Energy Economics 45 (2014) 196–204

Contents lists available at ScienceDirect

Energy Economics

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

A Fuzzy Goal Programming model for solving aggregate production-planning problems under uncertainty: A case study in a Brazilian sugar mill

Aneirson Francisco da Silva *, Fernando Augusto Silva Marins

Sao Paulo State University, Department of Production, Brazil

ARTICLE INFO

Article history:
Received 11 February 2012
Received in revised form 6 May 2014
Accepted 12 July 2014
Available online 24 July 2014

JEL classification:
C61
C63
C65

Keywords:
Aggregate production planning
Goal Programming
Fuzzy Goal Programming
Sugar and ethanol mills

ABSTRACT

This paper proposes a Fuzzy Goal Programming model (FGP) for a real aggregate production-planning problem. To do so, an application was made in a Brazilian Sugar and Ethanol Milling Company. The FGP Model depicts the comprehensive production process of sugar, ethanol, molasses and derivatives, and considers the uncertainties involved in ethanol and sugar production. Decision-makings, related to the agricultural and logistics phases, were considered on a weekly-basis planning horizon to include the whole harvesting season and the periods between harvests. The research has provided interesting results about decisions in the agricultural stages of cutting, loading and transportation to sugarcane suppliers and, especially, in milling decisions, whose choice of production process includes storage and logistics distribution.

1. Introduction

Brazilian Sugar and Ethanol Milling Companies have recently faced a major organizational change, and industry management is changing due to the international importance of their products, especially ethanol and electricity.

The evolution of the sugarcane plantation in Brazil: an increase in the 2010 harvest compared to the previous year was noted, being the Central-South region responsible for more than 80% of the Brazilian national production (Conab, National Supply Company, 2011).

Unfortunately, few quantitative models and optimization methods can be applied in the planning of industrial tasks of sugar and ethanol milling companies (Paiva and Morabito, 2009).

Moreover, Jamalnia and Soukhakian (2009) pointed that traditional Mathematical Programming techniques are not suitable to solve real-world aggregate production planning problems.

Özcan and Toklu (2009) commented that Goal Programming (GP) is a useful branch of the Multiple Criteria Decision-Making (MCDM), perhaps, the oldest and the most widely used MCDM technique to solve multi-objective problems. Caballero et al. (2009) also commented that GP has been successfully applied in many different areas.

As discussed by Wang and Liang (2004) real-world problems related to aggregate production planning are usually ill-defined, with more than one (and, eventually, conflicting) important objective. Besides, decision-makers are not generally able to specify precise goal values (baselines) to the objectives to be optimized, to the coefficients in the objective functions and to the constraints. The same is occurring with right-hand side coefficients associated with available resource quantities.

In fact, according to Chang (2007), imprecise aspiration levels (goals, baselines) may exist to the enterprise objectives, a typical situation in the sugarcane agro-industry where many uncertainties, such as: commodity markets, raw material quality, and results of production processes are inherent to their planning process. Thus, all these indicate that GP and Fuzzy Logic are very interesting decision tools to be used to solve this kind of problems.

Next, we present a few characteristics of this research that differ from those found in specialized literature on aggregate production-planning under uncertainty:

– Development of a Fuzzy Goal Programming model for the aggregate production problem under uncertainty in a sugar mill company;
– Integration of the agricultural, industrial, and logistics phases into a unique model, to support decision-makings during harvest seasons and periods between harvests.

* Corresponding author at: Sao Paulo State University, Av. Ariberto Pereira da Cunha, 333, CEP 12.516-410 Guaratingueta, SP, Brazil. Tel.: +55 12 3123 2866.
E-mail addresses: aneirson@feg.unesp.br (A.F. da Silva), fmarins@feg.unesp.br (F.A.S. Marins).

http://dx.doi.org/10.1016/j.eneco.2014.07.005
0140-9883/

This paper is organized into Sections. In Section 2 we present the GP and Fuzzy Logic concepts. In Section 3 we present the adopted research method. Section 4 refers to the description of the aggregate production-planning problem and its FGP model. Section 5 summarizes the model optimization, and, finally, the conclusions and suggestions for future researches are in the Section 6, followed by the references.

2. Fuzzy Goal Programming

One of the benefits of using multi-objective optimization models is the possibility of extracting a set of meaningful information related to the analyzed problem, enabling different analysis (Bellman and Zadeh, 1970; Chang, 2007; Deb, 2001). Zimmermann (1978) was the first to solve a Linear Programming problem with several objectives through a fuzzy programming approach that used the concept of the membership function introduced by Zadeh (1965).

