Asian Engineering Review
ISSN(E) : 2409-6725
ISSN(P) : 2518-0150
Vol. 3, No. 3, 17-23, 2016
http://asianonlinejournals.com/index.php/AER

Crew Dispatch for Commercial and Technical Services in an Electric Power Distribution Company Using ACO Technique

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Abstract

The aim of this paper is to describe the application of ACO optimization method for dispatch of road crews for commercial and supply restoration services in an electric power distribution company. The proposed methodology takes as input a large amount of different service orders (commercial and supply restoration), ranked by importance. Thus, it is able to create routes to be taken by each road crew, to select the sequence in which the requests will be met on the current day and the ones that will be met on another day in order to better achieve the company's targets. The methodology presented in this paper is of great relevance for electricity utilities because it optimizes the use of the potential capacity of the available road crews, increasing its efficiency and reducing costs. A computer program – named as ANTECOM – has been developed to apply this method and the results were compared with the ones from the current methodology used by CEMAR (and from other available on the literature), providing better results. Also, it is more suitable for real time applications.

Keywords: Ant colony optimization, Crew dispatch, Power distribution, Power system management, Real-time systems, Service assistance.

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Citation | Paulo H. Baumann; Tiago Milagres Miranda; Fabio Romero; Dário Takahata; Alden Uehara Antunes; João Castilho Neto; Leonardo H. T. Ferreira Neto; Ângelo C. Lorenzo Alves; Luísa Morais Azevedo; Sérgio L. P. de Castro Valinho (2016). Crew Dispatch for Commercial and Technical Services in an Electric Power Distribution Company Using ACO Technique. Asian Engineering Review, 3(3): 17-23.

DOI: 10.20448/journal.508/2016.3.3/508.3.17.23
ISSN(E) : 2409-6725
ISSN(P) : 2518-0150

Contribution/Acknowledgement: All authors contributed to the conception and design of the study.
Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no conflict of interests.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study was reported; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.
History: **Received:** 17 November 2016/ **Revised:** 13 January 2017/ **Accepted:** 27 January 2017/ **Published:** 15 February 2017
Ethical: This study follows all ethical practices during writing.
Publisher: Asian Online Journal Publishing Group

1. Introduction

The study presented on this paper is part of R&D Program of ANEEL (Brazilian Electricity Regulatory Agency), developed by Daimon in partnership with Energy Company of Maranhao (CEMAR). 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 power distribution companies), just a few variables are considered by the company´s dispatchers when the assignment of service orders (SO´s) is needed. Usually, the dispatchers make decisions per own technical knowledge. Also, the decisions are not re-evaluated even if the circumstances are different.

The literature shows that some studies deal with the subject of service prioritization and / or crew dispatch through different approaches, but in none of them the solution is fully automatic neither optimized. In Steiner, et al. [1] the service prioritization is evaluated by the operator, whereas in Gross, et al. [2] the crew dispatch is performed manually. Other studies like Perillo, et al. [3] and Amorim [4] have specific main goals. In Perillo, et al. [3] the aim is to to decrease the time spent in the service assistance, while in Amorim [4] the authors try to decrease the crew team trajectories length, instead of other company's targets like diminishing costs. Some papers do not take into consideration a optimized prioritization system [5] and cannot be used at real time applications [6].

The computer tool developed by the authors (ANTECOM – Ant Colony Optimization Tool for Prioritizing and Dispatching Commercial and Supply Restoration Services) presented by this paper comprises two different modules: The former uses the MACBETH multi-criteria decision method [7] for the prioritization of utility services [8]. The latter is the content of the present paper, which uses the Ant Colony optimization approach (ACO) [9] so as to assign the services to be met, its sequence and the route to be taken by each available road crew team.

The difference of this project from previous studies is the capacity of prioritize the services in accordance with what the company finds most important for it at a certain moment, allowing changes at any time. Also, it uses the ACO optimization method for road crew dispatching, which is able to find an optimal solution.

2. Ant Colony Optimization Technique

The Ant Colony is a meta-heuristic technique for optimization based on populations.. The concept of ACO can be adopted to deal with the crew dispatch problem, in which there is a set of places to be visited (that is, a set of service orders to be attend) and, in each of them, there is a prize to be taken by the visiting crew team. Once a team arrived at the point and received the prize, no other team can receive it. The goal is to maximize the total prize [9].

The ACO technique was deeply studied and was used by the fact that ants from a colony guide themselves by a pheromones trail, seeking 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 [9].

