SUPPLY CHAIN PLANNING OPTIMIZATION IN THE FRUIT INDUSTRY

G. Masini,
Dept. of Mechanical Engineering, Engineering Faculty, Universidad Nacional del Comahue
Buenos Aires 14000, (8300) Neuquén, Argentina

N. Petracci and A. Bandoni
Planta Piloto de Ingeniería Química - PLAPIQUI (UNS-CONICET)
Camino La Carrindanga, Km. 7, (8000) Bahía Blanca, Argentina
Fax: +54 291 486 1700
abandoni@plapiqui.edu.ar

Abstract

This paper presents a midterm tactical planning model for the supply chain of a typical large company operating in the High Valley of the Black and Neuquén Rivers area of Argentina. A Mixed Integer Lineal Programming model has been developed, which maximizes the net profit of the company along a one-year time horizon divided in twelve monthly periods. Based on customer orders from three major markets, estimated fruit production, economic information about costs and prices, and yield and availability of processing plants, the model optimally allocates plant operation levels, amount and place where raw material should be obtained and a monthly plan for fruit cold storage and final product delivery. The model has about 14300 continuous variables and 3300 discrete variables. Results are presented for an one year optimal operation of a typical company in the region under study.

Keywords: Supply Chain, Planning, MILP

Introduction

The production of fresh fruit (apples and pears) and concentrated juice is one of the major regional economic activities of Argentina. The High Valley of the Black and Neuquén Rivers (HV for short) of Argentina, located across two states southwest of the country, is the area where the apples and pears are grown. The region has been traditionally one of the world main fresh fruit and concentrated juice producers. During the 90's, companies made important capital investments on new machinery for efficiency improvement. But more recently, due to new worldwide competitors from Asia South West, local economic problems and volatile international markets, companies are compelled to improve even more their competitiveness to keep on business. In this context, they is a strong need for better decision tools to manage the whole supply chain.

In order to tackle this problem, advantages can be taken from the latest developments on formulations of planning and scheduling models for whole supply chains of different industries (Shah, 1998). In this work we present a first attempt to model the apples and pears industry of the HV area of Argentina, by developing a strategic planning model.

HV Fruit Supply Chain Description

There are a few large companies that operate along the complete fruit supply chain, and concentrate the largest part of the business in the HV region. Figure 1 shows a typical sketch of the supply chain of one of these companies. Each one operates one or more packaging and concentrated juice plants, which can be placed at different locations in the HV area. For feeding packaging (variables A and F respectively) and concentrated juice (variables C and G respectively) plants, the companies can obtain raw material from own farms and/or external suppliers. The companies produce several final products consisting in fresh fruit processed and packed in different ways (stream

B), and concentrated fruit juice of 72 degree Brix (stream E).

At a packaging plant (Figure 2), after raw material reception, a decision have to be made whether the fruit is directly sent to cold storage (stream AFC) for later processing or to the processing line (stream AFG). The processing stage implies several steps consisting in washing, manual and automatic classification (by size, color, external aspect, etc.), waxing (if required), and packaging in different ways depending on customer preferences. Another decision that have to be made at this stage is whether the fruit is kept in cold storage (stream K) for later selling (stream B) or processing (stream J).

