25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-2398
Consumer Units Measurement Planning Using Simulated Annealing

Antonio de Sousa Mourão Sobrinho
Anderson Silva Fonseca
Petterson Sousa Diniz
Victor Henrique Bezerra de Lemos
Mayara Gomes Silva
Anselmo Cardoso de Paiva
Geraldo Braz JÃžnior
Applied Computer Group NCA-UFMA, Federal University of Maranhão - UFMA, Av. dos Portugueses, 1966 - Vila Bacanga, São Luís - MA, 65080-805
antonio.mourao@nca.ufma.br, andsfonseca@nca.ufma.br, petterson.diniz@nca.ufma.br, victorhbl12@nca.ufma.br, mayara@nca.ufma.br, paiva@nca.ufma.br,
Eliana Márcia Garros Monteiro
Equatorial Energia
eliana.monteiro@cemar-ma.com.br

Abstract. *This paper describes an approach for generating the measurement planning, instead of the general manual process of the energy companies in Brazil. This process creates the consumer units groups for measurement. In Brazil, this process has some restrictions rules for group creation and modification of the created groups. For this purpose, it is proposed an integrated Simulated Annealing system that enables the automatic group creation, considering these rules. The obtained results indicate the creation of groups according to the criteria of homogeneity, conformity, and compactness, which has the benefit of lower operator displacement as well as generating fast-mode planning.*

Keywords: *Measurement Planning, Consumer Unit, Simulated Annealing, Operator displacement.*

1. INTRODUCTION

The electricity distribution management requires an efficient communication system along with the centers of the control, supervision, and measurement of the consumer units. A factor of great importance for the company's profit is the data collection of the regarding customer consumption and the invoice delivery. In general, this process is manual in Brazil, in other words, in each consumer unit, there is measurement equipment where the company employee should go and carry out the reading.

The electric power companies CELPA and CEMAR build monthly planning in order to realize the measurement of the consumer units. In this planning, the installations (consumer) are grouped considering the day of the month that will be realized the reading. This organization must follow the regulations of the National Agency of Electrical Energy (ANEEL) (ANEEL, Normative Resolution, 2010), that aims to guarantee a good relationship between companies and customers. This planning requires to analyze a lot of factors as considerate the active units and non-active, in this way is required a reorganization every month.

The planning of data gathering could be considered as a problem of district or redistricting. The redistricting aims to divide a geographic space, grouping small territorial units in contiguous districts, considering the size of the solution space, it is hard to find a great solution to this problem (Joshi *et al.*, 2011) (De Assis *et al.*, 2014). The multicriteria capacitated districting problem (MCDP), it is a generalization of the redistricting, applied in many situations, such as the redefinition of urban lots of billing of the electrical energy distribution companies (de Assis *et al.*, 2010).

This work presents the application of Simulated Annealing (SA) in the multicriteria capacitated districting problem (MCDP). This is a local search meta-heuristic that is used to generate solutions to be inserted in the grouping process and could be explored local search module (Van Laarhoven and Aarts, 1987). Solutions are evaluated in order to reduce their computational cost of recalculating the center of each group for every solution found, redefining the geographical borders of the regions, in order to generate groups more homogeneous and compact, balancing the load of readings of each reader.

The rest of this article is organized as follows: in section II we present the works related to the research theme, section III describes the challenges faced in the read process and the ANEEL regulation. Section IV presents the strategies in the process of grouping. Section V presents the results and the discussion.

2. RELATED WORK

The capacitated grouping or redistricting is a recurrent problem in several research works. Some works apply strategies for grouping customers that have similar behavior; other approaches apply for the measurement organization of the customer consumption, or route planning. This section presents some approaches used for solving the clustering capability problem.

The method for solving the capacitated grouping was proposed by Costa *et al.* (2018), that was applied in the organization of consumer units measurement groups in companies of distribution of electrical energy in Brazil. In general, the companies have been creating the groups manually by specialized people. So, the objective of this related work was to create homogeneous and compact groups using RCMeans methodology. The method was based on kmeans applied to data grouping using capabilities restrictions to define the groups. The results showed that the approach was better than the current situation of the company.

