustness Evaluation)

PROBE decision support system allows a multicriteria analysis of portfolios, implementing the optimization approach and also looking for the solutions given by the prioritization approach (Lourenço et al., 2012). This system considers multiple types of linear constraints, and given the benefits and costs of the project, identifies all portfolios convexly and not convexly efficient (Lourenço et al., 2017).

When several benefit criteria are defined, PROBE calculates the benefit value of each project through an additive value model (Lourenço et al., 2012).

The basic information of each project for a multicriteria portfolio analysis is the costs of each project and the performance values in the benefit criteria, and the weights that capture the trade-offs between the criteria (Lourenço et al., 2012). The system also allows to analyze the robustness of a selected portfolio, considering uncertainty margins regarding the project benefits, looking for other possible portfolios that offer a higher level of overall benefit without increasing the total cost associated with it (Lourenço et al., 2017).

The software identifies all efficient portfolios and depicts the Pareto frontier, distinguishing the portfolios convexly and not convexly efficient (Lourenço et al., 2012).

4. Applied Methodology

4.1 Structuring

The group of decision-makers is composed by Engineer Jorge Gomes, belonging to EDPD's asset management unit, and Engineer Cristina Carvalho, from EDPD's programming, control and management support unit. Both members of the decision-making group are currently linked to the JUMP project for the asset management of EDP Distribuição. The initial moment was the construction of a causal map on the problem in question (see Figure 4).

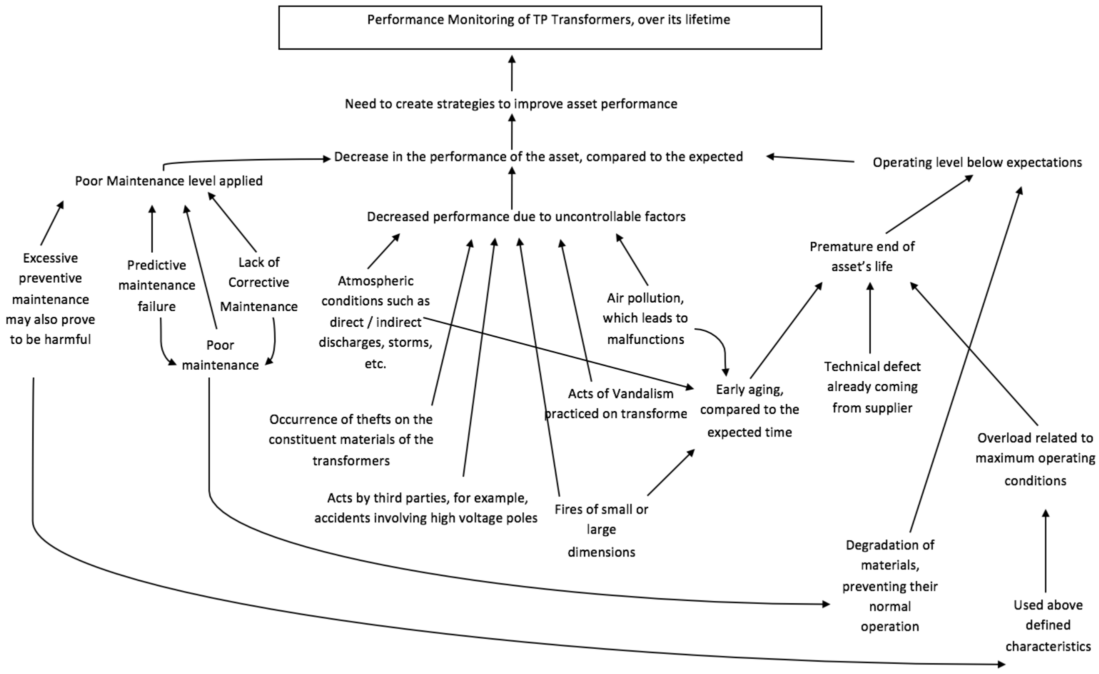


Figure 4 - Causal map for transformer's performance management process

From the analysis of the causal map it is possible to understand the main constituents of the problem under study, allowing to obtain an overview of the problem.

