SERVICE PRIORITIZATION AND CREW DISPATCH IN AN ELECTRICITY UTILITY

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ABSTRACT

This paper presents the application of a new real-time methodology for commercial and supply restoration service prioritization and crew dispatch for service assistance. The prioritization of services is based on a multi-criteria analysis method, named as MACBETH, whereas the Ant Colony Optimization metaheuristic algorithm is applied for crew dispatching. The methodology presented here evaluates a large amount of input parameters in order to set the relative importance of assisting a certain service as well as the impact of not meeting it, according to the utility's goals. Finally, the methodology is able to create routes – in real time – to be taken by each crew team and the sequence in which the services will be met.

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 Electricity Company of Maranhão (CEMAR) and Daimon Engineering & Systems. CEMAR is a distribution utility, located in the northern region of Brazil which supplies over 2,000,000 customers.
Currently, at many Brazilian electricity companies, just a few variables are taken into account by the company's operators when service assistance is needed. They make their decisions based on previous knowledge, usually intuitively or by ad hoc methods. Also, the decisions are not reevaluated for different circumstances.
Some previous studies and projects tried to solve this kind of problem with different approaches. Projects [1] and [2], for example, do not work totally automatic. In the first one the service prioritization is implemented by the operator, whereas in the second one the dispatch is manually resolved. Other works like [3] and [4] have specific main goals. The first one wants to decrease the time spent in the service assistance and the second one tries to decrease the trajectories length, instead of other company's targets, like diminishing costs. Some studies do not even take into account a prioritization system [5] and some cannot be applied at real time applications [6].
On this project, in order to give a relative priority to the services, it was implemented the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach, which is a multi-criteria decision method [7]. The services to be assisted, its sequence and the route to be taken by each available team, were selected by a consolidated meta-heuristic method: the Ant Colony Optimization (ACO) algorithm [8].

THE THEORIES

MACBETH

In a multi-criteria analysis, many parameters (criteria) are used to evaluate the attractiveness of an element. To define the strength of an individual's preferences for one element over another, it is necessary to quantify the relative attractiveness of the options that these parameters can assume [7]. The definition of the relative attractiveness of these parameters is also required to gather its contributions in a single value: the attractiveness of the element.
This problem inspired the development of the MACBETH method. On this procedure, it is asked the individual to compare two options of a parameter at a time. For each couple of options, the individual will say which one is more important. Then, it is asked him to tell the difference in the perceived attractiveness between them. In order to ease the process, it is offered him a set of semantic categories representing the difference of attractiveness, e. g., "very weak", "weak", "moderate", "strong", "very strong" or "extreme". These judgements will be the input of a linear programming model to build a value function for the parameter analyzed. Each parameter will have a value function [7].
A value function is an interval and non-dimensional numerical scale. Each option a parameter can assume is mapped to a value in this numerical scale. Such scale is calculated so that (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.

Ant Colony Optimization

This technique has been inspired by the fact that ants from a colony guide themselves by a trail of pheromones, searching for the best path to their food source. Good trails are chosen more often, making its pheromone concentration greater as well as the likelihood of it being chosen again. However, some ants can explore other possibilities, trying to find paths that are even better than the previous ones [8].

The problem can be presented as a graph. The service locations are the vertices and the paths are the edges. In ACO algorithms, an ant represents a solution. When constructing a solution, each ant is put on a starting point and then wanders from vertex to vertex in the graph. At each vertex, an ant probabilistically selects the next vertex according to a decision policy or transition rule, which depends on the pheromone trails and on the heuristic information on the edges and vertices. Also, they deposit pheromones on the edges in order to attract other ants towards the corresponding area of the search space. The pheromones can evaporate, allowing some past history to be forgotten, and helping diversify the search to new and hopefully more promising areas [8].

A fixed number of ants/solutions is predefined within a cycle (the amount of cycles is also defined previously). In a cycle, all ants independently try to find the better routes for the vehicles. In the next cycle, the ants will be influenced by the pheromones left by the ones from the previous cycles. A solution consists of a set of routes, one for each vehicle/team. [8].

METHODOLOGY

The system proposed can be divided into two sub-systems. The first one does the service prioritization whereas the second is responsible for crew dispatch. However, the sub-systems are integrated and communicate to each other all the time. As soon as a service call (SC) appears, the dispatch can be reorganized in order to better accomplish the utility's goals. Also, the importance of each SC to be assisted varies over time and depends on when it will be met by a crew team.

The next sub-sections will describe separately the two sub-systems.

Service Prioritization

A set of parameters that may indicate the urgency of a certain service were identified. These parameters (variables) represent multiple and possibly conflicting goals to be considered in the service prioritization.

