XXV IJCIEOM 2019

International Joint Conference on Industrial Engineering and Operations Management- ABEPRO-ADINGOR-IISE-AIM-ASEM (IJCIEOM 2019). Novi Sad, Serbia, July 15-17th

A Decision Support Model for Assisting Smallholder Farmers on Bidding to Supply to Institutional Markets

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Abstract: In Brazil, institutional markets emerged as an opportunity for family farmers to distribute their produce and secure and income. However, the lengthy bureaucratic process and relatively high cost associated to the bidding process for such markets determine the challenge faced by family farmers to decide which public calls to subscribe to in order to distribute their products to schools and public institutions through governmental programs as PAA and PNAE. This research proposes a Decision Support System (DSS) based on a mathematical model to help the farmers in the bid/no-bid decision. Based on the individual profitability of the products and the geographical area value concentration criterion, the DSS suggests to the farmers which bids to attend in order to obtain the expected highest profit if the bids are secured.

Keywords: institutional markets; public bidding; family farmers; decision support system; mixed integer linear programming.

1 Introduction

The Family Agriculture (FA) in Brazil was highlighted in the mid-1990s with the extension of the use of the term as a category of social movements in the countryside, led mainly by the rural union National Confederation of Smallholders Agricultural Workers (CONTAG). Another factor that consolidated FA was the creation of the National Program for Strengthening Family Farming (Pronaf) in 1996, legitimizing socio-politically family farming (SCHNEIDER, 2003). The family farmer is defined according to Brazilian Law 11.326 (2006) as the one who practices activities in rural areas, and who does not have a title of an area greater than 4 (four) fiscal modules, use family labor in the predominant economic activities and has a minimal percentage family income from agricultural activities.

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Despite the mentioned incentives, the family farmer suffers from many restrictions and difficulties in the development of his activities and insertion of his products in the market through the National School Feeding Program (PNAE). These difficulties are evidenced by Soares et al (2015) in their study, pointing out as the main difficulties the climatic interference in the production; maintenance and regularity of delivery for lack of equipment to carry out the planting or harvest, or adequate transportation to take the food to school; difficulty in meeting regulatory requirements for the marketing of processed foods; obtain certification of organic products; requirement of products that don't follow the seasonality of production. In addition, Reis (2016) complements quality assurance, bureaucratic access issues, selection of calls and products according to prices and logistical difficulties.

In the management of operations, to cope with, among others, logistical difficulties, Operational Research (OR) tools are used. This is an area of knowledge that has the characteristic of bringing tools to assist in decision making through linear, nonlinear programming, heuristics, always seeking the optimization of what is studied. The literature presents some applications of OR in agriculture through the use of linear programming in the optimization of the productive process as presented by Fonseca (2018), which seeks to define the maximum revenue in the commercialization of vegetables from a rural producer in Mato Grosso do Sul. Doriguel (2016) also highlights the development of a mathematical model of linear programming with computational assistance, to support a farmer from a small family farm in decision-making, seeking to better distribute the crop and maximize profitability.

Considering the examples of the contributions made by the operational research and the various difficulties pointed out by the family farmers regarding the participation of the National School Feeding Program, this study aims at the creation of a mathematical model of linear programming to promote the decision support of small farmers. Being that the model consists of making the decision of which call is feasible for the participation of the farmer and which foods are more profitable. This study is justified by the intention of helping and improving the decision-making of family farmers, who face many difficulties such as those mentioned, in addition to the absence of financial support, absence of schooling, the large number of calls, the short term of the calls, they only rely on experience and luck in choosing the calls.

2 Bibliography revision

2.1 PNAE and the Family Agriculture

The National School Feeding Program (PNAE) aims to ensure the right to school feeding, in order to meet at least partially the nutritional needs of students in the public network and contribute to an improvement in school performance, learning and training of healthy eating habits (MELÃO, 2012). In 2009, the family farmers were included in the program, based on Law No. 11,947 / 2009, in which at least 30% of the transfer from the National Development and Education Fund (FNDE) directed to purchase food for schools have to be used for buy the food produced by family farming (ROSSETTI; WINNIE; SILVA, 2016).

The purchase of food is realized through public calls, where the FA sends their proposals for items to be supplied and their respective prices, together with all required documentation, as specified in Resolution No. 26 June 2013 (RIOS; BARBOSA; SEVERINO, 2018). After the proposals are submitted, they are analyzed in public sessions and selected according to the criteria established in the same resolution, giving priority to local suppliers, agrarian reform settlements, indigenous traditional communities and quilombola communities (BRAZIL, 2013).