The problem of capacitated redistricting is presented in De Assis *et al.* (2014), that proposes a methodology based on a greedy randomized adaptive search procedure and multicriteria escalation techniques. The redistricting in this work was based on the following criteria: compactness (low scattered of districts), workload balance and limit of the number of customers attributed to each district. The results show that the proposed methodology gives efficient and high-quality solutions in acceptable runtime.

The multicriteria optimization is used by França *et al.* (2007) in the problem of redefining of the lots of billings of electrical energy companies. The purpose of the methodology was redefining the geographic bounds of the billing lots, according to the homogeneity, geographic and conformity criteria. For this, was used two approaches based on the improvement of already used strategies, generating new heuristics. The results show a comparison between the original algorithms and the method proposed, showing that the last one is better, getting a homogeneity of loads of lots, at the same time that preserves the proximity.

This work presents a proposal for generating automatic planning, creating the steps (groups) of a plan, to collect data about the consumption of electric energy, and for the billing delivery process. The approach used for solving this problem of group creation was the application of the Simulated Annealing technique. In order to generate the plans, our work analyzed some approaches, considering restrictions, such as measurement priorities and the creation of dense regions. In the following sections, we will detail the entire process of measurement of the consumer units and its restrictions.

3. CHALLENGES IN THE PROCESS OF READING CONSUMER UNITS

In the reading planning process, the specialists responsible for creating the groups of reading units should respect the following rules: (A) The number of consumer units for a reading group; (B) The geographical location of the consumer units; and (C) National laws on charges to the energy bill.

The specialized professionals for the distribution of the consumer units have as main responsibility divide and distribute the installations of a specific region of a county and organize them into reading units. A reading unit is defined as a grouping of consumer units that will be observed by a reader on a working day.

3.1 Number of consumer units per Reading Unit

During a day's work, a reader employee has the responsibility of performing electric power measurements for a single reading unit, that is, in one day the reader is in charge of measuring the consumption of all consumer units included in the grouping. Thus, a smaller number of reading units means fewer readers.

The distribution process consumer units should consist of creating a plan that minimizes the amount of reading units. However, each of the groups must have as many consumer units as possible so that a single reader can perform all measurements in one day.

3.2 The geographic positioning of consumer units

The work of creating the planning involves selecting a specific region of one or more cities and create reading units that have the shortest distance between their consumer units. Therefore, it's important to analyze the geographical information of each installation.

In the process of reading the meters, the readers must go to the location of each installation of a reading unit to carry out the measurement and issue the consumer billing. Aiming at saving the employee's travel time and in the largest quantity of consumer units measured, it's important to create groups that approach geographically, preferably as compact as possible, allowing the optimization of the route of the employees.

3.3 National laws on charges to the energy bill

The Brazilian companies of electrical energy must follow some criteria defined by ANEEL regulation (ANEEL, Normative Resolution, 2010). The proposed conditions were created aiming a better relationship between the energy company and consumers.

The regulation defines that the measurement must be executed in intervals of approximately thirty days, between twenty-seven and thirty-three days since the last billing. The companies are denied to generate two billings in the same month.

If necessary, the measurement beyond the defined deadline can be made by means of a warning made by the company to the consumer with a minimum advance calculated from the date of the last billing. The period for carrying out the measurements is changed to intervals between fifteen and forty-seven days. However, you can not send several warnings about changing the measurement date in a short period of time.

Is defined as the billing cycle the monthly planning of a measurement region, that is, each month a measurement region can have some different days to get the measurements to be executed, changing each month. In order to organize the monthly cycle, the companies groups the measurement units to be measured in a day. The grouping of measuring units is called Measurement Step.

In order to prevent that the employees walk through long distances to be the measurement, the steps should have units nearby, aiming the improvement of the distribution of the workdays.

4. GROUPING STRATEGIES

Clustering is an optimization problem, with the goal of finding the best group of a specified data set, minimizing dissimilarity between data that is contained in the same cluster. A clustering algorithm aims to organize the set of data into groups, taking into account similarity criteria between the data (Guerine *et al.*, 2017).