The problem can be presented as a graph. The work locations are the vertices and the paths are the edges. In ACO method, an ant represents a solution. When constructing a solution, each ant is put on a starting point and then wanders randomly from vertex to vertex in the graph. At each vertex, an ant probabilistically selects the next vertex according as a decision policy or transition rule, which depends on the pheromone trails and on the heuristic information on the edges. Also, they deposit pheromone in the edges with the purpose of 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 of the search space [9].

Adapting the ACO´s concept to the problem presented in this paper, an ant chooses a feasible path for each vehicle (a field crew). The criterion for the choice depends on the variation of the ACO approach to be used. There are four variations: sequential, deterministic-concurrent, random-concurrent and simultaneous. In the simulations of this paper, the "simultaneous" was applied, were, at first, all the possible vehicle-vertex pairs are considered. Then, the probability of each pair is calculated in accordance with the pheromone trails and the heuristic information. Therefore, one of these pairs is chosen respecting its probability. Thereafter, the problem constraints are verified and the set of vehicle-vertex pairs are updated. The process goes on until there are no more possible pairs [9].

A provided number of ants / solutions is predefined within a cycle (the amount of cycles is also defined previously). A solution consists of a set of routes, one for each vehicle / crew team. 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. At the end of the process, the solution that maximizes the prize is chosen [9].

3. Methodology

A. The System

The main goal of a Dispatch Centre is to assign the SO´s to the most suitable road crew considering the benefits of meeting a certain service as well as the impact of not meeting it. The attribution should consider the execution average time by service and by team, team location, acting area, expected travel time, maximum and minimum Standard Service Unities (SSUs – it is a time unity used by CEMAR to quantify the time duration of realized service orders of the field crews, varying from team to team in function of the average travel time in its acting area) to be accomplished, team shift duration, availability, connectivity, vehicle type, vehicle traction type and team costs matrix.

The characteristics of the region met by CEMAR and due to the set of Brazilian regulation laws of the electricity system require some rules that must be considered by the dispatch system. The main rules are presented as follows:

- Crew dispatch for shut-off service orders due to non-payment bills must start at 7:00 a.m. or as close to it as possible and must be done before 4:00 p.m.;
- No SO may interfere in another one that is currently being met;
- Shut-off service orders due to non-payment must be done before 4:00 p.m.;

- The shut-off location (pole, meter, secondary network) should be evaluated when dispatching crews for reconnection services;
- Each crew must meet a minimum and a maximum number of SSUs. Violations above the maximum limit are tolerated;
- Solutions of which a field crew could not achieve its production target must not be considered;
- The standard service duration, measured in SSU, varies according to the service order, crew team and Regional Agency;
- The lunch break duration is of 2 hours;
- Commercial SO´s can be realized at any time;
- A SO must be located in the team acting area, and;
- The SO can only be assigned to a crew team if there is enough time of it to be met before its shift ends.

With purpose of estimate the time to be spent by a team to meet the assigned SO´s and make sure they can be realized before the end of the shift, it is necessary to measure the assistance duration and travel time. The assistance duration will be estimated by the average time spent by the team in that type of service. The distances and travel times between SO´s are calculated using mapping available web tools, in this paper *Google Maps*. Alternatively, the linear distance between the coordinates and the average speed can be used to calculate the travel time.

The system assumes the existence of a previous system able to define the SO´s importance and that the importance of each of them can vary through time [8]. Also, in some days, there will be SO´s that cannot be assisted. Knowing this, the most important SO´s should be met preferably. The SO´s in this study comprise 3 different types of services carried out by the road crews, and their characteristics are briefly explained as follows: (1) Shut-off orders: disconnection procedures applied to the customers who failed to pay the electricity bills; (2) Commercial orders: these are service orders requested by the consumers for instance, to check their meters, realize new connections, realize reconnection after paying their debts etc., and; (3) Emergency orders: these are technical service orders, primarily to re-establish energy supply after a fault. In short, emergency orders have to do with disconnection of customers and safety issues and may be accomplished at any time.

From Ben-Ari [10] real time programs must guarantee response within specified time constraints, often referred to as deadlines. In the study present here, the deadline to inform a road crew that its next SO was altered is when the current SO is solved. That is absolutely accomplishable, once the average processing time of the software is much lower than the execution time spent in a SO and the displacement time between SO´s. 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 checked up later. Thus, from Shin and Ramanathan [11] 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.