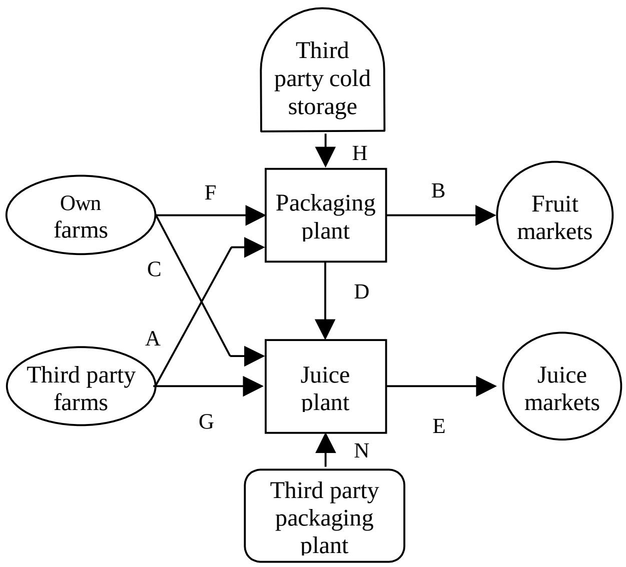

Figure 1. SC of a company in the HV area

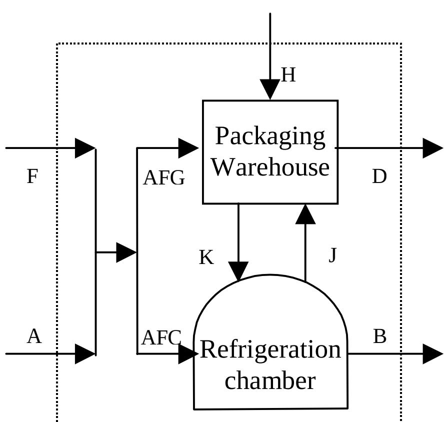

Figure 2. Scheme of a packaging plant

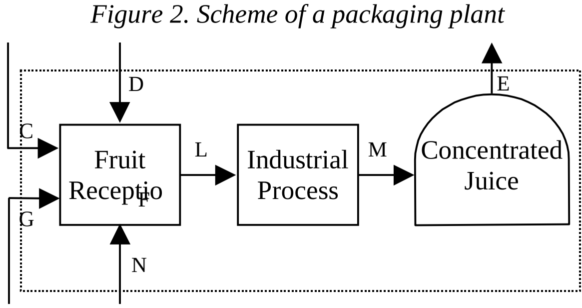

Figure 3. Scheme of a concentrated juice plant

The fruit that do not fulfill quality specifications at the classification stage is transferred (stream D) to juice plants (Figure 3) to produce concentrated juice and aroma (stream E). Each juice plant can also be fed with fruit from own or supplier's farms (streams C and G respectively) or from third party packaging plants (stream N).

Planning Model

The SC model was formulated as a midterm tactical planning problem over an one-year time horizon, which was divided in 12 monthly periods. The time horizon coincides with the business cycle that last from harvest to harvest. During this cycle, many decisions have to be made along the SC to decide from where and how much fresh fruit to acquire for processing. These decisions, which have to be taken for each final product, depend on customer demands, quality and fruit availability at own farms, amount and quality of fruit offered by external suppliers, production cost at own farms, cost of purchased fruit, distances from farms to processing plants, yield of processing at packaging and juice plants, etc. Most of these parameters are also depending on whether the time period considered is or not within the harvest period. Despite the harvest last from January to May, each fruit variety has a different harvest starting date and duration.

Model parameters include cost of each variety of raw material, selling prices of each product in different markets, fruit production for each farm and fruit variety, distances (among farms, processing plants and markets), packaging and juice plant capacities, demands for each product and market, etc.

For the sake of simplicity, in Figure 1 to 3, single blocks are used to represent farms, packaging and processing plants. But the developed model has a size similar to the size of one of the major companies operating in the HV. It includes 16 own farms for fresh fruit production and 4 packaging and 2 concentrated juice plants. There are also 1 external supplier of fresh fruit from farms, 1 of fruit from packaging plants and 1 of fruit from cold storage chambers. A number of 7 fruit varieties (pears: Williams, Beurre D'Anjou, Beurre Bosc, Packams Triumph; apples: Red Delicious, Reds others than Red Delicious and Granny Smith) and 2 juice varieties (pear and apple) has been used in the model. There are 3 different markets for packed fruit: market 1, overseas (mainly USA and Europe); market 2, regional (mainly Brazil); market 3, local (Argentina). For concentrated juice, 2 markets were considered: market 1, overseas (USA and Europe), market 2: regional (Brazil).

Fruit market 1 requires transportation to the ports by refrigerated trucks, and then by ships to the final destination. This market only requires fresh fruit during the harvest period, January to May, depending on the final product. For the regional and local fruit markets refrigerated trucks make the transportation and demands exist along the whole year. In the case of concentrated juice, overseas markets require transportation by trucks and ships, while the regional market only requires trucks, and in both cases the juice demand takes place along the year. There is no concentrated juice demand from the Argentinean market.