In the definition of the criteria for this problem, it is very important to consider the energy delivering laws as well as the restrictions to redefine the size and conformation of the groups, such as homogeneity, conformity, and geographical criteria.

- Homogeneity criterion: uniformity in the workload of the measurement operators in the new groups is objectively sought, thus obtaining a better cost-benefit, that is, the minimization of the workforce. This criterion is based on working time.
- Conformity criterion: new groups are created according to the current reading plan in order to change the reading day intervals as little as possible and are in compliance with ANEEL regulations.
- Geographical criterion: the new groups should be as compact as possible, so that the route definition is more efficient.

In Fig. 1, shows the steps of creating a reading plan, showing how the grouping is currently carried out by the companies CELPA and CEMAR. To find a better solution to the problem, initially the installations of the defined region are analyzed, and then create the reading units. Then, is created the steps containing reading units closer, generating a reading plane. Right after, the proposed plan is evaluated by specialists who reassign and redistribute the groups. Unlike the current method, the approach of this work carries out the planning defining initially the reading steps. Next, the reading units are defined, and the quantity of installations for each reader, respecting all the defined restrictions.

4.1 Objective function

Because of the difference in the total read time of each cluster, a varied number of employees is needed in each one of them, vacating employees on days of least demand. So, the objective function is minimize the read time difference between the groups, reducing the standard deviation of the read time (Eq. 1). Groups with close read times represent similar employee needs.

$$Min\sqrt{\frac{\sum_{i=1}^{n}(x_i - M)^2}{n}} \tag{1}$$

Where:

- i: Number of the group
- n: Number of groups
- x_i: Read time of the group i

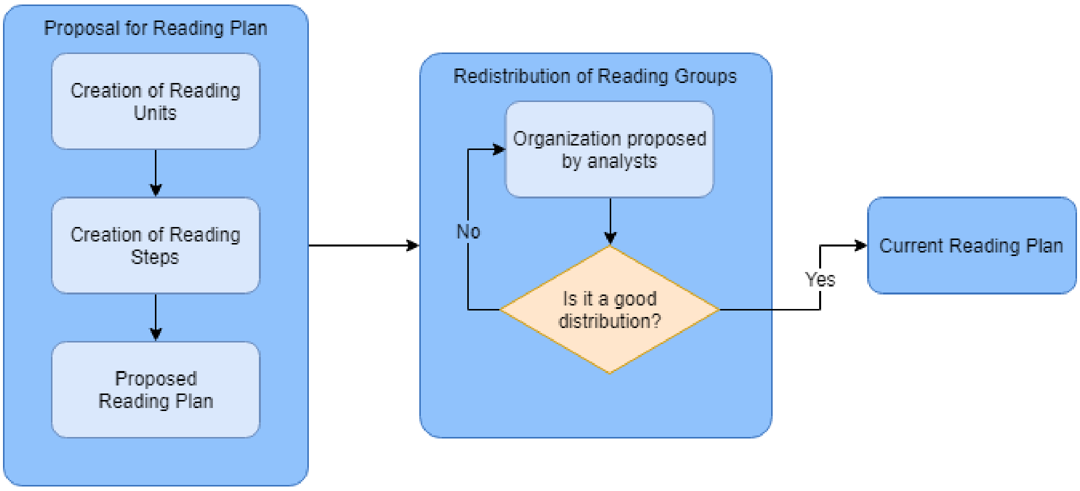

Figure 1. Stages of reading plan creation. Source: authors

- M: Mean of read time of groups

The equation 1 can be write as:

$$Min\sigma \tag{2}$$

4.2 Simulated annealing

To find a god solution for the equation 1, a simulated annealing approach was implemented. The solution was designed as a $2xn$ matrix, where n is a number of groups and 2 refers to the x and y coordinates of the Cartesian plane.

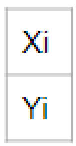

Figure 2. Solution structure. Source: authors

With a solution, an Euclidean distance was calculated for each read unit to define the closed group and which group does it belong to. The equation 1 is applied to know how good the solution is.