Two different approaches are used to give scores to each level of the variables according to their nature. Continuous variables are evaluated by linear functions, which means that the priority increases constantly according to the increasing (or decreasing) of the variable value. Discrete variables are evaluated through a value function built using the MACBETH method. In this case, the operators have judged the difference of priority between pairs of hypothetical SC. In each pair, the two hypothetical SC are very similar, differing only in the value assumed by one of the parameters.

The MACBETH method is also applied to define a a substitution rate (weight) for each parameter. These substitution rates are used to weight the sum of the scores of the parameters. This sum represents the urgency of the SC, and it will be called priority index (PI). The PI indicates which SC should be assisted preferentially.

The following subsection presents the methodology applied to an example of SC, a reconnection service (RC). After, it is presented how the PI is calculated and used to compare services from different areas.

Example - Reconnection Service

The following variables were identified as important for the prioritization of RCs: client importance; credit for assistance deadline violation; origin of the solicitation; assistance rate within the deadline in the district (regional and state) area in order to reach the monthly (and annual) target; and assistance rate in the district (regional and state) area in order to reach the monthly (and annual) productivity target.

In Fig. 1, three parameters of a RC with two levels each are shown. The other service types are shown in grey as well as the weights that allow us to calculate the PI.

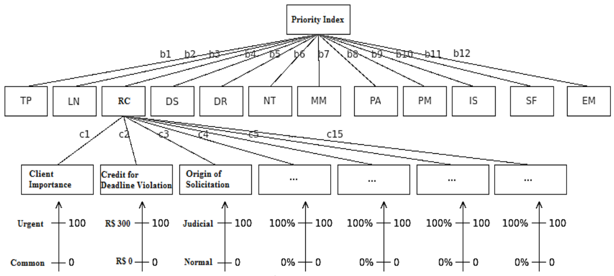

Fig. 1: Variables and weights for a reconnection service that are used for the PI calculation.

According to Fig. 1, a RC with the following characteristics: common importance, no deadline violation, judicial 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, as shown on Eq. 1:

$$\begin{aligned} PI(RC) = \big[&Imp(Common)\cdot c_1 + Cred(R\$0)\cdot c_2 \\ &+ Orig(Judicial)\cdot c_3 \\ &+ Rt_{Deadline_{Mon}}(100\%)\cdot c_4 \\ &+ Rt_{Deadline_{Ann}}(100\%)\cdot c_5 \\ &+ Rt_{Prod_{Mon}}(100\%)\cdot c_6 \\ &+ Rt_{Prod_{Ann}}(100\%)\cdot c_7\big]\cdot b_3 \\ = [0\cdot c_1 &+ 0\cdot c_2 + 100\cdot c_3 + 100\cdot c_4 + 100 \\ &\cdot c_5 + 100\cdot c_6 + 100\cdot c_7]\cdot b_3 \\ = 100\cdot (c_3 &+ c_4 + c_5 + c_6 + c_7)\cdot b_3 \end{aligned} \quad (1)$$

The same procedure is made to other SCs: a set of variables are identified and description lists are created. After that, it is possible to calculate the PI of the SC.

Comparing Different Types of Services

Finally, in order to compare SCs from different types, it is also necessary to use substitution rates.

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 Fig. 1, the weights are represented by the lines that link the boxes (and letters *b*

and *c* in the equations).
The weight's values are to be defined with the collaboration of the utility's operators. Beyond that, there must be a set of weights for different cases of contingency.

Crew Dispatch

The System

The goal of the dispatch is to assign the SCs to the most suitable crew teams, according to their PI. The attribution considers some variables like: the execution average time by service and by team, team location, expected travel time, team shift duration and vehicle type.
The assistance duration will be estimated by the average time spent by the team in the specific type of service. The distances and travel times between SCs are calculated using a web mapping tool like *Google Maps*.
According to [9], real time systems must guarantee response within specified time constraints, often referred to as deadlines. In the case of this project, the deadline to inform a crew team that its next SC was altered is when the current SC is solved. That is absolutely accomplishable, once the average processing time of the software is much lower than the execution time spent in a SC and the displacement time between SCs. Also, even in the case a deadline is not accomplished, it is not a critical situation. It will just comprise the quality of the solution, which can be recalculated later. Thus, according to [10], this project consists of a soft real-time system, because missing a deadline does not lead to failure, but only the system's quality of service.

The Solution

A solution is defined as a set of routes containing the SCs to be assisted by the crew teams observing the some constraints. The best solution will be the one that minimizes the sum of the importance of the non-assisted SCs (X) and, in case of draw, the one that minimizes the sum of the assisted SCs (Y). These scores will be presented in the next section in brackets like this: [X | Y]. They are used to measure the effectiveness of solutions.

