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Optimization approaches to support decision making in the production planning of a citrus company: A Brazilian case study

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ABSTRACT

In this study a frozen concentrated orange juice aggregate production planning is modeled using linear programming to support decision making in the production process of a citrus company with multiple products, stages and periods. Then the model is extended to take into account uncertainty in some model parameters using a robust optimization approach. Besides tactical decisions in the production, blending and storage of juices, the nominal and robust models include the orange harvesting plan, which considers orange maturation curves. The models also include the blending process of different types of juices to match product specifications, for example, using orange acidity to calculate the ratio specification. These planning models take into account a large portion of typical supply chains of frozen concentrated orange juice and a case study was developed in a citrus company, which has different facilities and a worldwide distribution system, similar to other companies in this sector. To solve the models, an algebraic modeling language and a state-of-art optimization software of mathematical programming problems were used. The computational results obtained indicate that these optimization approaches can be useful in real situations.

1. Introduction

In the citrus industry, the process of obtaining final goods through raw material available in the market requires a lot of information. The appropriate processing and analysis of such information can help the company to have a competitive degree of difference, which is the excellence in integrated supply chain management. The production, inventory and transport coordination of raw material (different orange varieties from different suppliers), semi-finished goods (frozen concentrated orange juices obtained from the mixture of different orange varieties from different suppliers in different periods, here called as bases of juice) and final goods (frozen concentrated orange juices obtained from the blending of the bases of juice) is particularly important due to the combination of raw material seasonality and the relatively stable demand of the products. Linear programming models to represent such processes can result in powerful tools to the analysis of tactical and operational decisions in the citrus industry, as pointed out, e.g., in Munhoz and Morabito (2001, 2010).

This study presents a deterministic linear optimization model to support decision making over this planning process. The model considers tactical decisions such as: how much, when and how the juices should be produced during the planning time horizon, involving operations from fruit supply until the final goods production to meet the demand. The model results take into account different constraints of the productive processes, so that the total costs are minimized. A typical Brazilian company from the citrus sector, which in the crop 2011/2012 was among the three largest orange processors in the world citrus sector, collaborated to guide this research. According to the company planning manager, the concepts used here can also be applied to other citrus companies. In Neves et al. (2010), the relevance of orange juice in the global economic scenario is highlighted, where Brazil occupies the 1st position in production with 56% of share and the 1st position in exportation with 85% of share.

Then this study extends the deterministic linear programming model to deal with uncertainty in some model parameters using a robust optimization approach, as the aggregate production planning of the company has uncertainty in different parameters. Examples of uncertainty parameters are: the ratio of the juice (a specification of the product calculated by dividing brix by acidity); the yield of the juice measured in quantity of oranges to produce a metric ton of juice; the final goods demand of the customers and the fruit availability from the suppliers along the time horizon, among others. The brix is the soluble solids content of the juice,

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measured using a reflactometer. The acidity is measured via titulation. The ratio of the juice is an important characteristic in this planning process. For more detailed discussions about citrus juice characteristics, the reader is referred to, e.g., Redd et al. (1986), KimBall (1999) and Ringblom (2004).

In citrus companies there is a major effort to accurately forecast the fruit maturation curve, which represents how fruit maturation evolves through a timeline. Usually it is represented by the ratio and soluble solids content of the orange juice. The typical practical approaches are based on statistics methods, as analysis of fruit samples, regression techniques associated with historical data analysis and inputs of experts about general factors that impacts fruit maturation (e.g., climate, soil, orchard maintenance, among others). Such approaches generate different curves representing the orange fruit ratio evolution along the timeline. Due to uncertainty associated to this important information, this work explores the use of a robust linear optimization approach to appropriately handle this problem under uncertain parameters.

In general, deterministic linear programming models assume that the input data is precisely known and equal to some nominal values. Bertsimas and Sim (2004) observed that this classical mathematical programming approach does not take into account the influence of data uncertainties on the quality and feasibility of the model. Incorporating uncertainties to some parameters of the model can lead to a better representation of the real problem. A robust optimization approach is an attractive technical and computational solution, as the resulted model remains as a linear programming problem, but robust. This approach is basically a worst-case technique that addresses the problem of data uncertainty ensuring the feasibility and optimality of the solution for the worst instances of the problem parameters, without assuming a specific probability distribution for the random variables involved (Bertsimas and Sim, 2003; Bertsimas and Thiele, 2006). However, this technique generally leads to over conservative solutions. Bertsimas and Sim (2004) proposed an alternative approach that allows controlling the degree of conservatism of the solution in terms of probabilistic bounds of constraint violation.