The Fuzzy Set (FS) theory, proposed by Zadeh (1965), is based on the extension of the classical definition of set A, where each element x of a given universe X, either belongs to set A or not, whereas in the FS theory an element belongs to set A with a certain "degree of membership".

In classic models of GP, the decision maker has to specify a precise aspiration level (goal) for each of the objectives. In general, especially in large-scale problems, this is a very difficult task, and the use of the Fuzzy Set theory in GP models can overcome such problem, allowing decision makers to work with imprecise aspiration levels (Yaghoobi and Tamiz, 2007). Therefore, an objective with an imprecise aspiration level can be regarded as a fuzzy goal.

There are three most common types of fuzzy goals to work with triangular fuzzy numbers (Jamalnia and Soukhakian, 2009; Yaghoobi and Tamiz, 2007). These types are given by expressions (1)–(3), where the symbol ~ is a fuzzifier that represents the imprecise fashion in which the goals are stated, and g_k is the aspiration level for kth goal:

$$G_k(x) \tilde{\leq} g_k, k = 1, \ldots, m \tag{1}$$

$$G_k(x) \tilde{\geq} g_k, \quad k = m+1, \ldots, n \tag{2}$$

$$G_k(x) \cong g_k, \quad k = n+1, \ldots, l \tag{3}$$

A fuzzy goal can be identified as the fuzzy sets defined over the feasible set with the membership function. The three fuzzy goals above are illustrated from Figs. 1 to 3, where L_k (U_k) is the lower (upper) limit for the kth fuzzy goal $G_k(x)$.

Usually, limits L_k and U_k are either subjectively chosen by decision makers or associated with tolerances in a technical process. The choice

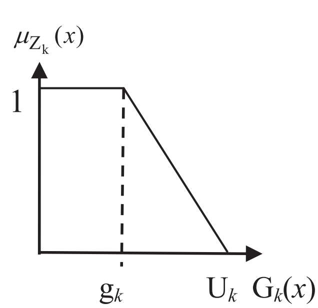

Fig. 1. $G_k(x) \tilde{\leq} g_k$.

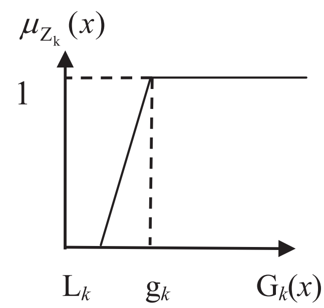

Fig. 2. $G_k(x) \tilde{\geq} g_k$.

of tolerance limits is very important as they directly influence the performance of the model optimization.

Fuzzy goals can be identified as fuzzy sets defined over the feasible set with a membership function. Linear membership functions are the most adopted functions, both in theoretical and in practical works (Jamalnia and Soukhakian, 2009). For the above three types of fuzzy goals here are the following linear membership functions:

$$\mu_{Zk}(x) = \begin{cases} 1 & \text{if } G_k(x) \leq g_k \\ \dfrac{U_k - G_k(x)}{U_k - g_k} & \text{if } g_k \leq G_k(x) \leq U_k \\ 0 & \text{if } G_k(x) \geq U_k \end{cases} ; k = 1, \ldots, m \tag{4}$$

$$\mu_{Zk}(x) = \begin{cases} 1 & \text{if } G_k(x) \geq g_k \\ \dfrac{G_k(x) - L_k}{g_k - L_k} & \text{if } L_k \leq G_k(x) \leq g_k \\ 0 & \text{if } G_k(x) \leq L_k \end{cases} ; k = m+1, \ldots, n \tag{5}$$

$$\mu_{Zk}(x) = \begin{cases} 0 & \text{if } G_k(x) \leq L_k \\ \dfrac{G_k(x) - L_k}{g_k - L_k} & \text{if } L_k \leq G_k(x) \leq g_k \\ \dfrac{U_k - G_k(x)}{U_k - g_k} & \text{if } g_k \leq G_k(x) \leq U_k \\ 0 & \text{if } G_k(x) \geq U_k \end{cases} ; k = n+1, \ldots, l \tag{6}$$

According to Chang (2007), since Narasimhan (1980) has applied the FS set theory with a preference-based membership function to GP, many achievements have been made in areas related to Fuzzy Goal Programming (FGP), including preemptive, weight additive, and stochastic models. As proposed by Yaghoobi and Tamiz (2007), a FGP model based

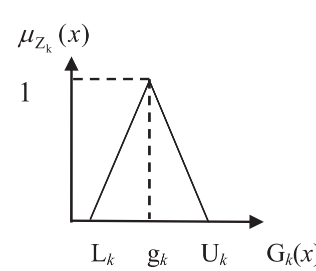

Fig. 3. $G_k(x) \cong g_k$.