RESULTS

A fictitious and simplified situation (not using all the possible variables) has been proposed in order to illustrate the results that can be obtained by the new tool. Thus, 36 SCs have been created to be assigned to 3 crew teams. The SCs can be met from 9am to 5pm (they can maybe finish the last SC after 5pm). The supply interruption services will take 30 minutes to be fixed and the other ones will take 1 hour. Therefore, the algorithm has to find out an optimized solution in order to meet the pending SCs with the 3 crew teams, meeting the utility's goals.
Also, the current prioritization and dispatch methods have been applied by CEMAR's operators in order to make a comparison between the two methods.

The characteristics of each SC are specified on Tables I, II and III:

TABLE I. LIST OF PENDING SUPPLY INTERRUPTION SERVICES

Supply Interruption Services Due to Non-payment	Customer´s Accumulated Debt (R$)
01	200.00
02	200.00
03	200.00
04	200.00
05	1,000.00
06	1,000.00
07	1,000.00
08	1,000.00
09	5,000.00
10	5,000.00
11	5,000.00
12	10,000.00

TABLE II. LIST OF PENDING COMMERCIAL SERVICES

Commercial Services (all reconnection)	Client Importance (1)	Origin of Solicitation	Process Started (2) (hours)	Deadline (hours)
13	S	Ordinary	24 before	8
14	S	Ordinary	3 after	32
15	S	Ordinary	6 after	32
16	S	Judicial	18 before	32
17	S	Ordinary	24 before	8
18	P	Ordinary	3 after	32
19	P	Judicial	18 before	32
20	P	Judicial	24 before	32
21	S	Ordinary	24 before	32
22	S	Ordinary	6 after	32
23	S	Ordinary	24 before	8
24	S	Judicial	24 before	32

(1) P – Primary; S – Secondary; T - Tertiary
(2) Hours after or before the dispatch time (9am on December 5th 2015)

TABLE III. LIST OF PENDING SUPPLY RESTORATION SERVICES

Supply Restoration Services	Clients Importance	Complaints (1)	Recalls (2)	Re-incidences (3)	Process Opening Time (hours before dispatch)
25	P	G	15	0	2
26	P	G	10	2	2
27	P	G	10	0	2
28	S	G	5	5	24
29	S	G	5	3	24
30	T	I	0	5	24
31	T	I	0	0	24
32	S	I	0	0	0
33	S	I	0	0	19
34	S	I	0	0	17
35	T	I	0	0	0
36	T	I	0	0	0

(1) I – Individual request; G – Group of consumers request
(2) Number of telephone calls from the same client
(3) Number of times that the same fault ocurred within a month

New Methodology's Solution

First of all, it is necessary to define the weights according to what is considered most important by the utility's leader operator.
The weights were given as follows on Tables IV, V and VI to the considered parameters. The most important parameters have higher values. In parenthesis, it is specified how a parameter is mapped on the MACBETH

scale. For example, a supply restoration service for a client with primary importance has weight equal to 1.0 and then this value is multiplied by 0.382:

TABLE IV. SERVICE AREA WEIGHTS

Service Type	Weight
Supply Restoration	1.000
Commercial	0.571
Supply Interruption	0.143

TABLE V. SUPLLY RESTORATION SERVICE WEIGHTS

Parameter	Weight
Client Importance	0.382 (P = 1, S = 0.5, T = 0)
Remaining time deadline violation	0.265 (linearly)
Recalls	0.250 (linearly)
Re-incidences	0.103 (linearly)

TABLE VI. COMMERCIAL SERVICES WEIGHTS

Parameter	Weight
Origin of solicitation	0.471 (judicial = 1, ordinary = 0)
Client Importance	0.353 (P = 1, S = 0.50, T = 0)
Credit for deadline violation	0.176 (linearly)

For supply interruption services, just one parameter is used, so its weight is equal to 1.0 and it is mapped linearly in the MACBETH scale.
Based on these weights, the system assigned the SCs to the available crew teams. Table VII shows the result.

TABLE VII. LIST OF ASSIGNED SCS BY THE NEW METHDOLOGY

Service Call Sequence	Crew Team		
	#37	#38	#39
1	12	09	10
2	11	27	26
3	20	24	33
4	18	04	25
5	19	01	29
6	34	02	16
7	30	05	07
8		03	06
9		28	
10		08	
Unattended SCs: 13, 14, 15, 17, 21, 22, 23, 31, 32, 35 and 36			

As presented on Table VII, crew team #37 starts at 9am heading towards the location of SC 12, after finishing its job there, it goes to the next location (SC 11), and so on, successively, until its last location of the day (SC 30). The same procedure happens to the other two crew teams. Table VIII shows the PIs of each SC at the time they were assisted. For the unattended SCs, the PI refers to 12 hours after the shift's end.