4.2 Performance Aggregation Measures

After defining the set of criteria and their descriptors, the M-MACBETH software was then used to organize the same set into areas of concern, through a value tree, as showed in Figure 5.

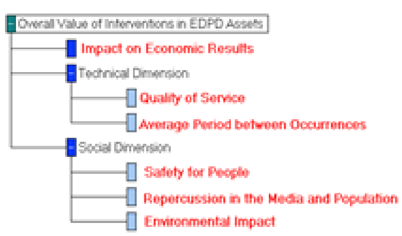


Figure 5 - Value tree "Overall Value of Interventions in EDPD Assets"

The criteria defined for the model were as follows:

- **Impact on Economic Results -** insofar as the reduction in the economic results of the company is required to be reduced as much as possible, being this reduction caused by losses on its property, plant and equipment and/or the costs necessary to recover the situation at a prior time to the occurrence of a particular event, and/or an income that is no longer received;
- **Quality of Service -** to the extent that the interruption of the service provided by EDPD should be as small as possible, in situations of internal responsibility for EDPD. Any liability situation outside EDPD is excluded;
- **Average Period between Occurrences -** the objective is to reduce the frequency of occurrences within a time interval of a given event;
- **Safety for People -** insofar as it if a particular event occurs, safety for the affected persons is increased as much as possible, avoiding situations that are potentially dangerous to their health;
- **Repercussion in the Media and Population -** insofar as it can affect the reputation/image of the company, seeking to reduce the population/area with knowledge of a given event and the possibility/extent of possible media coverage;
- **Environmental Impact -** the degree of damage suffered by the environment affected by a given event, taking into account factors such as size, quantity and time for extinction of the occurred event, should be as small as possible.

For each of the evaluation criteria presented, the respective performance descriptors were defined.

Considering the example of the "Quality of Service" criterion, the associated performance descriptor is described below in Table 1.

Table 1 - Performance descriptor and reference levels for criteria "Quality of Service"

Performance Descriptor	Reference Levels
TIEPI Performance that the realization of the potential intervention represents, that is, the intervention in an asset whose TIEPI is 3, will have the highest score (since it represents a very relevant intervention) and an intervention in a TIEPI 0.17 asset will have 0 points.	"Higher Level" TIEPI = 3
	"Lower Level" TIEPI = 0.17

The "Quality of Service" indicator is estimated by the simulated interrupted power in DPLAN, as well as by the duration of the replacement of the service provision, based on previous similar situations or, in the absence, evaluated from the closest existing situations (unit: minutes).

For the development of the multicriteria model, the next step was to construct value functions for each of the previously defined criteria using the M-MACBETH software based on the judgments expressed by the decision makers regarding the differences in attractiveness between each two levels of performance for each of the criteria. At reference levels "Higher" and "Lower" were assigned 100 and 0 values respectively, and it is particularly important to highlight that zero on the value scale effectively corresponds to the absence of value, and the value scales generated in this way are later used in the analysis of portfolios (Edwards, 1977; Clemen and Smith, 2009). For the group of the decision makers, it was asked to qualitatively evaluate the attractiveness between two levels of performance, using the semantic categories MACBETH - Null, Very Weak, Weak, Moderate, Strong, Very Strong and Extreme.

During the construction of the judgment matrix, in order to fill in the last column (comparing the lower level with the remaining ones), the first row (comparing the top level with the others) and the diagonal, questions were asked according to their order. As the matrix of judgments was completed, the M-MACBETH software was testing the compatibility of the information entered, so if there were any inconsistencies, suggestions would be provided for the correctness of the information.

After completing and validating the judgment matrix, the M-MACBETH software suggested a cardinal value scale for each criterion, which was presented to the decision-maker to validate the differences in scores between levels of performance and, if necessary, to adjust them. Subsequently, the same scale is visualized graphically allowing to compare the intervals between the scores, so that the proportions between intervals correctly reflect the relations between the intensities of preferences of the decision group regarding the differences of performance.