To define a "neighboring solution" of the current solution is changing the x and y of an unique group. With this new solution, the fitness is calculated and if is better than the current, the neighboring is defined as a current, if it is worse, a probability of acceptance is calculated.

The probability of acceptance is calculated defining an p between 0 and 1 (Eq. 3) and an δ (Eq. 4) where f is the fitness value. If the p is lower then the exponential of $\frac{-\delta}{T}$ (Eq. 5), the neighboring solution is defined as a current.

$$p = random[0..1] \tag{3}$$

$$\delta = f_{neighboring} - fcurrent \tag{4}$$

$$p < exp(\frac{-\delta}{T}) \tag{5}$$

The T value in equation 5 is the "Temperature" of annealing. How bigger is T, bigger is the probability of a worse solution be accepted as the current. In this work, the initial value of T was 1.000.000 and every 10 (ten) interactions, this value was decreased by 10% (Eq. 7). The algorithm stop when the $T \leq 1$

$$\alpha = 0.9 \tag{6}$$

$$T_i = \alpha(T_{i-1}) \tag{7}$$

$$T_{min} = 1 \tag{8}$$

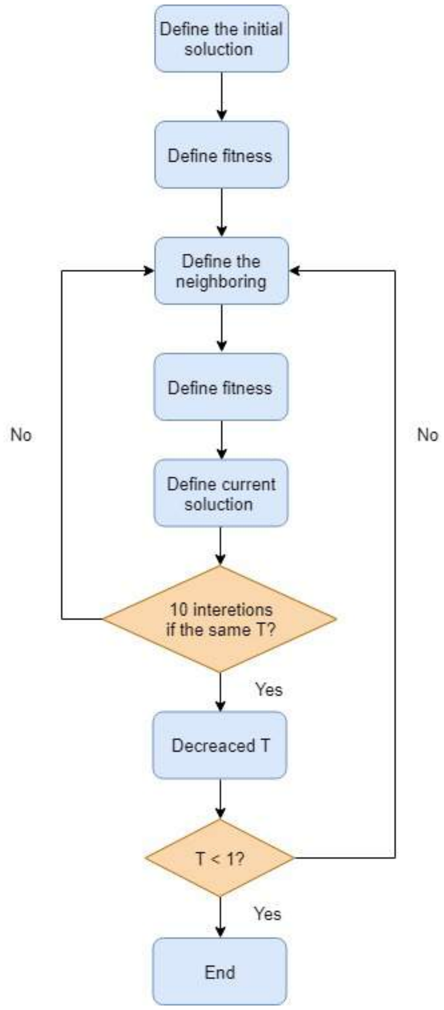

Figure 3. SA work flow. Source: authors

5. Results and Discussion

The algorithm was tested in an instance with 87.263 read units divided into 18 (eighteen) groups and standard deviation 899.65 of the reading time of each group. Initial, the groups are scattered throughout the region, so, close read units do not necessarily belong to the same group. Each read unit has an x, y and a time required for reading.

In this work was tested 4 (four) approaches within simulated annealing:

- Random group changing with no dense region(RC/ND)

  The group that will have the x and y changing in the neighboring solution selection step will be chosen randomly. The x and y maximum and minimum are defined by x and y maximum and minimum in instance.

- Prioritized group changing with no dense region(PC/ND)

  The group that will have the x and y changing in the neighboring solution selection step will be chosen among those who are outside the standard deviation of the solution, if all are within the standard deviation, the group that will change will be chosen randomly. The x and y maximum and minimum are defined by x and y maximum and minimum in instance.

- Random group changing with dense region(RC/DR)

  Like the first approach, the group it will change is chosen randomly, but a KDTree algorithm is used to define an area of radius 500 units of measurement where the choosing group have more individuals initially. The new center of group i is chosen within that region.

- Prioritized group changing with dense region(PC/DR)

  The the group that will be changing will be chosen among those who are outside the standard deviation of the solution, if all are within the standard deviation, the group that will change will be chosen randomly. The new center position will be defined with values of x and y within the dense region defined with KDTree.