B. The Solution

A solution is valid if it defines a set of routes containing the SO´s to be assisted by a road crew observing the previously mentioned rules. The best solution will be the one that minimizes the sum of the importance of the non-assisted SO´s (X) and minimizes the sum of the assisted SO´s (Y) respectively. These values (scores) are presented in this study in separated brackets: [X | Y]. They are used to measure the effectiveness of each solution.

The lexicographic method will be used here. In this method, capable of finding an optimal solution, it is given maximum importance to the first target (minimizing the sum of the importance of the non-assisted SO´s). In case just one solution is found when minimizing the first function, it is chosen and the other targets are not evaluated. In case there are multiple solutions, the next step is to minimize the second most important target. From the second minimization, a new constraint is considered to ensure that the value from the previous target does not increase [12].

One could think that it would be more interesting to select, at first, the solution that maximizes the Y value. However, in some cases it can lead to a bad result. If the priority is evaluated at the time a SO is assisted, solutions that delay the assistance of SO´s that get more urgent along the time would be favored. On the other hand, if the priority is calculated at the end of the day (or another predefined period), there would be no signal to assist a SO before it violates some deadline or target. In order to avoid this kind of problems, it was concluded that the best solution would be the one that, firstly, minimizes X and then Y. In that way, the assistance of the most important SO´s would still be favored and allowing a SO to reach an urgent condition would be penalized.

4. Results

A fictitious and simplified situation has been proposed with aim to illustrate the results that can be obtained by the proposed methodology. Thus, 36 SO´s have been created and prioritized in accordance with the Company's interests and the final score of each solution to be presented next was calculated by means of. The dispatch algorithm has been applied to this example. Also, the current dispatch method (mainly intuitively) has been applied by CEMAR's operator in order to make a comparison of the two methods.

Fig. 1 presents a map of São Luis with 36 pending SO´s which should be assigned to 3 road crews on December 5th 1915 at 09:00 a.m. across the city of São Luis, in Maranhão, Brazil, as if these SO´s were in a real-time environment within CEMAR´s Dispatch Centre. The current methodology used nowadays by CEMAR is basically intuitive with very simple restrictions, like avoiding the presence of crews in the same acting region.

In Fig. 1, the red balloons represent the emergency SO´s, the yellow ones represent the commercial SO´s, the green ones represent shut-off SO´s and finally, and the grey balloons represent the road crews, located at 09:00 a.m. on December 5th 1915, on the streets of São Luis, in Maranhão. Therefore, as one can see on Fig. 1, the algorithm must find out an optimized solution in order to meet these 36 pending SO´s through the 3 field crews as quickly as possible.