Considering the same criterion "Quality of Service", of quantitative nature, the matrix of judgments and the proposed numerical scale, resulting from the construction of the value function for the same criterion through the software M-MACBETH, is represented in Figure 6 and Figure 7, respectively.

	3	2.5	2	1.5	1	0.5	0	Escala atual
3	nula	mt. forte	mt. forte	mt. forte	extrema	extrema	extrema	100.00
2.5		nula	forte	forte	mfort-extr	mfort-extr	mfort-extr	63.98
2			nula	moderada	fort-mfort	mt. forte	mfort-extr	50.00
1.5				nula	forte	forte	mt. forte	40.00
1					nula	moderada	mt. forte	29.99
0.5						nula	forte	20.00
0							nula	0.00

Figure 6 - Judgments matrix for criterion "Quality of Service "

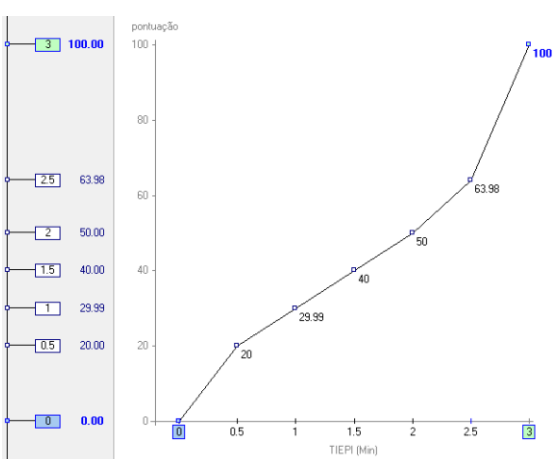


Figure 7 - Value scale for " Quality of Service "

In order to determine the weighting coefficients of the defined criteria, the good-neutral intervals of the criteria were sorted in order of decreasing attractiveness. To this end, the following question was asked to the group of decision-makers: "If there was an asset with a neutral performance level in all the criteria and it was possible to change only one of the criteria for good performance, what would be the criterion in which it would prefer the same change? " After that the chosen criterion was eliminated, and the same question was asked again, considering only the remain criteria. This procedure was repeated to the last criterion. It was then possible to identify the level of relevance for each interval between neutral and good levels for the decision group, in descending order, being possible to generate Table 2 for the global value model of interventions in medium/low voltage assets of the EDPD.

Table 2 - Sort order descending Neutral - Good

Sort order descending Neutral - Good from the evaluation criteria
Safety for People
Environmental Impact
Quality of Service
Average Period between Occurrences
Impact on Economic Results
Repercussion in the Media and Population

In a second phase, in the process of calculating the weighting coefficients, the matrix of weighting judgments was filled, according to the ordering indicated above. The group of decision-makers was asked to make judgments on the differences in attractiveness between the neutral and good intervals of each criterion, using the MACBETH semantic scale to fill the column to the right of the matrix. In this phase, as was also verified during the construction of the value scales, the M-MACBETH software points out possible inconsistencies between verified judgments. In Figure 8 is presented the matrix of weights judgments, defined by the group of decision makers.

	[SP]	[AMB]	[QS]	[PMO]	[RE]	[RMP]	[tudo inf.]
[SP]	nula	moderada	forte	forte	forte	forte	forte
[AMB]		nula	mod-fort	forte	forte	mod-fort	forte
[QS]			nula	mod-fort	forte	forte	mod-fort
[PMO]				nula	frac-mod	fraca	mod-fort
[RE]					nula	fraca	moderada
[RMP]						nula	frac-mod
[tudo inf.]							nula

Figure 8 - Weighting judgments matrix for the "Overall Value of Interventions in EDPD Assets"

After the process of filling the weighting judgments matrix, as mentioned previously, the M-MACBETH software suggests a scale of weights for the criteria, which is represented by the histogram of Figure 9.

