MULTI-CRITERIA APPROACH FOR EMERGENCY SERVICE ORDERS IN ELECTRIC UTILITIES

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ABSTRACT

This paper proposes a multi-criteria approach to handle emergency orders under real-time conditions in electric power distribution utilities. It is described how the problem related to serve work orders in electric utilities is considered, with an aggregated objective function developed to handle the minimization of the waiting time for emergency services, the total distance travelled and the sum of all delays related to already assigned orders. After that, actual cases have shown the effectiveness of the proposed model to be adopted in real world applications.

INTRODUCTION

Electric power distribution utilities are charged of managing customer attendance and maintenance procedures in their network. The consideration of emergency scenarios makes the problem harder especially by assuming resource constraints (human and material) and strict regulation policies that establish targets and indices related to this context.

Considering that maintenance crews help to maintain the network under normal conditions, i.e., all the customers with power supply and non-technical problems associated with the electric network, emergency orders are normally related to equipment failures, overload conditions and interrupted conductors.

From this context, the most relevant aspect to be considered refers to the waiting time associated with the emergency orders, since the level of injury or danger of death imposes immediate response from the network operations center (NOC). The decision-making problem involves a considerable amount of data and several aspects and criteria, all of them related to network and equipment operation procedures. This context is close to that one described by (Ribeiro et al. 1995): “decision making is a process of selecting ‘sufficiently good’ alternatives or course of actions in a set of available possibilities, to attain one or several goals”.

Such a decision making process when referring to emergency services in electric utility generally involves not only the waiting time for emergency orders but also two even important aspects: the total distance traveled and the sum of all delays related to already assigned orders. The former sounds really intuitive, because the minimization of the total distance traveled by all crews improves their productivity by aggregating more time in their workday to complete the assigned orders. The latter aspect is that one associated with one contribution of this paper: the consideration of multitasked maintenance crews. They are always charged of pre-established routes that include orders known a priori when a set or emergency orders come up. This criterion of minimizing the sum of all delays represents the desired trade-off between the planning and actual scenarios, in such a way that they could be as similar as possible.

This paper proposes a multi-criteria mathematical model to handle emergency orders under real-time conditions. It comprises three criteria related to this problem: the minimization of the waiting time for emergency services, the total distance travelled and the sum of all delays related to already assigned orders.

This paper is organized as follows: first the emergency work order dispatch problem is described, followed by the corresponding mathematical model. After that, the heuristic approach, preliminary results and final remarks are presented.

PROBLEM DEFINITION

The emergency work order dispatch problem (EWODP) is carried out within 24 hours a day, 7 days a week, corresponding to a main task of the electric NOC. Assuming this non-stop period and the critical issues involved, a real time system may be suitable to assign a repair crew to each remaining emergency work order (EWO).

When developing a system able to assign one order to a given repair crew, the following goals must be assumed:

- Reducing the dispatch time;
- Improving network security on operation and maintenance procedures;
- Standardization of dispatch criteria in such a way they could be closely related to business process.

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The main issue involved is the aim of reducing the average service time, which is defined as the sum of the waiting time, the travel time and of the order execution time. In this work we consider the decision problem of assigning an EWO to a given maintenance crew available, mainly focusing on the waiting time. The challenge comes from the business process usually adopted by utilities: they have multitasked repair crew generally in charge of commercial services (customer demand orders) when an EWO comes up. From this assumption follows specific characteristics that make the whole optimization problem some orders of magnitude greater in the sense of the complexity involved.

In this work it is described a problem that emerge from specific characteristics of route construction to meet customer demand in the context of an electric power distribution utility in Brazil, specifically with concern to the occurrence of EWO. The main inspiration for the analysis carried out to represent and solve the EWODP track its origin from the well-known traveling salesman problem (Lawler et. al. 1985) and its famous generalization: the vehicle routing problem (Toth and Vigo 2001).

In the considered utility, maintenance crews must execute a set of service orders, what remounts the construction of multiple routes. These crews have their start point in a depot that can be distinguished from each other and they do not need to return to their start point when the last service is completed.

The fundamental aspect that must be considered refers to the definition of several kinds of service orders, with high importance to the ones that are not known a priori. Two different sets can be defined: those orders known a priori and related to commercial services requested by customers and those orders that have their inherently aspect of emergency, which may occur at any moment. Every maintenance crew is able to execute these two kinds of orders.