TABLE VIII. SERVICE CALLS AND THEIR PRIORITY INDICES

Posit ion	SC	PI	Posit ion	SC	PI	Posit ion	SC	PI
1	12	857	**13**	08	86	**25**	14	25
2	11	429	**14**	07	86	**26**	15	25
3	09	429	**15**	06	86	**27**	17	25
4	10	429	**16**	28	81	**28**	21	25
5	25	121	**17**	29	77	**29**	22	25
6	20	118	**18**	18	50	**30**	23	25
7	19	118	**19**	34	46	**31**	04	17
8	26	97	**20**	33	44	**32**	01	17
9	27	93	**21**	30	37	**33**	02	17
10	24	92	**22**	32	31	**34**	03	17
11	16	92	**23**	31	26	**35**	35	12
12	05	86	**24**	13	25	**36**	36	12

The final score of this solution calculated by the algorithm is [256 | 3622].

CEMAR's Solution

The prioritization was given according to the following protocol, from the greatest importance to the lowest: supply restoration calls related to large outages; judicial commercial calls; reconnection with deadline lower than 2h; commercial or supply restoration calls from special clients; reconnection with deadline lower than 4h; individual supply restoration calls; reconnection with deadline greater than 4h; new connection; cut-off; and other SC's.
In cases not mentioned by the previous protocol, the operation leader must determine the priority of the SC.
According to the presented protocol, the SCs are ranked as presented on Table IX:

TABLE IX. SCS RANKED BY THE CURRENT PROTOCOL

Position	Service Call
1	25, 26, 27, 28 and 29
6	16, 19, 20 and 24
10	18
11	30, 31, 32, 33, 34, 35 and 36
18	13, 14, 15, 17, 21, 22 and 23
25	01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11 and 12

CEMAR's operators did the crew dispatch as well. The result is presented on Table X.

TABLE X. LIST OF SCS ASSIGNED BY CEMAR

Service Call Sequence	Crew Team		
	#37	#38	#39
1	06	04	16
2	08	02	07
3	10	01	26
4	09	05	17
5	15	03	19
6	28	24	18
7	25	33	21
8	27	31	20
9	13	29	11
10	22	12	
11		34	
Unattended SCs: 14, 23, 30, 32, 35 and 36			

Comparison of Solutions

From the results presented in the previous sub-sections, it is readily seen that the priority was given differently by each method. The new one suits better to the preferences mentioned by the leader operator, who represents the utility's goals, reflected on the PI's. The current protocol presented some problems like draws for more than one SC, needing the operator's constant intervention to solve the problem. Beyond that, its results are not in agreement with the leader operator's preferences.
Also, as predicted, CEMAR's dispatch solution has some inaccuracies, once it has been intuitively built and could not take into account all the problem's constraints. In this example, the dispatchers have not considered the

displacement time, so it would not be possible to meet all the SCs pointed by them within the teams' 8 hours shifts. Also, they have forgotten that SC 15 could only be met from 3pm onwards, nonetheless tried to meet it earlier.
In order to measure the effectiveness of CEMAR's solution, its dispatch was simulated by the proposed algorithm, helping the solution comparison. The simulation, however, took into account the crew teams shift duration and all the other constraints. In the new result, the SCs 11, 13, 22, 25 and 27 could not be met as well as the other SCs unattended by their previous solution. The final score of the solution was [852 | 3045].
Comparing both solutions, it is possible to notice that CEMAR tried to minimize the routes to be taken (what might not be the best strategy) and the SCs importance seemed to be less explored, while the new methodology was able to make the utility's targets more relevant to the solution. Thus, the set of SCs not attended in the solution proposed by the current methodology is about three times more important than the set of SCs not attended in the solution given by the new methodology.
It is also important to say that this is a simplified 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 utility's main goals and it is also able to evaluate much more parameters than the current method.

CONCLUSION

This paper presented a new methodology for prioritization of commercial and supply restoration services for an electricity utility as well as crew dispatch for service assistance.
The MACBETH approach was used for the calculation of a priority index for each SC and the ACO was implemented on crew dispatch.
The results obtained by the new methodology were considered better than the ones from the current method used by the utility, fitting better to its main goals. Besides, the new system is more adaptive and allows modifications according to the situation and to the utility's preferences. It can also evaluate more variables and can work automatically at real time without constant human intervention.
According to the calculated priority indices, the solution score of CEMAR's unattended SCs was 852, whereas the new methodology´s score was 256, a significant improvement. The former reflected the decisions made by CEMAR's dispatchers based on previous knowledge, intuition and experience, which may present an inaccurate response due to the real-time amount of information and pressure. The latter reflects an optimized solution according to the number of available crew teams and to the utility's main goals.

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