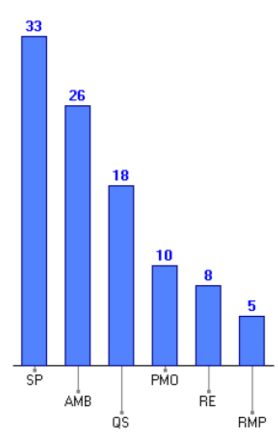


Figure 9 - " Overall Value of Interventions in EDPD Assets "critera weihgts

The last step in this process of weighting the criteria was the validation of the weighting coefficients obtained, by the decision group. When confronted with the value of the weights for each criterion, the decision makers agreed on the relative weight of the neutral intervals-good, assigned to each of the criteria and indicated by the M-MACBETH software.

In order to test the developed multicriteria model, the set of medium/low voltage assets was used. The 20 existing assets requiring intervention were implemented in the M-MACBETH software, as well as their performance in each of the defined criteria, as represented in Figure 10.

Opções	RE	QS	PMO	SP	RMP	AMB
AT1	1150	0.75	3.8	PS	NL	DP1-3
AT2	2300	1.5	2.6	TM	NR	DP+5
AT3	3400	2.25	1.3	TH	NN	DS1-3
AT4	4500	3	0.9	IM	NI	DS+5
AT5	4500	2.25	0.1	SI	NR	DP1-3
AT6	700	0.75	5	IM	NR	DS1-3
AT7	900	0.01	3.2	IM	SI	SI
AT8	2100	0.01	5	SI	SI	DS+5
AT9	1150	0.01	5	SI	SI	SI
AT10	1150	3	5	SI	SI	SI
AT11	4500	0.01	5	SI	SI	SI
AT12	1300	0.01	0.1	SI	SI	SI
AT13	1150	0.75	3.8	IM	NL	DP1-3
AT14	1150	0.75	3.8	PS	NL	DS+5
AT15	1150	0.75	3.8	PS	NI	DP1-3
AT16	1150	3	3.8	PS	NL	DP1-3
AT17	4500	0.75	3.8	PS	NL	DP1-3
AT18	1150	0.75	0.1	PS	NL	DP1-3
AT19	2300	2.25	1.3	TM	NN	DP3-5
AT20	3400	3	0.9	TH	NN	DS1-3

Figure 10 - M-MACBETH performance table

Following the implementation of the different options as well as their performance in each of the criteria, the M-MACBETH software calculated the scores corresponding to the performance value of each of the alternatives in the respective evaluation criteria, as well as the consequent overall value of each one, as shown in Table 3.

Table 3 - Score table to EDPD's Overall Value of Interventions

		Intervention Needed					
Assets	**Overall**	**RE**	**QS**	**PMO**	**SP**	**RMP**	**AMB**
AT1	18.64	21.8	24.99	22	20	20	10
AT2	43.4	43.79	40	38	49.99	40	40
AT3	62.2	64	59.99	66.8	70	70	50
AT4	98.4	100	100	83.99	100	100	100
AT5	35	100	59.99	116.01	0	40	10
AT6	53.57	13.4	24.99	0	100	40	50
AT7	37.31	18	0.4	28	100	0	0
AT8	29.32	40.6	0.4	0	0	0	100
AT9	1.82	21.8	0.4	0	0	0	0
AT10	19.74	21.8	100	0	0	0	0
AT11	8.07	100	0.4	0	0	0	0
AT12	13.58	23.8	0.4	116.01	0	0	0
AT13	45.04	21.8	24.99	22	100	20	10
AT14	42,04	21,8	24,99	22	20	20	100
AT15	22,64	21,8	24,99	22	20	100	10
AT16	32.14	21.8	100	22	20	20	10
AT17	24.9	100	24.99	22	20	20	10
AT18	28.04	21.8	24.99	116.01	20	20	10
AT19	47.48	43.79	59.99	66.8	49.99	70	25
AT20	71.12	64	100	83.99	70	70	50

It is possible to see the ordering in descending way of global value of the potential interventions to be performed, depending on the scores obtained in each of the criteria defined for the model, represented in Table 4.

