Applied Mathematical Modelling 39 (2015) 5540–5558

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

# Addressing uncertainty in sugarcane harvest planning through a revised multi-choice goal programming model

Aneirson Francisco da Silva *, Fernando Augusto Silva Marins, Erica Ximenes Dias

*Sao Paulo State University, Department of Production, Brazil*

ARTICLE INFO

*Article history:*
Received 26 August 2013
Received in revised form 22 December 2014
Accepted 5 January 2015
Available online 21 January 2015

*Keywords:*
Goal programming
Uncertainty
Scenario
Optimization
Sugarcane

ABSTRACT

In this paper a new revised multi-choice goal programming (RMCGP-LHS) model is proposed to deal with uncertainty in sugar cane harvest scheduling for sugar and ethanol milling companies. The RMCGP-LHS model uses a weekly decision-making horizon and takes into account the time and condition of land management, cane cutting decisions, and agricultural logistics. Its objective is to obtain information in order to harvest sugar cane plots in the period closest to the highest saccharose levels, while also minimizing agro-industrial costs. The RMCGP-LHS model was applied to a real case sugar and ethanol mill, and its optimization has provided harvesting policies that were validated by the company's managers. Besides that the RMCGP-LHS model is a very practical tool for simulating in a fast way different scenarios involving uncertainties on model parameters and helping the managers in decision making process in real time.



## 1. Introduction

In Brazil, the total sugarcane production in 2013 reached a national record of 652.02 million tons with an increase of 10.70% compared to results in 2012, however, the total sugarcane production in 2014 decreased 2.5%, according to the Brazilian National Supply Company (Conab) [1].

Since then, much research has been carried out with the aiming of improving the sector's operational and financial performance [2]. Colin [3] points out that Brazil has the largest fleet of vehicles running on ethanol in the world. In Brazil, the total production of ethanol during the season 2014/15 is estimated in 28.66 billion in liters, 2.53% increase with respect to season 2013/14 [1]. In fact, sugar and ethanol generation are important for global economics, particularly for Brazil, where the sector represents a relevant portion of the gross domestic product (GDP).

Paiva and Morabito [4] highlighted some important particularities of the sugarcane-based energy sector:

- Seasonal demand;
- Relatively high cost of raw material, accounting for 60% of the product's final cost;
- Lack of an adequate harvest-planning model, which takes into account the expenses of each plot on each farm, harvest strategies, the logistical transportation fleet, the maturation curve, and the perishability of the raw material after harvesting.

* Corresponding author.
*E-mail address:* aneirson@yahoo.com.br (A.F. da Silva).

http://dx.doi.org/10.1016/j.apm.2015.01.007

The same authors state that it is important to properly define the specific moment at which to harvest each sugarcane plot, given the necessity of obtaining raw material with the greatest level of total reducing sugars (TRS) and a high level of purity. TRS are parameters of the sugarcane payment system. Further, the difference between the TRS and the losses incurred during the cane washing, to the filter cake or the presses, and to the final bagasse is considered the standard of average efficiency in these processes.

Thus, one important aspect in terms of agricultural stage is the sugarcane maturation curve, a graphical representation of the sugarcane's lifecycle, illustrated in Fig. 1. The curve is commonly found as a function of the polarity (POL) and the time to cutting, usually able to be divided into two phases:

- The first phase of vegetative growth in which the plant accumulates energy in the form of saccharose, thus increasing the POL value;
- In the following phase, the plant utilizes the energy accumulated in the previous period for the reproduction of the species, and a decrease in the POL value occurs.

Although the best harvest period is when the POL is at its maximum, it is unfeasible to harvest all canes at peak POL, given that this would generate an inefficient zigzag of machines along the cutting plots as individual plants matured, thus creating increased harvest costs. Therefore, sugarcane harvesting usually occurs in a period close to maximum POL, but not exactly pinpointed on this date [5].

The POL curve can be estimated using a second-order polynomial equation, considering time (in weeks) and POL (% of sugarcane) as variables. With this curve, by means of agricultural samples, one can determine when the optimum TRS are going to occur.

In order to better characterize in which period the sugarcane can be processed, Brazilian mills created the industry life cycle (ILC) standard, which establishes sugarcane POL of 13% as being satisfactory for the processing of different varieties. As the payment is determined per saccharose content (PSC), the POL should be converted from the percentage of sugarcane juice into POL in metric tons, according to the CONSECANA Manual (www.unica.com.br).

The milling company that is the object of this study, is a sugar and ethanol producer situated in the southeast of Brazil. It is able to produce many types of products such as very high POL (VHP) sugar, very very high POL (VVHP) sugar, crystal sugar, two types of ethanol fuel, and some sub-products such as filter mud, bagasse, vinasse, and fuel oil.

The milling company owns more than 200 farms; however, for the application of the model hereby proposed, only 16 out of the 200 farms were considered, as this was the data for this study made available by the company. On each of the 16 farms, there are, on average, 34 sugarcane plots, including 12 different varieties of sugarcane.

About 115 varieties of sugarcane are available in Brazil with different productivity features (TRS), which enables their maturation to be classified as early, intermediate, and late. Therefore, sugar mills can choose among the varieties available with a view to perform their cuts at the most suitable time, thus increasing TRS and production [6].

Observe that, in a typical harvesting season, the milling company crushes 3.5 million tons of sugarcane, of which, on average, 1.4 million tons of cane are acquired from partner farmers that do not belong to the company.

The case study involving the milling company is aimed at checking whether the proposed model could improve the corresponding sugarcane harvest, having been conducted using data from the 2012/2013 harvesting seasons. In fact, for reasons of confidentiality, we worked with proportional values associated with real data from the milling company.

According to Paiva and Morabito [4], agro-industrial costs account for 60% of a plant's total cost; therefore, good planning involving the choice of the sugarcane source (from within the company or partner farms acting as third parties), the plot to cut, the cutting technique (mechanized or manual), and the transport mode (own, third-party) is essential.

The main contribution of this study is to extend a revised multi-choice goal programming model [7] to treat uncertainties of left-hand side coefficients (RMCGP-LHS), which encompasses coefficients of uncertainty on the LHS in the restrictions to aid in decision-making processes for sugarcane harvest planning to produce sugar and ethanol. This uncertainty affects the plant's industrial efficiency, as the choice to cut sugarcane in plots with low TRS could impair the yield of alcohol and sugar production and increase agro-industrial costs.

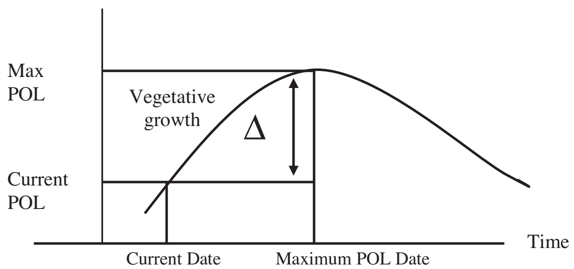


**Fig. 1.** Illustration of the maturation curve.