When a maintenance crew begins its journey, its corresponding route to execute only those commercial orders known a priori is available. The occurrence of emergency scenarios imposes the most appropriate treatment in order to consider these EWOs that are coming up and have precedence over the commercial orders. Following the number and their corresponding geographical location of EWOs, one or more maintenance crews will be considered to complete these services and, as consequence, they will have their routes modified.

The problem that arises from this context is related to the need of restructuring the existing routes only populated by commercial orders, now including the pending EWOs in the beginning of each existing route. From this perspective, two scenarios may be assumed: (1) reprogramming the set of remaining commercial services of all maintenance crews; and (2) only inserting the pending EWOs in the beginning of each route while maintaining unchanged the route related to commercial services. The first option has strict technological constraints since each maintenance crew receives a batch of orders to be executed when its journey starts and the communication to reprogram the route during the day may be a bottleneck by the existing status quo of telecommunication services in Brazil.

One important definition is related to the main goal of the problem. There are several objectives that can be assumed, including those conflicting ones. One of these is reducing the waiting time to execute emergency services, exactly by the risks associated with security of the electric power network.

Another objective, this one related to economical aspect, is reducing the total cost of routes, corresponding to the total time to complete all designed routes. In this case, both commercial and emergency are considered when calculating the cost. Even in this case it is already possible to note a conflict between cost and precedence of emergency services: the higher is the importance of emergency services, the greater will be the cost.

The third and last aspect to be considered refers to minimizing the sum of all delays related to the previously assigned services, in order to maintain the desired trade-off between the planning and actual scenarios.

Following these concepts and definitions, a mathematical model was developed as depicted below.

The mathematical model developed

The first assumption is that there is a given set of crews with their corresponding a priori routes, which include services called commercial orders. Given an instant of time in that a certain number of emergency orders come up, it is assumed that they will be assigned to the given crews in such a way that previous routes will not be changed. This fact will cause insertion of emergency services in the previous known routes, involving a decision of which subset will be assigned to each crew and in which position on the route.

On the following mathematical model, three criteria are used to integrate the objective function: the first, weighted by W_1, corresponds to the latency cost of all emergency orders; the second, weighted by W_2, includes the cost of all routes; the third, weighted by W_3, aims to reduce the delay when considering the time when a commercial order i is completed and the end time of each route.

The following parameters are considered:

0	:	dummy order to define the final destination point of every crew;
V_e	:	set of emergency orders;
V_c	:	set of commercial orders;

V_s	:	set of start points, which represent the initial position of each crew;
V	:	$V = V_e \cup V_c \cup V_s \cup \{0\}$
R	:	set of routes / crews;
$t0$	:	initial time for every crew;
T	:	end time for every crew's workday;
$suc(i)$	:	the successor point of i in the a priori route, $i \in V_c$;
$pre(i)$	:	the antecessor point of i in the a priori route, $i \in V_c$;
$rC(i)$	:	the route index in which point i is inserted $i \in V_c$;
te_i	:	time when the emergency request i came up, $i \in V_e$;
ts_i	:	execution time of order i, $i \in V \setminus \{0\}$;
C	:	cost related to each non-assigned emergency order;
E	:	$E = \{<i,j,r>; i \in V_e, j \in V, r \in R, r == rC(j)\} \cup \{<i,j,r>; i \in V, j \in V_e, r \in R, r == rC(i)\} \cup \{<i,j,r>; i \in V_e, j \in V_e, r \in R, i \neq j\} \cup \{<i,0,r>; i \in V_e, j \in V, r \in R\}$
$c_{i,j}$	:	travel time between points i and j;
M	:	a huge value, typically 2T;
$W1, W2, W3$	:	weighted factors of each objective function component, with W1+W2+W3 =1.

The following decision variables are defined:

x_{ijr} : 1 if point j is successor of point i in the route r; 0 otherwise;

y_i : 0 if the emergency order i is assigned to some route; 1 otherwise;

t_i : time when order i is completed;

ta_i : $ta_i = T - t_i$ if $t_i < T$; 0 otherwise;

td_i : $td_i = t_i - T$ if $t_i > T$; 0 otherwise;

$$Min \quad W_1 \sum_{i \in V_e} t_i + W_2 \sum_{<i,j,r> \in E, i \in V_e} c_{ij} x_{ijr} + W_3 \sum_{i \in V_c} td_i \tag{1}$$