Table 4 – Overall Value of Interventions in EDPD Assets, in descending way

Global value of the potential interventions to be performed, in descending order	
1º AT4 (98.8)	**11º** AT16 (32.14)
2º AT20 (71.12)	**12º** AT8 (29.32)
3º AT3 (62.2)	**13º** AT18 (29.32)
4º AT6 (53.57)	**14º** AT17 (24.9)
5º AT19 (47.48)	**15º** AT15 (22.64)
6º AT13 (45.04)	**16º** AT10 (19.74)
7º AT2 (43.4)	**17º** AT1 (18.64)
8º AT14 (42.04)	**18º** AT12 (13.58)
9º AT7 (37.31)	**19º** AT11 (8.07)
10º AT5 (35)	**20º** AT9 (1.82)

The global values of the potential interventions to be performed on the assets analyzed are translated into a gain in value relative to the realization of the corresponding intervention in each of the assets. The greater the overall value of each of the potential interventions, the greater the need for intervention on the respective asset.

4.3 Priority Index

After obtaining the global value of each of the potential interventions to be performed, the second phase of the model was carried out. Taking into account the overall value scale for the existing alternatives, four different categories of priority were defined and assigned to each comparable interval of the scale with respect to the greater or less need for intervention on one of the alternatives (active) compared to the others. The defined categories as well as their respective ranges of values are defined in Table 5.

Table 5 - Emergency categories

Performance Value > 75	Very Urgent
50 < Performance Value ≤ 75	Urgent
25 < Performance Value ≤ 50	Moderate Priority
Performance Value ≤ 25	Low Priority

The "Very Urgent" category also covers situations where the safety of people can be seriously compromised (can cause death or permanent disability). In these situations, the interventions are immediately classified as "Very Urgent", even before the multicriteria model is applied to them, given the high degree of importance with respect to the criterion referenced. The association of each of the categories with the evaluated alternatives (assets) is based on the evaluation model previously defined, taking into account the overall values obtained for each of the potential interventions to be carried out.

Table 6 lists the 20 assets distributed across the four categories of urgency. It should be noted that assets AT6, AT7 and AT13 despite their overall score are not within the defined range for the category, because they all represent a situation whose safety for people may be compromised (can cause death or permanent disability).

Table 6 - Assets Distribution by categories of urgency

Very Urgent	AT4 AT6 AT7 AT13
Urgent	AT3 AT20
Moderate Priority	AT19 AT2 AT14 AT5 AT16 AT8 AT18
Low Priority	AT17 AT15 AT10 AT1 AT12 AT11 AT9

However, the model created so far is not completely realistic. It is considered a priority index for all the potential interventions to be carried out, but this does not include a very important constraint that must be considered: the budget available by the company to carry out the said interventions, due to the limited resources that the company has.

4.4 Portfolio Analysis

Considering now the budget available for EDP Distribuição to carry out interventions, an analysis was made of portfolios of assets to intervene, which for a given defined cost, presented the maximum sum of multicriteria value, taking into account a budget defined by the EDPD for the intervention on MT/BT transformers.

For this purpose, it was used the decision support software PROBE (Portfolio Robustness Evaluation). For the calculation of the costs by intervention to be performed, an analysis of previous similar occurrences was carried out, or if it was not possible, by perception or estimation. It should be noted that for this portfolios analysis, the assets whose associated urgency category was "Very Urgent" (AT4, AT6, AT7; AT13) were not considered, since the intervention associated with these will always be considered necessary, will always be included in any portfolio.

In order to carry out the above analysis, EDPD established a budget for interventions on the 20 assets, of € 35,000. Once the available budget was established, the benefit value tree was created using the PROBE software.

For the development of the referred tree, the previously defined criteria for the multicriteria model were used, as well as their respective weights calculated by the M-MACBETH software. Then, the alternatives for the model were introduced, in this case the 16 medium/low voltage transformers to be interceded (the assets whose priority level was "Very Urgent" for the reasons mentioned above were not considered), as well as the scores obtained for each of the defined criteria, and subsequently the costs of each of the potential interventions were introduced, as shown in Figure 11 and Figure 12.

