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A Multi-crieria Analysis Method for the Prioritization of Commercial and Supply Restorarion Services in an Electricity Utility

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Abstract*—This paper shows the application of a multi-criteria analysis method for the prioritization of commercial and supply restoration services in an electricity company. The methodology is based on the Macbeth algorithm and on a large amount of input parameters that are evaluated in order to set the relative importance of each service. This study is of great relevance and complexity because it dynamically optimizes the use of the potential capacity of the available crew, increasing their efficiency and enabling the Company to be prepared to unpredictable situations. A computer program was developed to apply this method and the results were considered better than the ones from the current methods used by the Company and from other methods available on the literature. Also, it is more suitable for real time daily applications.

***Index Terms*— commercial services; supply restoration services; Macbeth approach; service prioritization**

I. INTRODUCTION

The study presented on this paper is part of a Research and Development (R&D) Project of ANEEL (Brazilian Electricity Regulatory Agency), developed jointly by Maranhão Electricity Company (CEMAR) and Daimon Engineering & Systems. CEMAR is a private-owned electric distribution utility, located in the northern region of Brazil which supplies over 2,000,000 customers, in the state of Maranhão, in Brazil.

Currently, at CEMAR (and many other Brazilian electric companies), just a few variables are taken into account by the company's dispatchers when restoration service prioritization is needed. They make their decisions based on previous knowledge, usually intuitively or by ad hoc methods. Also, the decisions are not usually reevaluated even if the circumstances are different.

In order to give a relative priority to the restoration services (commercial and supply), it was implemented the Macbeth (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach, which is a multi-criteria decision method [1].

The product developed offers to CEMAR and also to the technical community and to the society some important solutions and tools that are not yet contemplated by the current systems, making it an original project. Also, by its capacity to evaluate – in a totally automatic way - all the variables considered relevant by the Company's

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dispatchers in real time and dynamically, the product is a sophisticated tool that makes the most suitable decisions for the priority selection.

II. MACBETH METHOD

Given a list of elements and an individual, he is supposed to compare the importance of each one of them. There are two different ways to determine a preference order (importance order) for the elements: one qualitatively (ordinal) and another quantitatively (cardinal) [1].

Analyzing the parameters only qualitatively is not a difficult task. However, in a multi-criteria analysis, the conclusions are based on the evaluation of many elements (criteria). A parameter is one of the many possible characteristics of an element and can be linked to a value. Then, all the parameters' values of an element can be summed and the result leads to an index that represents the element relative importance. That being said, a comparison not only qualitative (that means saying which parameter is more important) but also quantitative (that means saying how much this parameter is more important than that parameter) is necessary, a task not as simple as the first one [1].

This problem inspired the development of the MACBETH method. On this procedure, it is asked the individual to compare just two hypothetical parameters at a time. For each couple of parameters, the individual will say which one is more important (ordinal judgment). Then, in case the objects do not have the same importance, it is asked him to tell the difference between them. In order to ease the process, it is offered him a set of semantic categories representing the importance differences, e. g., "very weak", "weak", "moderate", "strong", "very strong" or "extreme". Based on this information, a numerical scale is built in which each level (parameter) of a certain element receives a value [1].

The number given to the parameter in the scale for each element of an object will be summed and the result will be called priority index (PI) and will be used to compare the importance between different objects. In the case of this application, an object is a service call (SC) that will be compared to other existing SCs in order to determine which one should be assisted preferentially.

III. METHODOLOGY

A number of 29 parameters that may indicate the urgency of a certain service (as commercial as technical ones) were identified by CEMAR and Daimon. Also, the possible services were divided in 7 different types. These parameters represent multiple and possibly conflicting interests to be considered in the service prioritization. For example, commercial services have the goal to decrease the credit for deadline violation and also, it is preferred to assist the most important clients first. In case of supply restoration services, the reason of the service call (broken wire, for example) is evaluated as well as the number of recalls. However, depending on the case, it is not possible to achieve two or more interests at the same time and a decision must be taken.

In order to compare the multiple interests, two tools were used: a description list and a value function. The description list is a set of values that a variable (parameter) can assume ordered from the lower to the greater priority. To each description list, a function value was created. A function value is an interval (i.e., it is possible to evaluate a difference but not a reason, like the Celsius scale for temperature) and non-dimensional scale [2]. Each level of the description list is mapped to a value in the numerical scale. This scale is calculated so (a) levels with greater priority are related to greater values on the scale than levels with lower priority and (b) the relative distances between two values in the scale are proportional to their priority difference. A value function allows us to quantify the priority intensity of a service call (SC).