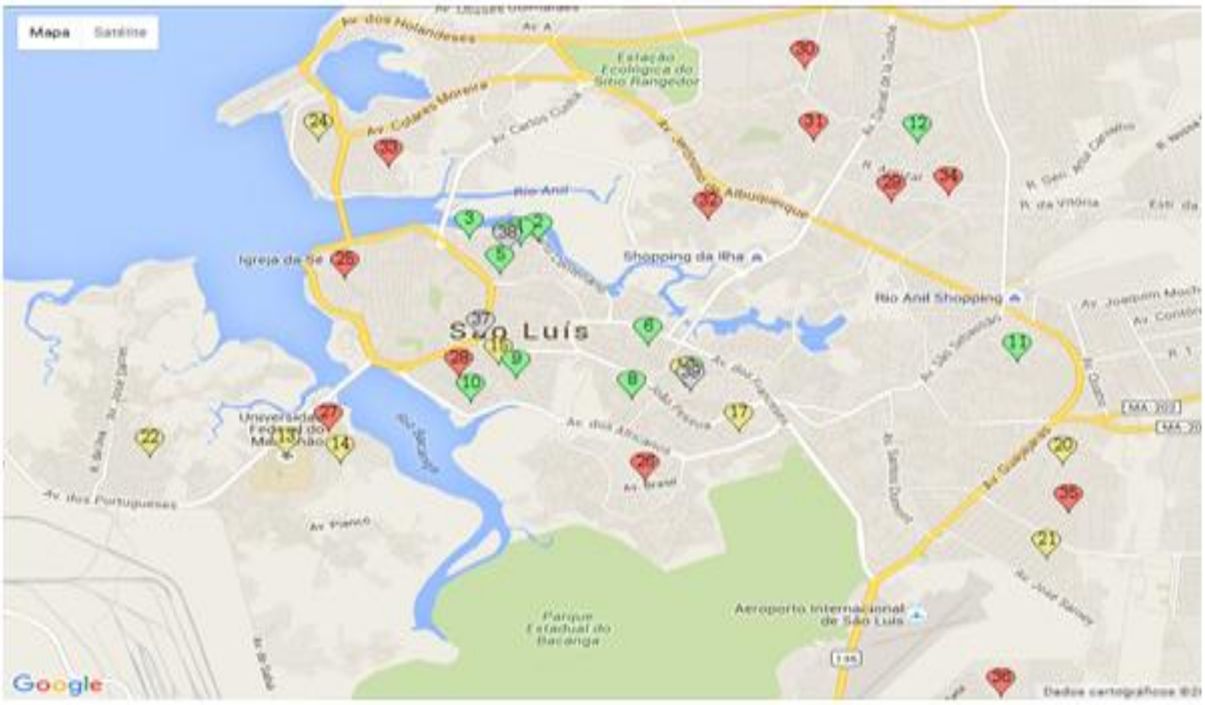

Fig-1. Map of São Luis with 36 pending service orders.

Source: GOOGLE MAPS.

Table 1 presents a list of the pending Shut-off Service Orders which appears on the screen of CEMAR´s OPER (Electric Distribution System Operational Management) at 09:00 a.m.

Table-1. List of Pending Shut-off Service Orders

Shut-off Service Order (SSO)	Customer´s Accumulated Debt (US$)	Process Started Before Dispatch (hours)
01	200.00	24
02	200.00	24
03	200.00	18
04	200.00	96
05	1,000.00	24
06	1,000.00	24
07	1,000.00	24
08	1,000.00	18
09	5,000.00	24
10	5,000.00	24
11	5,000.00	24
12	10,000.00	24

Source: Own construction in this paper.

One should stress that the shut-off SO´s do not cause any kind of regulatory penalty to the electric power distribution company by not meeting standard, because in Brazil there is no standard regarding shut-off clients. It is up to the distribution company to reduce the amount of pending electricity bills, aiming to diminish its commercial losses.

Table 2 presents a list of the pending Commercial Orders which appears on the screen of CEMAR´s OPER, at the same time of the day as the Table 1.

How fast the commercial SO´s should be assisted depends on the importance of the client to the distribution company as well, in accordance with the classification index. Primary importance means that this type of customer is the most important one to the utility, followed by the secondary client and by the tertiary one.

Table-2. List of Pending Commercial Service Orders

Commercial Service Order (CSO)	Client Importance ([1])	Type of Request	Client´s Average Bill (US$)	Process Started in relation to Dispatch (hours)	Deadline (hours)
01	S	Ordinary	5,000.00	24 before	8
02	S	Ordinary	5,000.00	3 after	32
03	S	Ordinary	5,000.00	6 after	32
04	S	Judicial	5,000.00	18 before	32
05	S	Ordinary	5,000.00	24 before	8
06	P	Ordinary	5,000.00	3 after	32
07	P	Judicial	5,000.00	18 before	32
08	P	Judicial	15,000.00	24 before	32
09	S	Ordinary	15,000.00	24 before	32
10	S	Ordinary	15,000.00	6 after	32
11	S	Ordinary	500.00	24 before	8
12	S	Judicial	500.00	24 before	32

([1]) P – Primary; S – Secondary; T - Tertiary

Source: Own construction in this paper.

Table 3 presents a list of the pending Emergency Service Orders which appears on the screen of CEMAR´s OPER, at the same time of the day as the Table 1 and 2.

Table-3. List of Pending Emergency Service Orders

Emergency Service Order (ESO)	**Clients Importance**	**Complaints (1)**	**Recalls (2)**	**Re-incidences (3)**	**Process Started Before Dispatch (hours)**
01	P	G	15	0	2
02	P	G	10	2	2
03	P	G	10	0	2
04	S	G	5	5	24
05	S	G	5	3	24
06	T	I	0	5	24
07	T	I	0	0	24
08	S	I	0	0	0
09	S	I	0	0	19
10	S	I	0	0	17
11	T	I	0	0	0
12	T	I	0	0	0

(1) I – Individual request; G – Group of consumers request
(3) Number of telephone calls from the same client
(3) Number of times that the same fault ocurred within, for instance, a month
Source: Own construction in this paper.