To the best of our knowledge, there are only a few studies in the literature presenting optimization approaches for supporting production planning in citrus companies and we are not aware of studies in this line of research, based on deterministic and robust optimization models and methods that help solving real world problems in this sector. For instance, Caixeta Filho (2006) presented mathematical models for the management of orange harvesting. Munhoz and Morabito (2001, 2010) presented linear and goal programming models to support decision making in the production and distribution planning of orange juice. Munhoz and Morabito (2013) presented a preliminary study exploring parameter uncertainty in the citrus industry. Other studies not directly related to frozen concentrated orange juice, but related to the optimization approaches of the present study and applied to other agroindustrial companies can be found in the literature. For example, Kawamura et al. (2006) and Paiva and Morabito (2009) presented linear programming models for the aggregate production and distribution planning of sugar and ethanol milling companies, and Zuo et al. (1991) and Junqueira and Morabito (2012) studied linear programming models to support decision making in the tactical planning of production and distribution of seed corn. Several examples of successful applications in production and logistics planning of agribusiness supply chains can be found in, e.g., Shapiro (1993, 2001), Le Gal et al. (2009), Ahumada and Villalobos (2009), INFORMS (2012) and the references therein. The main contribution of this paper lays in the development of deterministic and robust mathematical programming models for the citrus industry and their practical application to solve tactical production planning problems in this sector.

This paper is organized as follows: Section 2 briefly presents the frozen concentrated orange juice production process and the corresponding aggregate production planning. Section 3 models this tactical planning with multiple products, stages and periods by means of linear programming. Section 4 presents a robust optimization approach based on this linear programming model, assuming uncertainty in the technological coefficients matrix, more precisely in the juice acidity parameters, which are part of the blending constraints of the model. Section 5 analyses the computational results from the deterministic linear programming model and the robust optimization approach under uncertainty in the orange juice acidity, using the modeling language GAMS with the solver CPLEX (Brooke et al., 1992) and data from the case study in Munhoz (2009). The behavior of such approach is analyzed through the results obtained using different protection levels against violation in the blending constraints. Finally, Section 6 presents concluding remarks of this study and some perspectives for future research.

2. The orange juice production process and its aggregate production planning

In this section a brief description of the orange juice production process and its production planning process is presented. The reader can also consult the citrus processing material in, e.g., Kimball (1999) and Ringblom (2004) for more detailed discussions of this topic. After the harvesting in the fields, fruit should be industrially processed as soon as possible because orange deteriorates quickly at the high temperatures found in citrus-growing areas. On the other hand, orange products are produced in a form that allows them to be stored for extended periods and shipped over long distances (Ringblom, 2004). The oranges arrive from the fields to the processing plants by trucks and are discharged into storage silos (Fig. 1). During fruit unloading, a sample is collected to measure its physical–chemical characteristics. Brix, ratio and variety are among the main fruit characteristics. Based on these orange characteristics and in the production plan, fruits are removed from the storage bins by feed belts and elevators and sent to the hygienization and selection areas. In this sector, the oranges are washed and the unsuitable fruit are removed by manual inspection. Selected oranges are then sent to the most suitable extractor to achieve optimum juice quality and yield (Fig. 1). At this stage the oranges are split into three phases: pulpy juice, emulsion of oil and water with particles of peel and rag.

The peel and rag are sent to the feed mill area by screw conveyors and are dried in a rotary dryer and pelletized, generating the citrus pulp pellets, which are then stored in silos and sold to produce animal feed (Kesterson and Braddock, 1976). Back to the extraction sector, there are the emulsion of water and oil with particles of peel that are sent by screw conveyors to the peel oil recovery area. The oil is extracted from the emulsion through centrifugation process using centrifuges and after a dewaxing process, the peel oil is ready for sale, either in 200 l drums or in bulk (Ringblom, 2004). From the extraction sector, there is also the pulpy juice phase that goes to the finishers and centrifuges (Fig. 1) to adjust pulp level and remove defects that can be in the juice, besides adjusting bottom pulp in the desired standard. The pulp removed from the juice in this stage are washed with water to remove juice solids and generates the byproduct pulp wash, which is a juice with lower quality characteristics. The water rich in juice solids is concentrated in a multistage evaporator that combines vacuum (low pressure) and temperature to concentrate the product to the desired specification. Then the product is cooled by exchanging heat devices and stored in cold stores until the time to be sold in drums or in bulk (Fig. 1).