Subject to:

$$\sum_{<i,j,r> \in E} x_{ijr} + y_i = 1 \qquad \forall i \in V_e \tag{2}$$

$$\sum_{<i,j,r> \in E} x_{ijr} + y_j = 1 \qquad \forall j \in V_e \tag{3}$$

$$\sum_{<i,j,r> \in E} x_{ijr} \leq 1 \qquad \forall i \in V_c \cup V_s, \forall r \in R \tag{4}$$

$$\sum_{<i,j,r> \in E} x_{ijr} \leq 1 \qquad \forall j \in V_c, \forall r \in R \tag{5}$$

$$\sum_{<i,j,r> \in E} x_{ijr} - \sum_{<j,l,r> \in E} x_{jlr} = 0 \qquad \forall j \in V_e, \forall r \in R \tag{6}$$

$$\sum_{<i,j,r> \in E} x_{ijr} - \sum_{h \in V_e} x_{h,suc(i),r} = 0 \qquad \forall i \in V_c \cup V_s, \forall r \in R \tag{7}$$

$$t_i = t0 \qquad \forall i \in V_s \tag{8}$$

$$t_j \geq t_i + (c_{ij} + ts_j) + \sum_{<i,j,r> \in E} (x_{ijr} - 1) M \qquad \forall j \in V, \forall i \in V \tag{9}$$

$$t_i \geq t_{pre(i)} + c_{pre(i),i} + ts_i \qquad \forall i \in V_c \tag{10}$$

$$t_i + ta_i - td_i = T \qquad \forall i \in V_c \tag{11}$$

$$t_i - ts_i \leq T \qquad \forall i \in V_e \tag{12}$$

$$t_i - ts_i \geq te_i \qquad \forall i \in V_e \tag{13}$$

$$ta_i \geq 0 \qquad \forall i \in V_c \tag{14}$$

$$td_i \geq 0 \qquad \forall i \in V_c \tag{15}$$

$$t_i \geq 0 \qquad \forall i \in V \tag{16}$$

$$y_i \in \{0,1\} \qquad \forall i \in V_e \tag{17}$$

$$x_{ijr} \in \{0,1\} \qquad \forall <i,j,r> \in E \tag{18}$$

COMPUTATIONAL METHODOLOGY PROPOSED

When observing the literature, several contributions explain how to consider the vehicle routing problem in a context much similar to that one defined in this paper.

(Okonjo-Adigwe 1988) proposes a method to generate balanced routes to the vehicle routing problem that includes upper and lower bounds on the route time of each vehicle, obtained by a heuristic algorithm. After that and incorporating these limits, one mathematical model is derived and the problem is optimally solved. (Chandran et. al. 2006) have developed an approach to have balanced workload by modeling the vehicle routing problem first as a clustering problem, in a classical cluster-first, route-second approach. (Weintraub et. al. 1999) consider the emergency vehicle dispatching problem and the workload balanced is obtained by a post-optimization procedure that includes order interchange between routes, clustering and routing.

(Anbuudayasankar et. al. 2009) have pointed out that the workload balanced should not be assumed in the sense of total route cost but in the sense of equity when considering dangerous and strenuous activities.

One can note that the goal of balancing routes has strict relation with human relations in the company, since it is the most apparent aspect that is evaluated when comparing the work effort between two given crews. In this work, the considerations of (Anbuudayasankar et. al. 2009) are included in the form of priority and execution time of each service, what allows minimizing and balancing the total route time.

The methodology to solve the EWODP proposed in this paper comprises a mixed linear programming mathematical model to be included in a computational system, which is able to execute a real-time automatic dispatch of EWOs. However, real-time conditions, strict constraints related to workday of every crew and even pre-assigned orders endow a certain degree of complexity to the problem of this approach.

The previous defined mathematical model can be used to solve "small" instances (i.e, with less than 20 orders) to optimality. Actual instances, mainly by assuming the proposal of applying this methodology to actual scenarios, may typically involve more than 100 orders to be assigned to 4 to 10 crews.

A heuristic procedure may be suitable and convenient to this context, and exactly this root was followed by the computational methodology proposed in this paper.

```
IterativeConstructDeconstruct(V, E, R, T, c, W, N)
S=Construct(0,V, E, R, T, c, W);
i=0;
S=evaluate(S, V, E, T, c, W);
while(i<N) do
        Sd=Deconstruct(S,V, E, R, T, c, W);
        Sd= evaluate(Sd, V, E, T, c, W);
        if ( Sd<S ) then S=Sd;
        i=i+1;
return(S);
```

Figure 1: Algorithm proposed to solve the EWODP.