Because it is a heuristic, the algorithm was executed 5 (five) times for each modification, collected the final result, and calculated the mean and standard deviation of the results to analyze how is the behavior of simulated annealing implemented

The Tab. 1 shows the values found in the tests. The lowest standard deviation find in the grouping of reading units was using prioritized group changing with dense region (PC/WD) (906.69), while the greater was using prioritized group changing with no dense region (15383.91). PC/WD was the approach with a lower mean between the results and obtained the second lowest standard deviation in executions, showing low variation in results.

Table 1. Result values

	RC/ND	PC/ND	RC/DR	PC/DR
Min value	9950.07	8950.07	1280.66	906.69
Max value	11382.91	15382.91	1568.15	1292.59
Mean	10791.07	12191.07	1443.59	1199.41
Standard Deviation	595.75	2647.57	110.30	165.54

The Fig. 4 shows how the instance was distributed before grouping. How is it possible to see, some groups are mixed. The Fig. 5 shows how the instance was distributed after the execution of the SA when the best value was find (PC/WD). The Figs. 6 and 7 represent the central area with zoom for better visualization of the groups.

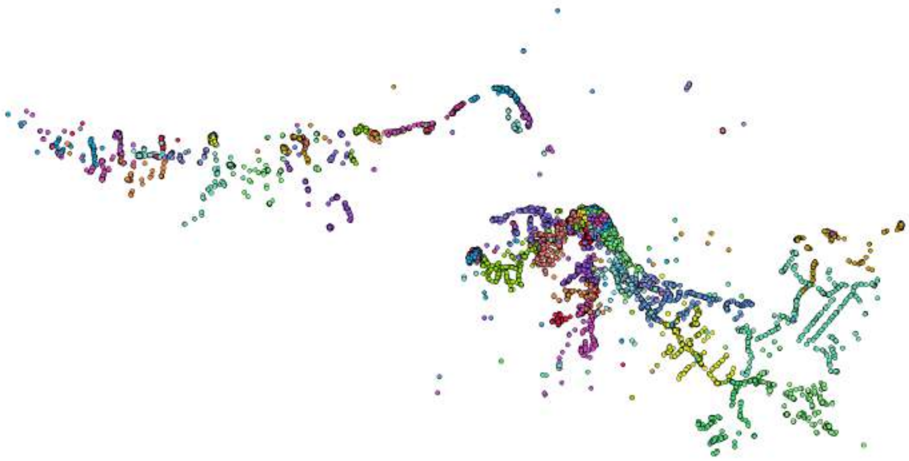

Figure 4. Instance before grouping. Source: authors

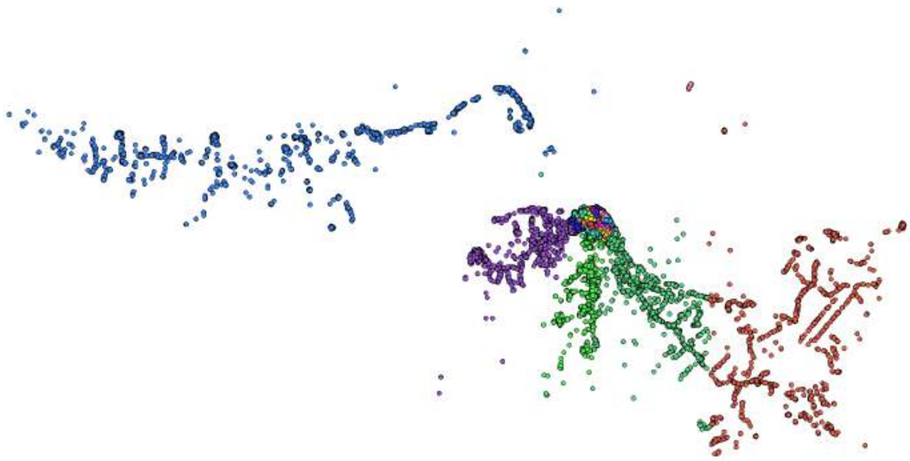

Figure 5. Instance after SA. Source: authors

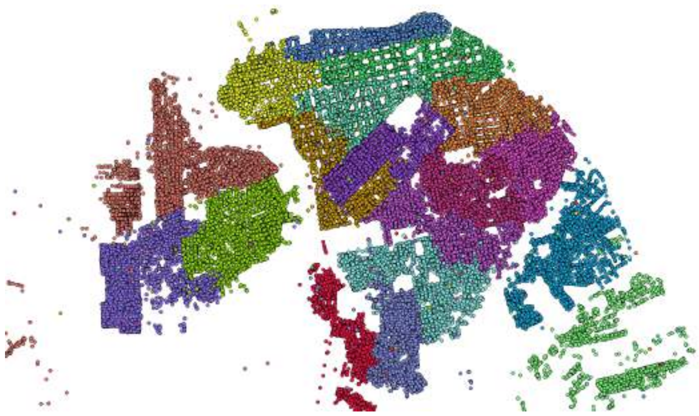

Figure 6. Center of the instance before grouping. Source: authors

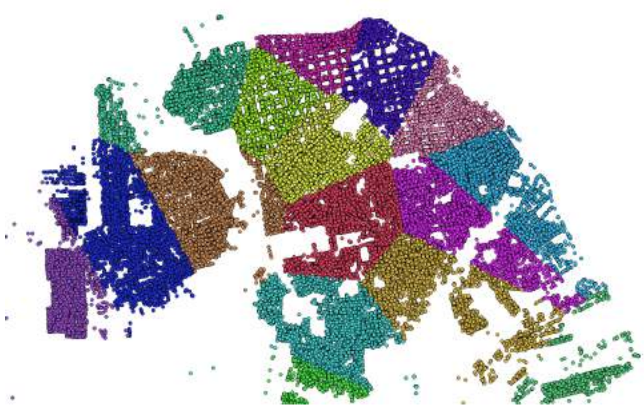

Figure 7. Center of the instance after SA. Source: authors

6. REFERENCES

ANEEL, Normative Resolution, 2010. "414/2010". `www.aneel.gov.br/cedoc/bren2010414.pdf`.