Building a value function requires two reference values (like 0ºC to freeze water and 100ºC for water ebullition in the Celsius temperature scale). In this case 0 was chosen for neutral level and 100 for warning level (urgent SC). Two different approaches will be used to locate the other levels in the scale according to the variable nature.

Continuous variables will be evaluated by linear functions, which means that the priority increases constantly according to the increasing (or decreasing) of the variable value, without saturation [3].

Discrete variables will be evaluated by a semantic judgment method called Macbeth. In this case, a value function is obtained by linear programming models applied to comparisons of two hypothetical SC's priority difference [1]. In that way, the value function will present linear behavior. Such comparisons are made by asking the

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operators to say the difference between one action and the other, according to a semantic scale, i.e., by words. The semantic scale implemented was:

- C0: there is no priority difference (indifference);
- C1: the priority difference is very weak;
- C2: the priority difference is weak;
- C3: the priority difference is moderate;
- C4: the priority difference is strong;
- C5: the priority difference is very strong; and
- C6: the priority difference is extreme.

The following subsections present the methodologies applied to 3 different service areas: (A) commercial services, (B) supply interruption and (C) supply restoration services. And, at the end, how a global priority index (PI) is calculated and used to compare services from different areas.

A. Commercial Services

All the commercial services (except supply interruption for non-payment) will be evaluated using the same set of variables. The service types that will use the same variables are:

- Electricity meter substitution (ES);
- New connection (NC);
- Reconnection (RC);
- Cutoff (CO); and
- Miscellaneous (MS).

The following variables were identified as important for the prioritization of SCs of this type:

- Client importance;
- Credit for assistance deadline violation;
- Origin of the solicitation;
- Assistance rate within the deadline of a certain type of service in the district area in order to reach the monthly target;
- Assistance rate within the deadline of a certain type of service in the regional area in order to reach the monthly target;
- Assistance rate within the deadline of a certain type of service in the state area in order to reach the monthly target;
- Assistance rate within the deadline of a certain type of service in the district area in order to reach the annual target;
- Assistance rate within the deadline of a certain type of service in the regional area in order to reach the annual target;
- Assistance rate within the deadline of a certain type of service in the state area in order to reach the annual target;
- Assistance rate of a certain service type in the district area in order to reach the monthly productivity target;
- Assistance rate of a certain service type in the regional area in order to reach the monthly productivity target;
- Assistance rate of a certain service type in the state area in order to reach the monthly productivity target;
- Assistance rate of a certain service type in the district area in order to reach the annual productivity target;
- Assistance rate of a certain service type in the regional area in order to reach the annual productivity target, and;
- Assistance rate of a certain service type in the state area in order to reach the annual productivity target.

The credit for assistance deadline violation is calculated as determined by ANEEL [4].The possible origins of the solicitations can be organized as follows, from the least important to the most: complaint/regular solicitation, ANEEL, justiciable.

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The assistance rates within the deadline in order to reach the monthly (or annual) target (ARD) describes the amount of SC's to be assisted within the deadline, according to the amount of opened SCs, in order to reach the monthly (or annual) target. Equations (1), (2) and (3) are used to calculate ARD:

$$ADT_{t,k,p} = \frac{AAD_{t,k,p} + AA_{t,k}}{AC_{t,k,p} + AO_{t,k}} \quad (1)$$

$$AA_{t,k} = ADT_{t,k,p} \cdot \left(AC_{t,k,p} + AO_{t,k}\right) - AAD_{t,k,p} \quad (2)$$

$$\Rightarrow ARD_{t,k,p} = \min\left(1, \frac{AA_{t,k}}{AO_{t,k}}\right) \quad (3)$$

Where:

- t is an index referring to the SC's service type;
- k is an index referring to the geography area (district, regional or state);
- p is an index referring to the analysis period (monthly or annual);
- $ADT_{t,k,p}$ is the assistance within the deadline target for a type t SC in the region k and period p;
- $AAD_{t,k,p}$ is the amount of SCs assisted within the deadline (it refers to the SCs assisted within the deadline throughout the analysis period and also to the SCs that have already been assisted in the current day) for a type t SC in the region k and period p;
- $AA_{t,k}$ is the amount of opened type t SCs in the region k that should be assisted in the current day in order to reach $ADT_{t,k,p}$;
- $AC_{t,k,p}$ is the amount of type t SCs calls in the region k and period p (refers to SCs calls in p and also the ones that have already been assisted in the current day, within the deadline or not);
- $AO_{t,k}$ is the amount of opened type t SCs in the region k that might be assisted or not; and
- $ARD_{t,,}$ is the proportion of the amount of opened type t SCs in the region k and period p that should be assisted in the current day to reach $ADT_{t,k,p}$.

The parameter $ARD_{t,,}$ cannot be greater than 1, because $AA_{t,k}$ cannot be greater than $AO_{t,k}$ (it is impossible to assist more SCs than the number of opened SCs).

The assistant rates (AR) of a certain service type in order to reach the monthly (or annual) target are calculated similarly. However, they refer to the proportion of the chosen type assisted SCs (within the deadline or not) in relation to the number of opened SCs (of any type). Equations (4), (5) and (6) are used to calculate AR:

$$AT_{t,k,p} = \frac{AADN_{t,k,p} + AA_{t,k}}{AC_{t,k,p} + AO_{t,k}} \quad (4)$$

$$AA_{t,k} = AT_{t,k,p} \cdot \left(AC_{t,k,p} + AO_{t,k}\right) - AADN_{t,k,p} \quad (5)$$

$$\Rightarrow AR_{t,k,p} = \min\left(1, \frac{AA_{t,k}}{AO_{t,k}}\right) \quad (6)$$

Where:

- t is an index referring to the SC's service type;
- k is an index referring to the geography area (district, regional or state);
- p is an index referring to the analysis period (monthly or annual);
- $AT_{t,k,p}$ is the assistance (within the deadline or not) target for a type t SC in the region k and period p;
- $AADN_{t,k,p}$ is the amount of SCs assisted within the deadline or not (it refers to the SCs assisted throughout the analysis period and also to the SCs that have already been assisted in the current day) for a certain type t SC in the region k in the period p;
- $AA_{t,k}$ is the amount of opened type t SCs in the region k that should be assisted in the current day in order to reach $AT_{t,k,p}$;
- $AC_{t,k,p}$ is the amount of type t SCs calls in the region k and period p (refers to SCs calls in p and also the ones that have already been assisted in the current day, within the deadline or not);
- $AO_{t,k}$ is the amount of opened type t SCs in the region k that might be assisted or not; and

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- $AR_{t,,}$ is the proportion of the amount of opened type t SCs in the region k and period p that should be assisted in the current day to reach $AT_{t,k,p}$.

$AR_{t,,}$ cannot be greater than 1, because $AA_{t,k}$cannot be greater than $AO_{t,k}$(it is impossible to assist more SCs than the number of opened SCs).

These variables represent multiple possibly conflicting interests that must be considered in order to give priority to the SCs.

In Figure 1, the description list of the commercial SCs is shown (just the neutral and warning levels). The other SC types are shown in grey as well as the weights that allow us to calculate the PI used to compare SCs of different types and areas.

According to the figure, a reconnection SC s_i, with the following characteristics: common importance, no deadline violation, justiciable solicitation and in a moment that the company needs to assist all the reconnection SCs within the deadline in order to reach all the targets, would have the following PI:

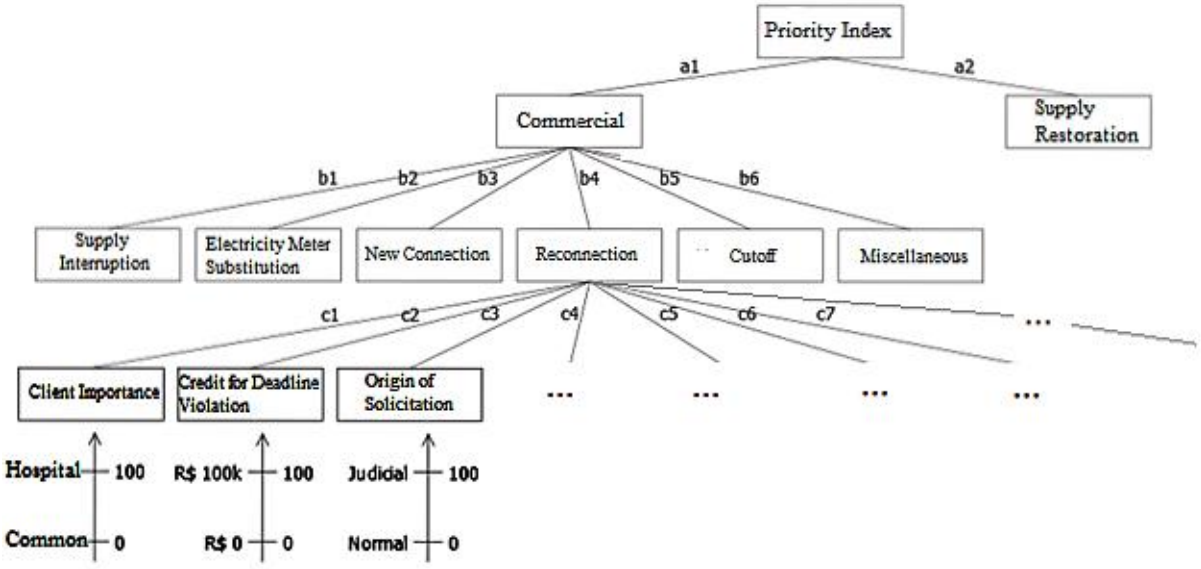

Fig1 - Variables and weights for a reconnection service that are used for the PI calculation.

$$PI(s_i)=[Imp(Commom)\cdot c1+Cred(R\$0)\cdot c2+Orig(Judicial)\cdot c3+RtDeadlineMon(100\%)\cdot c4+RtDeadlineAnn(100\%)\cdot c5+RtProdMon(100\%)\cdot c6+RtProdAnn(100\%)\cdot c7]\cdot b4\cdot a1 \quad (7)$$

$$PI(s_i)= [0\cdot c1+0\cdot c2+100\cdot c3+100\cdot c4+100\cdot c5+100\cdot c6+100\cdot c7]\cdot b4\cdot a1 \quad (8)$$

$$PI(s_i)=100\cdot(c3+c4+c5+c6+c7)\cdot b4\cdot a1 \quad (9)$$

B. Supply Interruption Services Due to Non-Payment

Although this is also a commercial service, the supply interruption (SI) will be evaluated using different parameters. They are:

- Total debt value;
- Amount of assisted SI services in the district area rate;
- Amount of assisted SI services in the regional area rate;
- Amount of assisted SI services in the state area rate;
- Value of the assisted SI services in the district area rate;
- Value of the assisted SI services in the regional area rate;
- Value of the assisted SI services in the state area rate;

The total debt value is shown in Brazilian currency (R$). The other variables are calculated similarly to the rates previously used in the evaluation of the commercial services. The amount rates (MR), divided by geographic region (district, regional or state) are defined by (10), (11) and (12):

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$$PTA_{CT,k} = \frac{AADN_{CT,k} + AA_{CT,k}}{AC_{CT,k} + AO_{CT,k}} \quad (10)$$

$$AA_{CT,k} = PTA_{CT,k} \cdot (AC_{CT,k} + AO_{CT,k}) - AADN_{CT,k} \quad (11)$$

$$\Rightarrow MR_{CT,k} = \min\left(1, \frac{\max(0, AA_{CT,k})}{\max(1, AO_{CT,k})}\right) \quad (12)$$

Where:

- k is an index referring to the geography area (district, regional or state);
- SI is an index saying it is a supply interruption service;
- $PTA_{CT,k}$ is the SI productivity target by amount in region k;
- $AADN_{CT,k}$ is the amount of SI SCs assisted (it refers to all the SIs assisted throughout the analysis period until the ones that have already been assisted in the current day) in region k;
- $AA_{CT,k}$ is the amount of opened SI SCs in region k that should be assisted in the current day in order to reach $PTA_{CT,k}$;
- $AC_{CT,k}$ is the amount of SI SCs calls in the region k (refers to SI SCs assisted in the past and also the ones that have already been assisted in the current day);
- $AO_{CT,k}$ is the amount of opened SISCs in the region k that might be assisted or not; and
- $MR_{CT,}$ is the proportion of the amount of opened SI SCs in region k that should be assisted in the current day to reach $PTA_{CT,}$.