Thus, the challenge of ANTECOM is to optimize the route of the 3 road crews in order to meet these 36 pending WO´s at 09:00 a.m. on December 5th 1915, considering their characteristics and their respective impact by prioritizing a few orders in detriment of others, and also pondering the possibility of not meeting some of them.

A. CEMAR´s Crews Trajectories

With the aim to compare the performances of ANTECOM and the method currently used by CEMARS´s dispatchers, Fig. 2, 3 and 4 show the trajectories of the 3 road crews (grey balls of Fig. 1), initially located on the streets of São Luis, in Maranhão at 09:00 a.m. on December 5th 1915. From then on, each crew visited the SO´s according to the instructions of the Dispatch Centre of CEMAR, as shown on Table 4.

Tabel-4. List of Service Assignments to Field Crews Dispatched by CEMAR

Work Service Sequence	**Road Crew**		
	# 37	**# 38**	**# 39**
1	S06	S04	C04
2	S08	S02	S07
3	S10	S01	E02
4	S09	S05	C05
5	C03	S03	C07
6	E04	C12	C06
7	E01	E09	C09
8	E03	E07	C08
9	C01	E05	S11
10	C10	S12	
11		E10	
Labour Hours	8	8	8

Source: Own construction in this paper.

As one can see by Table 4, # 37 road crew starts at 09:00 a.m. heading towards the location of WO S06, and after finishing its job, goes to the next WO (S08), and so on, successively, until its last WO of the day (C10). The same procedure happens to the other two road crews. Fig. 2 shows the route of # 37 road crew from 09:00 a.m. onwards, as an example of route that the algorithm can draw.

Fig-2. Route of the # 37 road crew, from 09:00 a.m. onwards

Source: Result of this paper.

As predicted, CEMAR’s solution has some inaccuracies, once it has been intuitively built and could not ponder all the problem’s constraints. In this example, the dispatcher has not considered the displacement time, so it would not be possible to meet all the SO´s pointed by them. Also, he has forgotten that WO C03 could only be met at 3 p.m. onwards, nonetheless tried to meet it earlier.

With the purpose to measure the effectiveness of CEMAR’s solution, its dispatch was simulated by ANTECOM’s for solution comparison. In the simulation, however, the road crews shift duration and all the other constraints were considered. In the new result, the SO´s E01, E03, C01, C10 and S11 could not be met as well as the other SO´s unattended by the previous solution. The final score of non-assisted SO´s of the solution was 852.04 (the higher the score, the worse is the solution).

B. ANTECOM´s Crews Trajectories

Table 5 shows the WO met by each road crew from ANTECOM’s dispatch.

Table-5. List of Service Assignments to Field Crews Dispatched by ANTECOM

Service Order Sequence	**Road Crew**		
	# 37	**# 38**	**# 39**
1	S12	S09	S10
2	S11	E03	E02
3	C08	C12	E09
4	C06	S04	E01
5	C07	S01	E05
6	E10	S02	C04
7	E06	S05	S07
8		S03	S06
9		E04	
10		S08	
Labour Hours	8	8	8

Source: Result of this paper.

Again, Fig. 3 shows the route of # 37 road crew from 09:00 a.m. onwards.

Comparing both solutions, it is possible to notice that CEMAR intuitively tried to minimize the routes to be taken and the SO´s importance seemed to be less explored, while ANTECOM’s approach was able to make the company’s interests more relevant to the solution. The final score of non-assisted SO´s of ANTECOM’s solution is 258.84, an improvement of 229%.

Fig. 4 shows a graph of the scores of non-assisted SO´s of both CEMAR and ANTECOM dispatch throughout the day. One can see that ANTECOM presented the best score all day long.

