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Location problem method applied to sugar and ethanol mills location optimization

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ABSTRACT

Brazil is the world's largest producer of sugarcane and has a great potential for sugar and ethanol production. Sao Paulo is its main producer state and produced more than 367,450 million tons of sugarcane in 2012/2013 harvest season. In this study, operations research techniques are applied to obtain optimum locations for establishing new and/or to expand sugar and ethanol mills in the state of Sao Paulo. Data were obtained from the CANASAT project, which annually maps the sugarcane cultivated areas in Sao Paulo, using remote sensing and geospatial processing techniques. Since sugarcane is processed at mills near the cane fields, it has been used data from 2012/2013 harvest season to identify the largest cultivation areas in the state. The *p*-median problem was formulated as a binary linear programming problem and two methods were applied for approaching the solutions: MATLAB© optimization package (standard branch-and-bound) and a heuristic greedy algorithm. As a result, one noticed that the difference between the two methods ranges from 1.6% to 12% in the distance sum. Regarding to CPU time, MATLAB© standard branch-and-bound is 157 times slower in the best case and up to 43,446 times in the worst. It were also compared two different approaches for computing the distance among the predefined locations, Euclidean straight-line and shortest-path drive distances. When shortest-path drive distance is used rather than the Euclidean distance, facilities locations change. However, by the Pearson's correlation coefficient (r=0.99036; R^2=0.98075), it was found that the drive distance is strongly correlated to the Euclidean distance and the dispersion is homogeneous for short distances. This result indicates that for studies on mills optimum location, one could rely on Euclidean distances since mills must be located near the cane fields.

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1. Introduction

The great potential for ethanol production in Brazil comes from its highlighted sugarcane culture, mainly in its Center-South region where the state of Sao Paulo is located. Also a consistent highway network, complemented by rail and river transport, enables an easy distribution of the production. These factors can be associated to obtain a better cost-benefit relationship related to installation of sugar and ethanol mills for ethanol production. Thus, studies focused on network location-allocation problems for facilities and customers location-allocation around cultivated areas, considering the particular characteristics of the sugarcane crops fields and industry, is proving very useful, given its direct impact on return on investment, as the price of the final product [1].

These studies are also important because some facilities were installed based on Government subsidies. When the Brazilian Government withdrew such subsidies those facilities faced serious problems. Despite an optimistic forecast of 3% growth in the supply of raw material in the Center-South region, it is estimated that others 12 plants cease activities in the 2015/2016 harvest season [2]. From 2008 to 2014, thereabout 80 mills closed activities [3].

Sao Paulo state (SP), the top producing, had produced more than 367,450 million tons of sugarcane in 2012/2013 harvest season [1]. The state typically contributes with about half of the Brazilian production (653,519 million tons) [1].

In 2015 the number of sugar and ethanol mills installed in the country was 409 of which 383 were authorized by the ANP (National Agency of Petroleum, Natural Gas and Biofuels) to produce ethanol with 366 in ethanol's production activity. Sao Paulo has 157 mills in operation from a total of 176 installed [4].

By associating the launch of flex-fuel technology with the world's growing concern to CO_2 levels in the atmosphere, it is possible to see a highly favorable scenario for increasing ethanol consumption. To meet this growing fuel demand for both national and international markets, new areas for sugarcane cultivation are necessary. However, the increases in cultivated areas are not sufficient to meet the growing demand, and it is necessary to expand or install new ethanol plants.

The creation of plants in areas with good flow of inputs and transfer of products to the consumer market reduces the cost of production therefore becomes the value of the more competitive end product, thus increasing their consumption before their supply, even with increasing it.

There has been considerable interest in the development of procedures for solving specific network location-allocation models, such as the *p*-median problem. Commonly used procedure includes linear programming with branch-and-bound, special relaxation techniques based on the application of Lagrange multipliers and heuristics, meta-heuristics, genetic algorithms, among others.

Since several network location-allocation models have been formulated within the context of integer-linear programming problems, general purpose linear programming packages have been used. Thus, after a relaxed linear program is solved, the branch-and-bound routines can be used to resolve any fractional variables.

Here, it is considered the network location-allocation *p*-median problem of establishing *p* facilities at some of *n* predefined points. In the *p*-median problem, the objective is to minimize the distance sum from each point to the nearest facility. This is a well-known problem in the field of discrete location problems, being *NP*-hard for general *p*, even when the network has a simple structure [5,6].

Integer linear programming has remained a standard technique to solve network location problems of moderate size. As the problem size increases, approaching the solution with linear programming becomes unpractical. For larger problems, specialized Lagrangean procedures such as Lagrangean relaxation with subgradient optimization have proven to be robust. Lagrangean relaxation is a well-known procedure to approach combinatorial optimization problems. For a review of Lagrangean relaxation techniques and applications, see [7].

Heuristic methods have been a popular choice of solution methods for the facility location [8–15], and the *p*-median problem [16–22,6]. They range from simple greedy algorithms to genetic algorithms. For a review of heuristic methods, see [23–26].

Although many heuristic algorithms for *p*-median problems have been proposed, the computational cost can still be high for larger problems. Thus, computationally efficient parallel CPU and GPU-based implementations have also been reported [27,28].

Also specific applications of these techniques to energy systems are available.

Optimal locations for polygeneration systems with simultaneous production of electricity, district heating, ethanol and biogas in Sweden were presented by [29] with the aim to reduce the total production cost and the environmental impact, where a detailed process model was used to generate input data for an optimization model and optimal geographic locations for polygeneration plants in Sweden were found using a mixed integer linear programming model [30].

In [31], the cellulosic ethanol infrastructure investment was modeled using a mixed integer program that locates ethanol refineries and connects these refineries to the biomass supplies and ethanol demands in a way that minimizes the total cost.

In [32], the location problem of micro hydropower plants was studied and a methodology was proposed to this analysis.

The investment activity of ethanol plants at the county level for the contiguous 48 United States from 2000–2007 was analyzed by [33], using bivariate probit regression and spatial clustering methods as basis.

In [34], the location problem of solid biomass power plants in an agricultural region was studied. In [35], geographical information systems (GIS) were associated to multi-criteria decision making methods, proposing a solution for solar farms location problem.

In [36], a model to reduce costs and to maximize revenue was developed, where mixed-integer linear programming appears to be the prevailing optimization framework [12] and involves multiple decision variables, such as the capacity, facility location, technology selection, number of facilities, biomass type and other logistical variables (transport, biomass flow, biofuel flow, warehousing, etc.) [37,38].

In [39], location problem of wind power generation-transmission systems was studied with application of hierarchical fuzzy DEA. In [40], linear regression theory was applied to wind energy systems placed at the Brazilian state of Ceara. In [41], an optimization algorithms review was done for wind energy systems. In [42], heuristic algorithms were used to optimize electrical power systems. In [43,44], optimal location problem of renewable energy facilities was reviewed and several criteria to make decision had been considered.