The parameter $MR_{CT,}$ cannot be greater than 1, because AA_{CT} cannot be greater than AO_{CT} (it is impossible to assist more SI SCs than the number of opened SI SCs).

The value rates (VR) are also divided by geographic region (district, regional or state) and can be calculated by (13), (14) and (15):

$$PTV_{CT,k} = \frac{VADN_{CT,k} + VA_{CT,k}}{VC_{CT,k} + VO_{CT,k}} \quad (13)$$

$$VA_{CT,k} = PTV_{CT,k} \cdot (VC_{CT,k} + VO_{CT,k}) - VADN_{CT,k} \quad (14)$$

$$\Rightarrow VR_{CT,k} = \min\left(1, \frac{VA_{CT,k}}{VO_{CT,k}}\right) \quad (15)$$

Where:

- k is an index referring to the geography area (district, regional or state);
- SI is an index saying it is a supply interruption service;
- $PTV_{CT,k}$ is the SI productivity target by value in region k;
- $VADN_{CT,k}$ is the value (in R$) of SI SCs assisted (it refers to all the SIs assisted throughout the analysis period until the ones that have already been assisted in the current day) in region k;
- $VA_{CT,k}$ is the value of opened SI SCs in region k that should be assisted in the current day in order to reach $PTV_{CT,k}$;
- $VC_{CT,k}$ is the value of SI SCs calls in region k (refers to SI SCs assisted in the past and also the ones that have already been assisted in the current day);
- $VO_{CT,k}$ is the value of opened SISCs in the region k that might be assisted or not; and
- $VR_{CT,}$ is the proportion of the value of opened SI SCs in region k that should be assisted in order the current day to reach $PTV_{CT,}$.

The parameter $VR_{CT,}$ cannot be greater than 1, because VA_{CT} cannot be greater than VO_{CT} (it is impossible for the values obtained by the assisted SI SCs to be greater than the value of all the opened SI SCs).

At last, the PI is calculated similarly to what was done in the previous subsection.

C. Supply Restoration Services

The following variables were considered for this type of service:

- Monthly SAIDI;
- Annual SAIDI;
- Compensation for violation of the reliability standards;
- Service required by the consumer;

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- Client importance;
- Number of recalls;
- Number of re-incidences; and
- Remaining time for the violation of the 24 hour deadline.

The compensation refers to the violation of DIC, DMIC and DICRI standards (Brazilian reliability standards). The compensation calculation is defined by ANEEL [5].

At last, the PI is calculated as it was done previously.

Finally, in order to compare SCs of different types it is necessary to use substitution rates (weights). They are needed because normally a SC does not have a greater priority than the others in all the parameters analyzed. So, these weights are used to convert local values (used to compare SCs of the same type) to global values (used to compare SCs of all types). In Figure 1, the weights are represented by the lines that link the boxes (and letter a, b and c in the equations).

The weights must be implemented after the description list and the value function of all the types be created. Their values will be defined with the collaboration of a Company's dispatcher. Beyond that, there must be a set of weights for no contingency situations, a second set for a situation of commercial contingency and a third one for supply contingency.

IV. RESULTS

A fictitious and simplified situation was created in order to illustrate the results that can be obtained by the new method and compare it to what is currently being used by the company. 15 SCs were created and the weights were defined according to what was considered most important by the company's leader operator.

Generally, the weights were chosen in order to prioritize the supply restoration services. Also, within the Utility Dispatch Center, the greatest weight was given to the number of re-incidences followed by the client importance. Then, the most important services are the commercial ones and their main parameter considered is the solicitation origin. At last, the supply interruption was considered the least important service and it was taken into account the debit value alone.

The current method used by the Company gives priority as follows, from the greatest importance to the lowest:

- Calls related to large outages;
- Judicial emergency or commercial calls;
- Reconnection with deadline lower than 2h;
- Commercial or supply restoration calls from Special Clients (VIP´s);
- Reconnection with deadline lower than 4h;
- Individual supply restoration calls;
- Reconnection with deadline greater than 4h;
- New Connection;
- Supply interruption, and;
- Other SCs.