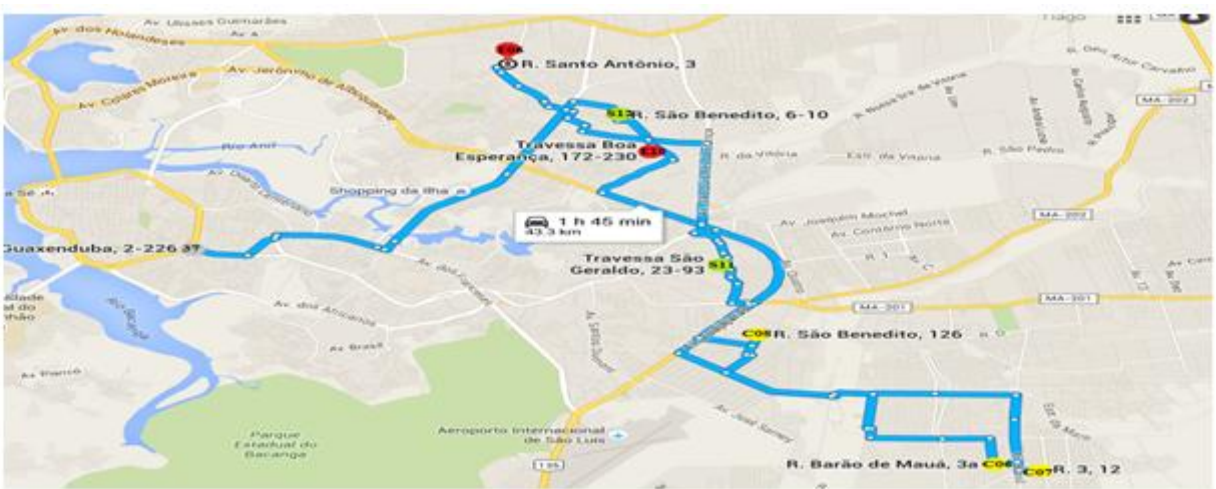

Fig-3. Route of the # 37 road crew, from 09:00 a.m. onwards

Source: Result of this paper.

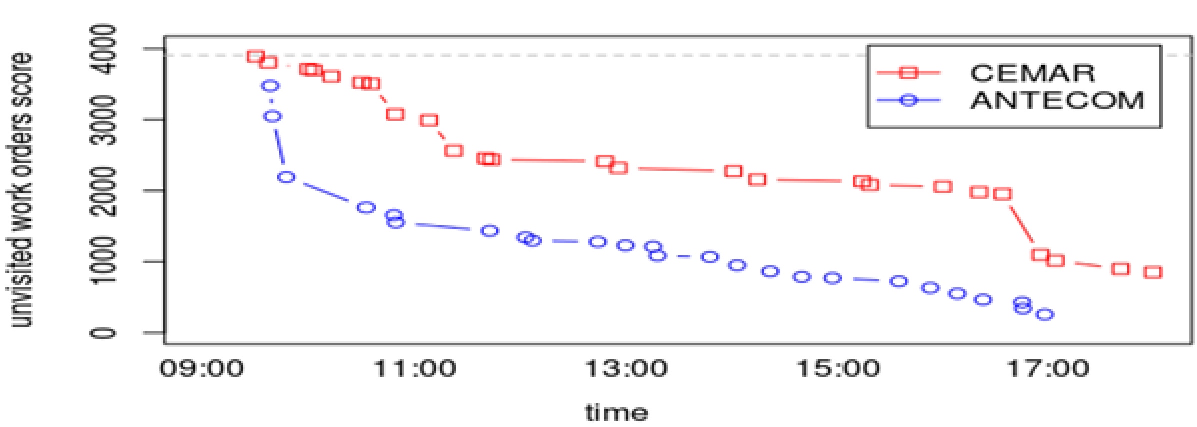

Fig-4. Non-visited SO´s score throughout the day

Source: Result of this paper.

5. Conclusions

Dispatching field crews is a nonstop process, compelled by the arrival of new SO´s, weather conditions, loss of connectivity etc. It is a very hard work to the Dispatch Centre to keep the electric systems working, with regards to the changing circumstances. ANTECOM is a tool available to help the electric power distribution company to face this task, providing an optimized way to prioritize and assign the SO´s to the available road crew teams. The latter is the subject of this paper, using the ACO approach, providing an optimized SO´s sequence and routes to be taken by each available field crew. According as the simulated merit indexes, the solution score of CEMAR´s unattended SO´s was 852.04, whereas ANTECOM´s score was 258.84. The former reflected the decisions made by CEMAR´s dispatchers by means of previous knowledge, intuition and experience, which also may present an inaccurate response due to the real-time amount of information and pressure. The latter implemented the simultaneous ACO algorithm to optimize the result in function of the number of field crews available and to the company's main goals. The product developed offers to CEMAR, to the technical community and to society an important tool that is not yet contemplated by the current systems. Also, by its capacity to evaluate – in a totally automatic way - all the variables considered relevant by the company in real time and dynamically, the product available is a robust computational tool for prioritization and road crew dispatch for commercial and supply restoration services in an electric power distribution company.

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