Weights	0.18	0.08	0.1	0.33	0.05	0.26	Weighted
Projects/Criteria	QS	RE	PMO	SP	RMP	AMB	values
AT1	24.990	21.800	22.000	20.000	20.000	10.000	18.642
AT2	40.000	43.790	38.000	49.990	40.000	40.000	43.400
AT3	59.990	64.000	66.800	70.000	70.000	50.000	62.198
AT5	59.990	100.000	116.010	0.000	40.000	10.000	34.999
AT8	0.400	40.600	0.000	0.000	0.000	100.000	29.320
AT9	0.400	21.800	0.000	0.000	0.000	0.000	1.816
AT10	100.000	21.800	0.000	0.000	0.000	0.000	19.744
AT11	0.400	100.000	0.000	0.000	0.000	0.000	8.072
AT12	0.400	23.800	116.010	0.000	0.000	0.000	13.577
AT14	24.990	21.800	22.000	20.000	20.000	100.000	42.042
AT15	24.990	21.800	22.000	20.000	100.000	10.000	22.642
AT16	100.000	21.800	22.000	20.000	20.000	10.000	32.144
AT17	24.990	100.000	22.000	20.000	20.000	10.000	24.898
AT18	24.990	21.800	116.010	20.000	20.000	10.000	28.043
AT19	59.990	43.790	66.800	49.990	70.000	25.000	47.478
AT20	100.000	64.000	83.990	70.000	70.000	50.000	71.119

Figure 11 - Table of partial scores (QS, RE, PMO, SP, RMP, AMB) and the weighted values of the potential interventions

Projects and synergie	Costs	Benefits
AT1	1150.000	18.642
AT2	2300.000	43.400
AT3	3400.000	62.198
AT5	4500.000	34.999
AT8	2100.000	29.320
AT9	1150.000	1.816
AT10	1150.000	19.744
AT11	4500.000	8.072
AT12	1150.000	13.577
AT14	1150.000	42.042
AT15	1150.000	22.642
AT16	1150.000	32.144
AT17	4500.000	24.898
AT18	1150.000	28.043
AT19	2300.000	47.478
AT20	3400.000	71.119

Figure 12 - Table of costs and multicriteria value (Benefits) of potential interventions

The data from Figure 11 is also shown graphically in Figure 13. The costs related to interventions associated with assets whose priority level was considered "Very Urgent", as demonstrated in Table 7, were also calculated.

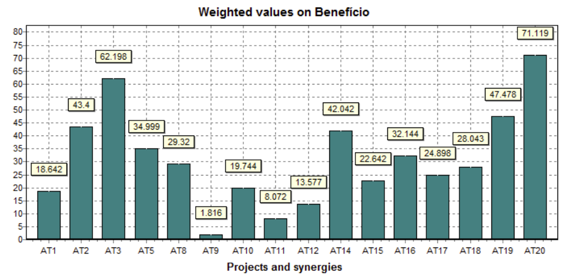


Figure 13 - Global benefit value of each potential intervention

Table 7 - Costs of "Very Urgent"Priority Interventions

Asset	Intervention Cost
AT4	4 500 €
AT6	700 €
AT7	900 €
AT13	1 150 €
Total Cost	**7 250 €**

As the total budget available for carrying out interventions on assets was € 35.000, and considering that assets whose urgency level was considered "Very Urgent" will always be selected as assets to intervene, the remaining budget for potential interventions not yet considered, is € 27,750.

Once all the necessary data of the alternatives had been entered, the analysis of the priority of interventions was carried out, taking into account the benefit/cost ratio of each alternative. The results obtained are shown in Table 8.

It is possible to observe that the alternative AT14 is the alternative with higher level of priority, since it has the highest benefit/cost ratio. On the other hand, the alternative with the lowest level of priority over the rest is the AT9 option, whose benefit/cost ratio is the lowest. In the multicriteria model developed, this alternative had also been considered as one of the alternatives with a lower intervention priority index. The cumulative cost of the interventions is € 36.200 and the cumulative benefit is 505,133.

Then, considering the remaining budget available for intervention on medium/low voltage transformers, excluding the "Very Urgent" (€ 27.750) emergency assets, the efficient portfolios of projects were analyzed.