In cases not mentioned by the previous protocol, the operation leader must determine the priority of the SC.
The SCs and their characteristics are:

- SI with a debt of USD 50.00;
- SI with a debt of USD 50.00;
- SI with a debt of USD 50.00;
- SI with a debt of USD 50.00;
- SI with a debt of USD 200.00;
- Supply restoration service for client with importance 20 and 10 re-incidences;
- Supply restoration service for client with importance 20 and 0 re-incidences;
- Supply restoration service for client with importance 15 and 2 re-incidences;
- Supply restoration service for client with importance 5 and 3 re-incidences;
- Supply restoration service for client with importance 2 and 5 re-incidences;

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- New connection with regular solicitation;
- New connection with ANEEL solicitation;
- Electricity meter substitution with regular solicitation;
- Electricity meter substitution with justiciable solicitation; and
- Reconnection with regularsolicitation.

A simulation was implemented. The results are below from the most important to the least important SC to be assisted. The PI was calculated as well:

1. Supply restoration service for client with importance 20 and 10 re-incidences. PI = 74.4;
2. Supply restoration service for client with importance 2 and 5 re-incidences. PI = 38.7;
3. Supply restoration service for client with importance 15 and 2 re-incidences. PI = 38.1;
4. Supply restoration service for client with importance 5 and 3 re-incidences. PI = 36.7;
5. Supply restoration service for client with importance 20 and 0 re-incidences. PI = 36.6;
6. Electricity meter substitution with justiciable solicitation. PI = 32.1;
7. New connection with ANEEL solicitation. PI = 22.8;
8. Electricity meter substitution with regular solicitation. PI = 8.3;
9. New connection with regular solicitation. PI = 6.9;
10. Reconnection with regular solicitation. PI = 5.5;
11. SI with a debt of USD 200.00. PI = 1.4
12. SI with a debt of USD 50.00. PI = 0.2;
13. SI with a debt of USD 50.00. PI = 0.2;
14. SI with a debt of USD 50.00. PI = 0.2; and
15. SI with a debt of USD 50.00. PI = 0.2.

If instead of using the new method, it was used the current protocol, the importance would be given as follows:

1 - Supply restoration service for client with importance 20 and 10 re-incidences;
1 - Supply restoration service for client with importance 20 and 0 re-incidences;
1 - Supply restoration service for client with importance 15 and 2 re-incidences;
4 - New connection with ANEEL solicitation;
4 - Electricity meter substitution with justiciable solicitation;
6 - Supply restoration service for client with importance 5 and 3 re-incidences;
7 - Supply restoration service for client with importance 2 and 5 re-incidences;
8 - Reconnection with regular solicitation.
9 - New connection with regular solicitation;
10 - SI with a debt of USD 250.00;
10 - SI with a debt of USD 50.00;
10 - SI with a debt of USD 50.00;
10 - SI with a debt of R USD 50.00;
10 - SI with a debt of USD 50.00, and;
15 - Electricity meter substitution with regular solicitation.

It is readily seen that that the priority was given differently by each method. The new one suited better to the conditions mentioned by the leader operator, who represents the Company's interests. The current method presented some problems like the draw between two or more SCs and a SC not mentioned in the protocol (electricity meter substitution with regular solicitation), which would be considered the least important or would have to be evaluated by the operator. Beyond that, its results are not in agreement with the leader operator's preferences. It is also important to say that this is a simple fictitious situation. A lot of other variables could have been considered and the problem would be much more complex for human evaluation alone.

That being said, it is possible to note that the project makes an important improvement to the area. It works automatically and in real time, it is very adaptive, allowing weights to be changed according to the company's interests and also, it takes into account many variables that are not considered in the current protocol.

V. CONCLUSION

This paper presented a new method for commercial and supply restoration services for an electric energy company. This is an essential procedure in order to achieve high efficiency on Utility Dispatch Center and to prepare the Company for unpredictable situations.

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The Macbeth approach was used for the calculation of a priority index for each service call for comparison. A computer program was developed for implementation.

The results obtained by the new method were considered better than the ones from the current method used by the Company, fitting better to the Company's interests. Besides, the system is more adaptive and allows modifications according to the situation and to the company's interests. It can also evaluate more variables and can be implemented automatically in real time without constant human intervention.

Further investigations are currently being carried out on crew dispatch optimization. This combined project would be able to make the dispatch of crew teams taking into account not only the SCs' importance and urgency but also their geographic location and the best path to be taken by each team in order to optimize the service assistance.

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