Costa, P.B., da Silva, I.F.S., Vieira, P.H.C., Santos, R.D.A., Silva, M.G., Lima, C.S.C., Júnior, D.L.G., Garros, E.M., da Silva, I.F.S. and Pinheiro, L.P.A., 2018. "Rcmeans: A recursive capacitated means for districting problem". *Journal on Advances in Theoretical and Applied Informatics*, Vol. 4, No. 1, pp. 28–35.

de Assis, L.S., França, P.M. and Usberti, F.L., 2010. "Reagrupamento capacitado multicritério: Problema de redistritamento de lotes de faturamento". *XLII Simpósio Brasileiro de Pesquisa Operacional*, pp. 219–230.

De Assis, L.S., Franca, P.M. and Usberti, F.L., 2014. "A redistricting problem applied to meter reading in power distribution networks". *Computers & Operations Research*, Vol. 41, pp. 65–75.

França, P.M., Garcia, V.J., Morelato, A. and Usberti, F.L., 2007. "Enfoque multicritério para o problema de redistritamento capacitado". *XXXIX Simpósio Brasileiro de Pesquisa Operacional-SBPO*, pp. 1–12.

Guerine, M., Stockinger, M.B., Rosseti, I. and Plastino, A., 2017. "Heurística híbrida com mineração de dados para o problema de agrupamento capacitado com centro geométrico".

Joshi, D., Soh, L.K. and Samal, A., 2011. "Redistricting using constrained polygonal clustering". *IEEE Transactions on Knowledge and Data Engineering*, Vol. 24, No. 11, pp. 2065–2079.

Van Laarhoven, P.J. and Aarts, E.H., 1987. "Simulated annealing". In *Simulated annealing: Theory and applications*, Springer, pp. 7–15.

7. ACKNOWLEDGEMENTS AND RESPONSIBILITY NOTICE

The authors thank the group Equatorial Energia, in partnership with the Applied Computing Center of the Federal University of Maranhão (NCA-UFMA), for the financial support and data supply that were of vital importance for this work.

The authors are the only responsible for the printed material included in this paper.