The graph of Figure 15 shows all the efficient portfolios analyzed by PROBE software, when the available budget ranges from zero to the sum of the costs of all the alternatives included in the represented portfolios.

In Figure 26 represented with a red cross (B), is the efficient portfolio whose cost is the closest to the budget available for interventions on all assets except the assets AT17 and AT11 whose priority index was previously defined as " Low Priority" (€ 27.200), and represented immediately before this (A) is the efficient portfolio whose cost is € 26.050, for interventions on the group of assets except assets AT17, AT11 and AT9, whose priority index had also been set as "Low Priority".

However, by analyzing the additional amount of investment to move from portfolio A to B, it follows that for the required additional cost of € 1.150, only an additional global benefit amount of € 1.816 would be added.

In terms of the emergency categories that characterize the potential interventions included in portfolio A, this includes all assets classified as "Very Urgent", as previously mentioned, all assets classified according to the "Urgent", "Average Priority" and almost all assets of the least significant emergency category except AT17 and AT11.

When the chart was presented to EDPD's group of decision-makers, the group decided that portfolio B showed a better use of the available budget relative to the benefit it provided, as well as the high total set of assets selected for intervention. Portfolio B was then accepted by the decision group.

5. Portfolio Robustness Evaluation

Subsequently, a robustness analysis was performed on the chosen portfolio of efficient interventions, in order to compare it with possible competing portfolios.

One of the functionalities of PROBE software is the ability to evaluate the robustness of a selected portfolio, considering several sources of uncertainty simultaneously. Since it is a problem of selection of interventions taking into account the available budget, it is important to analyze whether the optimal portfolio chosen previously is robust.

Uncertainties were defined regarding the benefit values of the alternatives. For the benefit values of the alternatives in each criterion, several degrees of uncertainty were defined, in order to identify competitive portfolios, in order to perceive the robustness presented by the proposed portfolio, ie for these levels of uncertainty that portfolios may be better than the proposed portfolio. The process started with an uncertainty of 1% ($\alpha = 0.01$), which corresponds to ± 1 unit value in the value score of each potential intervention in each of the criteria.

The analysis of robustness made to the proposed portfolio, was carried out through the variation of $\pm\alpha$ % ($\alpha \geq 1$, 1% increase in each iteration) affecting the benefit value of the alternatives simultaneously. For a level of uncertainty $\alpha < 20\%$, no competing portfolios were found. Table 9 shows the composition of the competing portfolio, as well as a comparison between the composition of both. In addition to the assets AT4, AT6, AT7, and AT13, previously classified with the "Very Urgent" priority index, the competing portfolio only presents assets AT11 and AT17, whose priority index was classified as "Low Priority". For a considerable variation in the overall benefits of the potential interventions, 20%, the chosen portfolio is therefore quite robust.

Next, the robustness of the chosen portfolio was analyzed, considering this time a variation on the values of the costs of the potential interventions. For a variation of the costs of the potential interventions between 0% and 100%, no competitive portfolios were found in the proposed portfolio.

Table 8 - Alternatives by benefit/cost order of priority

Assets by order of priority (in €)						
Priority Order	**Asset**	**Benefit**	**Cost**	**Benefit/Cost**	**Cumulative Benefit**	**Cumulative Cost**
1	AT14	42.042	1 150	0.037	42.042	1 150
2	AT16	32.144	1 150	0.028	74.186	2 300
3	AT18	28.043	1 150	0.024	102.229	3 450
4	AT20	71.119	3 400	0.021	173.348	6 850
5	AT19	47.478	2 300	0.021	220.826	9 150
6	AT15	22.642	1 150	0.020	243.468	10 300
7	AT2	43.399	2 300	0.019	286.867	12 600
8	AT3	62.198	3 400	0.018	349.065	16 000
9	AT10	19.744	1 150	0.017	368.809	17 150
10	AT1	18.642	1 150	0.016	387.451	18 300
11	AT8	29.32	2 100	0.014	416.771	20 400
12	AT12	13.577	1 150	0.012	430.348	21 550
13	AT5	34.999	4 500	0.008	470.347	26 050
14	AT17	24.898	4 500	0.006	495.245	30 550
15	AT11	8.072	4 500	0.002	503.317	35 050
16	AT9	1.816	1 150	0.002	505.133	36 200