The procedure of Figure 1 is mainly inspired by (Ahmadi and Osman 2004) and includes two main phases: the former, charged of construct a solution; and the latter that deconstructs the previous assignment of "construct" phase. Since every crew route will be formed by a sequence of orders, the EWODP should define essentially a sequence of orders including the emergency ones. In "construct" phase, a Monte Carlo method is conducted by defining this sequence, according to the objective function of equation (1). In "deconstruct" phase, all emergency orders are extracted from the sequence at random and included in the best position according to the objective function of equation (1). This procedure is repeated by N iterations, always keeping the best solution found. Parameters V, E, R, T, c and W are exactly the same described in the previous section as part of the mathematical model described.

PRELIMINARY RESULTS

In order to evaluate how suitable may be the algorithm developed, preliminary results were obtained when the system approaching the following actual case:

- 25 commercial orders;
- 3 repair crews;
- 5 emergency work orders (EWO).

Figure 2 shows 3 repair crews and their corresponding routes, namely 3056, 4019, and 4025. All of them begin their work at 10 am and finish their journey before 3:10pm. The scenario of Figure 2 shows that every repair crew is already charged of commercial orders when it will serve EWOs. There are two main charts on this figure: the former points out how much of the total time of each crew will be on attendance services and how much time will be spent on displacement; the latter is the timeline for each crew, where the black color refers to emergency orders, red color refers to orders with priority p0, yellow color refers to orders with priority p1 and green color refers to orders with priority p2. This interface is of Google Earth platform (Google Earth 2013) that shows the result of the developed algorithm after describing a kml file.

From scenario of Figure 2, Table 1 shows the schedule for each maintenance crew only considering commercial orders previously assigned to. There will also be three kinds of priority levels for all commercial orders: lower will be the most critical service and all routes have their first part formed by orders of level 0 (p0), followed by orders of level 1 (p1) and finally orders of level 2 (p2).

Table 1: Schedule for commercial orders.

#Crew	Start time	Finish time	#orders p0	#orders p1	#orders p2
3056	10:00am	3:06pm	3	5	4
4019	10:00am	2:33pm	3	3	2
4025	10:00am	12:22pm	0	4	1

At 10:10 am, 5 EWOs come up and three available crews must attend them. This aspect conducts a new routing for all crews in order to minimize the function of equation (1), whose result is shown in Figure 3.

It can be noted in Figure 3 that there is more time spent in displacement when comparing the Team'profile of Figure 3 with Team's profile of Figure 2. That behavior is easy to understand since these 5 EWOs are included in the beginning of all routes, as depicted in Table 2. One important aspect refers to the maintenance of the previous assigned routes: for all routes, it was maintained the commercial orders assigned, just causing a delay on the finish time due to attendance of emergency orders.