Access to the calls for proposals is a complication for family farmers, when they have access to the calls for papers, the bureaucracy for sending documents is the complication, the frequency of delivery, and the logistical costs are also aggravating for the FA when deciding whether to participate in the PNAE (REIS, 2016). Marques et al. (2014) corroborates that transportation costs, due to the quantities consumed and the weekly delivery frequency, are very high, making the program unprofitable, although attractive. In a study of the literature on PNAE and family farming, Rios, Barbosa and Severino (2018) conclude that AF's main difficulties are the reach of the markets, the bureaucracy of the calls for tenders, a lack of adequate transportation, low prices, lack shared planning, communication and partnership between managers responsible for food purchases and farmers.

2.1 Operational Research and the Family Agriculture

Operational research (OR) is an area of knowledge focused on the "development of scientific methods to analyze complex systems, in order to predict and compare alternative strategies or decisions" (ARENALES et al, 2015). The OR can support decision making in a variety of ways, including mathematical modeling. This modeling portrays social phenomena, problems that require a decision, and involves three fundamental aspects: the definition of decisions to be made, the constraints that limit this decision to acceptable values and objectives that determine preferences in the choice of decisions (ARENALES et al, 2015).
The application of operational research and mathematical models in agriculture is not something new in the literature. A literature review developed by Fuchigami et al (2018) presents a survey of fifteen articles between the years 1991 to 2017 that deal with the subject of food supply chain agricultural practices that apply PO techniques in order to minimize transport costs, production, time to maximize profit and quality. Fuchs (2017) corroborates the results of the mentioned paper, through the elaboration of a mathematical model with the purpose of maximizing profit and improving the utilization of the available resources in the commercialization of agricultural products apple, papaya and banana.
The mathematical models to be worked can be of the linear programming (LP) type, in which "it is a tool used to obtain optimal results through the resolution of problems that contain a restricted object" (CARNEIRO et al, 2017). Ruberto et al (2013) applied this tool to assist in the process of cost management of rural properties, raising all the costs incurred in the production processes, contribution margins of each product, profitability and through LP, can optimize its production.
The application of OR in agriculture is evident, and can be applied in several problems, optimization of production space, product mix, logistics, supply chain, cost management. In specific family agriculture, the application of OR was not found in scientific studies, within the limitations of the data collection to elaborate this work. In view of the lack of knowledge about the work done by this group of farmers, and the difficulties pointed out by them in the participation of the PNAE, it is proposed to develop a mathematical model of linear programming, in order to select which calls are more advantageous and which products of each call is feasible.

3 Methodology

The methodology used is a quantitative research applied who proposing the elaboration of a generic mixed integer linear programming model, which was thought and proposed from the observation of the needs and difficulties of family farmers, in interviews and field research carried out in the rural settlement of Canudos, located in the municipalities of Campestre de Goiás, Palmeiras de Goiás and Guapó, in the Goiás state, Brazil. The linear programming model was selected because it is a mathematical technique that aims to optimize solutions to problems that may have their models represented in their objective function by linear expressions (NOSSA; CHAGAS, 1997). The proposed model is classified as a mixed integer because the variables have discrete values, that is, they assume integer values, and some of their variables are subject to the integrality condition (ALVES; DELGADO, 1997).
One of the methodological procedures used was the field research developed in the Canudos rural settlement. The main difficulties faced by the farmers in participating in the PNAE were raised, and also the factors that directly influenced these difficulties. Once the survey was carried out, it was proposed as variables of decision of the model, the selection of published calls and which products of the selected

calls should be proposed by farmers, based on the list of products produced by them. The restrictions are related to the price of the products of the bidding documents, quantities of products requested, production costs, bureaucracy and transportation, distance between the settlement and the places of delivery, capacity of vehicle weight and volume, capacity, among others that will be described in presentation of the model.
In order to optimize the program, a cluster analysis was used as strategy, which seeks to divide the elements of a sample into groups, so that elements of the same group have characteristics that are common to each other and the same characteristics that are different from the other group's (NETO et al, 2008). The characteristic takes into account for the formation of the clusters in the model were the distance between the cities and the settlement, together with the route to be carried out. Figure 1 exemplifies the cluster:

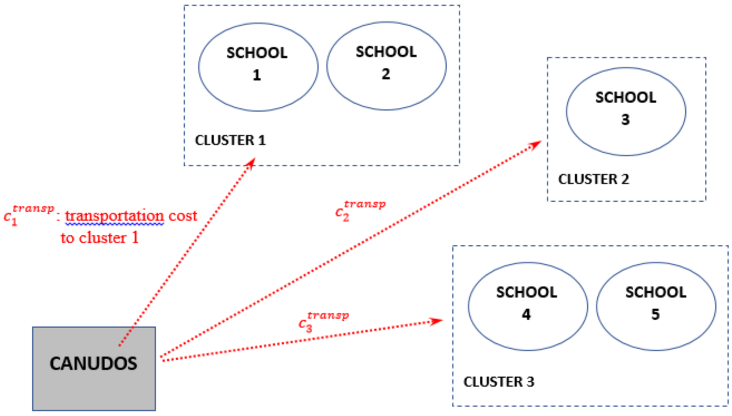

Fig. 1 Example of cluster for the model

Another methodological procedure used is the documentary research, carried out through the collection of data from the PNAE's calls on the municipalities' websites, the website of the State Secretariat of Education, Federal Official Gazettes, laws and resolutions related to the topic. To validate the model, the edicts for the second half of 2018 were selected from the cities of Aparecida de Goiânia, Guapó, Indiara, Nova Veneza, Palmeiras de Goiás and Pirenópolis. Being the cities of Aparecida de Goiânia and Pirenópolis with municipal announcements with a requested volume of products, more attractive prices, but more distant from the settlement. In addition, the other cities were selected state schools, being a total of 6 schools, 3 of them, located in the city of Guapó, forming a cluster.
The elaborated model was written and implemented in the syntax of the Julia/JuMP modelling language using the environment JuliaPro 1.0.2.1. It was solved with the branch-and-cut algorithm included in the IBM-CPLEX 12.8.0. All the computational experimentation was conducted on a Pentium Intel Core i7 with 1.99GHz processor, 16.0GB RAM and Windows Operation System.

4 Results

4.1 Problem Description

The Secretary of State for Education and the Municipalities publish the public calls on their respective websites and from this publication, family farmers learn about which schools, products, quantities, prices and delivery deadlines, and send documentation to plead the supply of food to schools through the PNAE

program. Once the call information is identified, farmers should select which calls to attend and which products to provide.
However, because they do not have the knowledge about the economic feasibility of participating in a particular call, which products would be more profitable, if the production capacity is sufficient to handle the selected calls and the short term for sending documentation and proposal, farmers participate in a smaller number of calls, in some cases cannot meet the demand or have damages with the supply of the products.
In order to assist family farmers, the mathematical model of linear programming was developed in order to optimize the decision making of these farmers of which calls to participate and which products to provide.

4.2 Mathematic Model

4.2.1 Parameters

m: number of calls
k: index of calls and/or schools ($k = 1, \dots, m$)
n: number of products (types)
i: index of products ($i = 1, \dots, n$)
r: index of clusters ($r = 1, \dots, nclus$)
$cluster_{kr}$: cluster *r* holding school *k* (binary)
q_{ik}: quantity of products *i* of call *k* (in kg)
v_{ik}: volume of products *i* of call *k* (number of crates) – calculated in pre-processing
p_{ik}: price of product *i* of call *k*
c_i^{prod}: production cost per unit of product *i*
c_r^{bur}: bureaucracy cost per cluster *r*
$dist_r$: distance (in km) from Canudos to cluster *r*
c^{km}: transportation cost per km
CV_{avg}^{weight}: average capacity of the vehicles in weight (kg)
CV_{avg}^{volume}: average capacity of the vehicles in volume (number of crates)
$ntrip_r$: number of trips to cluster *r*
nweeks: total number of weeks of the semester
Cpb_i: capability of product *i* (binary, 1 if product *i* can be produced and 0 otherwise)
$maxcalls$: maximum number of calls to attend
M: a number very large
f_k: penalty of call *k* (binary, 1 if call *k* is forbidden and 0 otherwise)

2.2.2 Decision variables

$x_k = 1$ if call *k* is to be applied and 0 otherwise
$y_{ikr} = 1$ if product *i* of call *k* in the cluster *r* is proposed and 0 otherwise

2.2.3 Model

$$Max\ \sum_{i=1}^{n}\sum_{k=1}^{m}\sum_{r=1}^{nclus}(p_{ik}-c_i^{prod})q_{ik}y_{ikr}-\sum_{k=1}^{m}\sum_{r=1}^{nclus}c_r^{bur}\ cluster_{kr}\,x_k-\sum_{r=1}^{nclus}2dist_r ntrip_r c^{km} \quad (1.1)$$

Subject to

$$y_{ikr}\le Cpb_i, \qquad i=1,\dots,n,\ k=1,\dots,m,\ r=1,\dots,nclus \qquad (1.2)$$