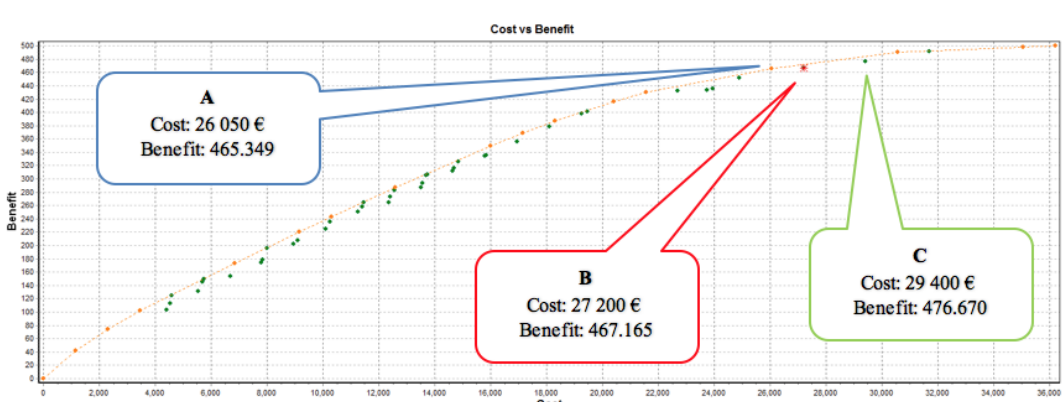


Figure 15 - Representation of the efficient frontier by PROBE software (in €)

Table 9 - Differences between the proposed and competitive portfolio

Level of Variation	Number of Competitor Portfolios	Projects exclusive to the optimal portfolio	Projects exclusive to the new competitor portfolio
$\alpha = 20\%$	1	AT1 AT2 AT3 AT5 AT8 AT9 AT10 AT12 AT14 AT15 AT16 AT18 AT19 AT20	AT11 AT17

Conclusions

In the present dissertation the need for an asset management system was analyzed, specifically regarding the need for a prioritization considering the maintenance over them. The main objective of this research was the development of a model that would allow to select the interventions to be carried out on EDPD medium/low voltage transformers.

The development of research on this topic was very interesting, allowing to understand the entire process of asset management of EDP Distribuição, as well as its importance for the development of the company's activity. The relationship with the group of decision-makers was also very interesting, both from a professional and personal point of view, allowing an increase in knowledge in the area of energy as well as a first contact with the professional world.

One of the difficulties encountered during the model was the most assertive classification possible with respect to the values of the potential interventions in each of the defined criteria, in order to make the model as realistic as possible due to the excess of information associated with these assets. The optimum portfolio of interventions to be carried out was found, which allowed maximizing the multi-criteria value associated with the interventions, as well as making the most of EDPD's available budget, a portfolio that was accepted by the decision-makers.

With the application of the proposed model, as well as the results obtained from it, it is possible to say that the objectives outlined initially for this dissertation were reached.

The group of decision-makers considered both the methodology and the results obtained, quite interesting, given the expected positive impact after implementation of the developed model, to the analyzed assets.

As a possible future work, one of the proposals would be that the intervention prioritization model developed for medium/low voltage assets would be used over a wider range of EDPD assets, as well as their use in conjunction with other types of models such as the development of a model that allows monitoring and managing the risk associated with the set of analyzed assets, something that already happens, but only for high voltage transformers. To that end, both monitoring and risk management associated with the assets should be updated periodically, using for example a database, in order to be able to identify and analyze the specific characteristics associated with each type of asset.

As a way of finalizing the conclusion, it is desired that the work performed be considered a useful tool for the prioritization of interventions on the medium/low voltage assets of EDP Distribuição, and that it could be used in the same scope.

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