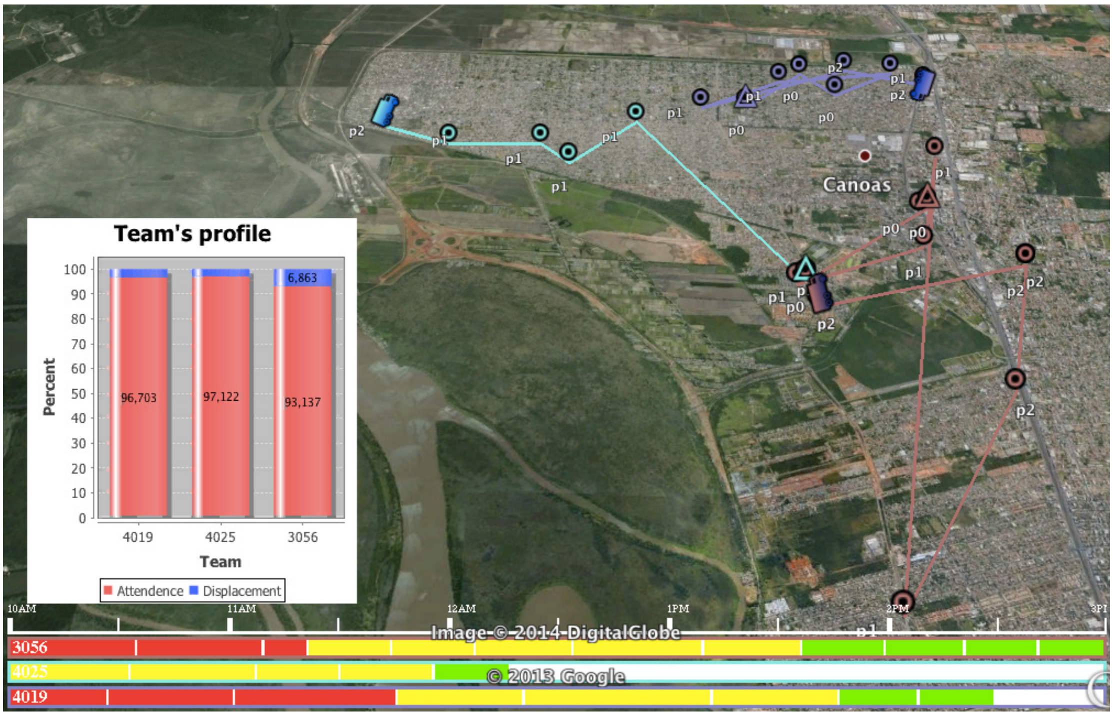

Figure 2: Maintenance crew routes for commercial orders.

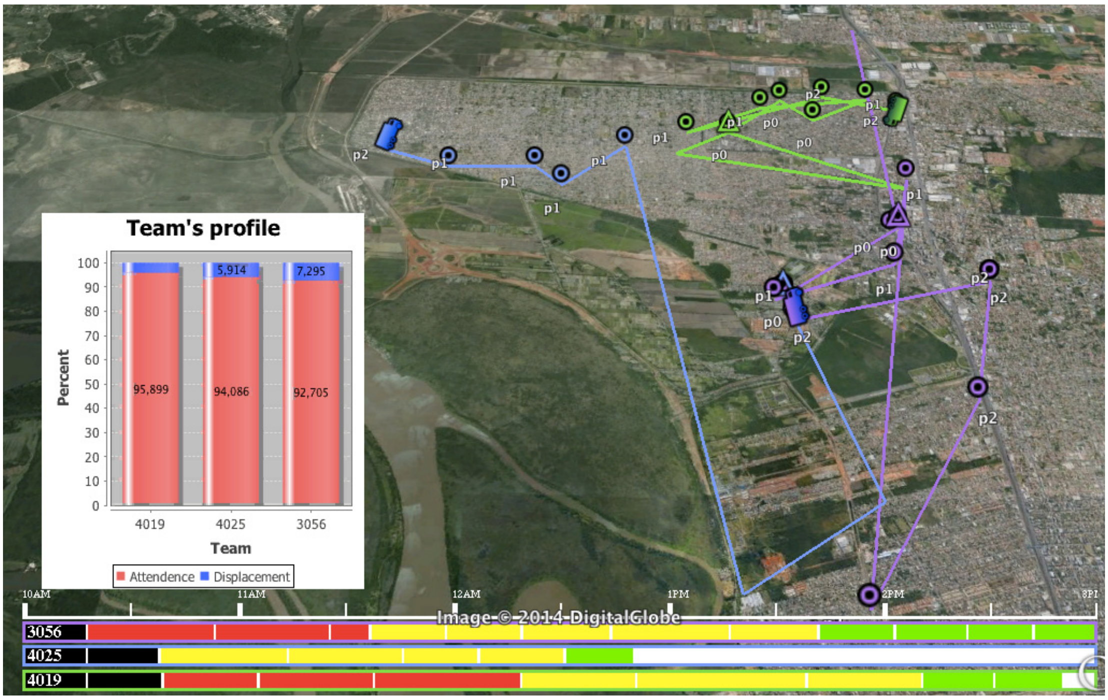

Figure 3: Maintenance crew routes after considering 5 EWOs.

Table 2: Schedule for both commercial and emergency orders.

#Crew	Start time	Finish time	#emerg. orders	#orders p0	#orders p1	#orders p2
3056	10:00am	3:32pm	1	3	5	4
4019	10:00am	3:19pm	2	3	3	2
4025	10:00am	1:08pm	2	0	4	1

FINAL REMARKS

This paper has presented a computational methodology to address the emergency work order dispatch problem. One key aspect involved in this system corresponds to the real-time condition, leading to development of an algorithm with response times in the order of microseconds or at least milliseconds.

Considering the main contributions of this paper, the following must be mentioned:

1. Reducing on the dispatch time;
2. Improving network security on operation and maintenance procedures;
3. Standardization of dispatch criteria in such a way that they could be closely related to the business processes adopted.

The benefits from adopting this approach may refer not only to the capability of managing in a secure manner high critical tasks but also by making possible a great amount of calculations and analysis required in the decision making process.

Future works should address the development of alternative mathematical models to this problem.

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