Capability of products

$$\sum_{k=1}^{m}x_k\le maxcalls, \qquad (1.3)$$

Max number of calls to attend

$$\sum_{i=1}^{n}\sum_{r=1}^{nclus}y_{ikr}\le M.x_k, \qquad k=1,\dots,m, \qquad (1.4)$$

Linkage products-calls

$$\sum_{r=1}^{nclus}y_{ikr}\le M.q_{ik}, \qquad i=1,\dots,n,\ k=1,\dots,m, \qquad (1.5)$$

Consistency with the quantity of products

$$x_k\le 1-f_k, \qquad k=1,\dots,m, \qquad (1.6)$$

Forbidden calls

$$\sum_{i=1}^{n}y_{ikr}\le M.cluster_{kr}, \quad k=1,\dots,m,\ r=1,\dots,nclus \qquad (1.7)$$

Linkage cluster-calls

$$ntrips_r\ge\frac{\sum_{i=1}^{n}\sum_{k=1}^{m}q_{ik}y_{ikr}}{cv_{avg}^{weight}}, \qquad r=1,\dots,nclus \qquad (1.8)$$

Number of trips related to weight

$$ntrips_r\ge\frac{\sum_{i=1}^{n}\sum_{k=1}^{m}v_{ik}y_{ikr}}{cv_{avg}^{volume}}, \qquad r=1,\dots,nclus \qquad (1.9)$$

Number of trips related to volume

$ntrips_r \geq nweeks, \qquad r=1, ..., nclus \qquad (1.10)$

Number of trips related to weeks

The number of trips to each cluster will be at least the number of weeks of the semester (average of a trip a week), except if the total weight of the products to be delivered divided by the average capacity of the vehicles (in weight – kg) demands a greater number of trips in a week. The same for the total volume of the products divided by the average capacity in volume (number of crates).

$x_k, y_{ikr} \in \{0,1\}, i = 1, ..., n, k = 1, ..., m, r=1, ..., nclus. \qquad (1.11)$

4.3 Application Results

The elaboration of the model was carried out, but it is also important that its functionality and consistency in the results generated are validated. For this purpose, data were collected from the Canudos settlement, eight calls were selected from the cities of Aparecida de Goiânia, Guapó, Indiara, Nova Veneza, Palmeiras de Goiás and Pirenópolis, with three calls from the city of Guapó. In addition, selected five foods among those proposed in these calls, are: lettuce, garlic, pineapple, banana silver and mandioca flour. From the data selected and collected to fill the information of each proposed variable, the model was applied.
After execution, a profit of R$ 35,387.71 was obtained as an optimal solution, with the participation of farmers in the 8 calls. However, not all products were selected in the calls. The five products were selected only in calls 4 and 7 that represent the Colégio Estadual de Indiara, in the city of Indiara and the Colégio Estadual Professora Lindosia, in the city of Guapó. From the calls 1, 2, cities of Pirenópolis and Aparecida de Goiânia respectively, we selected 4 products, banana, garlic, cassava flour and pineapple. Call 3, from the Escola Estadual Francisco Alves, city of Nova Veneza, the products chosen were banana, lettuce and pineapple. In the call, 5, the banana and pineapple products were selected and lastly in the 6 call, only one product was selected, the garlic. Both calls, 5 and 6, are from the city of Guapó, the Colégio Estadual Barão do Rio Branco and the Colégio Estadual José de Assis respectively.
From the verification of the consistency of the obtained results, the model was validated and considered fit for new simulations in different scenarios, so that it continues generating the optimal solution. It should be noted that for the various situations, costs, prices, capacity and other variables undergo changes and must be carefully evaluated. It needs to verify if there is no particularity that can interfere directly in the solution of the model too, making it unfeasible or should be adapted.

5 Conclusion

The development of this study allowed some of the difficulties of family farmers to be attenuated. So, with the use of the linear programming model it optimizes the time of selection of edicts, and products, being able to dedicate itself to its final activity, which is the agricultural crop. In addition, the model also allows the farmer to have an idea of the possible benefit that can be obtained if it is selected in all the calls and with all the products that propose.
In addition, farmers are prevented from having losses by providing food to schools, enabling an improvement in the living conditions of this social group, increasing farmers' participation in the PNAE, and possibly reaching the 30% that should be directed to FA and perhaps until this percentage will be increased. On the other hand, the mathematical model is restricted to some variables and does not solve all FA problems. In this way, there are other work fronts in the search to try solutions other difficulties.

For example, creation of a system of certification of processed products that helps them in supplying these products in the program these matters, revision of the calls to meet the seasonality of the products. The main contribution of this study is the creation of a generic model that allows the small farmer to make more cost-effective decisions regarding his participation in the PNAE.

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