One of the most relevant production cost items is the cost of cooling storage of fresh fruit and final products. Depending on the current level of customer demand satisfaction at a given period of the year, the fruit can be cold stored or sent directly to commercialization. Usually the companies have two alternatives for cold storage, normal or controlled atmosphere cold chambers. The decision about which one to use depends on the quality of the fruit and the estimated storage period.

Mathematical Model

The mathematical model of the supply chain was formulated as a Mixed Integer Linear Problem. It consists of the following components:

1. Objective function: maximization of benefit along one year operation. Income terms correspond to selling of different fresh fruit and concentrated juice products in the three fruit markets and the two juice markets. Expenses are represented by raw material costs, packaging and juice plant operating costs, production costs at farms, cold storage costs, inter plant transportation costs, delivery cost of final products to markets, penalty costs for not fulfilling customer orders, etc.
2. Equality constraints: equations representing variable definitions, mass balances, production equations at farms and packaging and juice plants.
3. Inequality constraints: are given by production limits at proprietary farms, bounds on fruit supply from third party suppliers, bounds on internal processing capacities at packaging plants, cold storage, and juice plants, demand satisfaction, stock limits at cold storage and storage at juice plants.

Binary variables are used to assign alternatives for raw material purchase, processing plant selection, time periods, etc. Model parameters were taken from annual reports published by the Federal Investment Council (2000), data acquired in the field by the authors, and from personal communications with plant engineers working in the different companies.

The whole model comprises 14335 continuous variables, 3372 binary variables, 4421 equality and 7524 inequality constraints. The GAMS package (Brooke et al., 1998) was used in order to implement the MILP optimization model and generate their solutions. The OSL (IBM, 1991) solver within GAMS was used to solve the problem.

Numerical Results.

The model was run for a typical set of data corresponding to a very realistic scenario of one company operating in the HV. The model optimization gives an optimal level of fresh fruit processing of 107,556,300 Kgs. per year, distributed in 57,618,690 Kgs. from own farms, 16,864,810 Kgs. from suppliers´ farms, 27,481,230 Kgs. from suppliers' cold chambers and 5,591,578 Kgs. from suppliers' packaging plants. The total packed fruit production of the company is 74,573,930 Kgs., from which 15 % is commercialized in overseas markets, 40.5 % in the regional market and 44.5 % in the Argentinian market. The total concentrated juice production is 1,137,000 Kgs., from which 50.4 % is delivered to the overseas markets and 49.6 % is commercialized locally.

The optimal net yearly profit is 31.4 Million U$S. The most important cost items, summing up 85.5 % of the total, are the transportation cost of packed fruit, production cost at packaging plants and the fresh fruit purchase and production costs at juice plants.

Figure 4 shows the optimal annual plan for juice production for the two juice markets. As it is observed, there is a minimal production at the first two periods of the year, coincidentally with the beginning of the harvest season; thereafter the profile is kept equilibrated for the rest of the year.

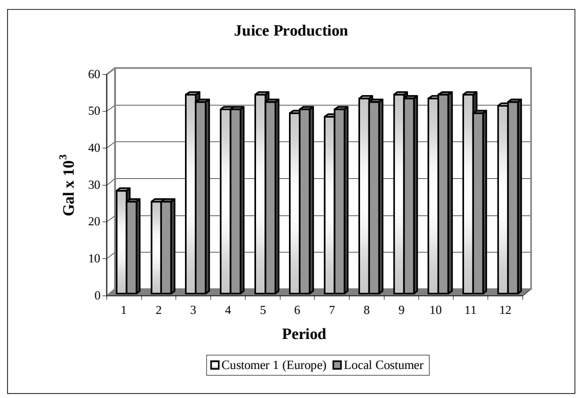

Figure 4. Optimal plan for juice delivery to the two juice market.

Figure 5 shows the same type of result for the case of fresh fruit. Again the demand is slower at the beginning of the harvest season, and then increases for the rest of the year. As it is observed, the product delivery to overseas markets (USA and Europe) is made during the harvest season. Thereafter the company only supplies to the regional and local markets according to the customer orders.

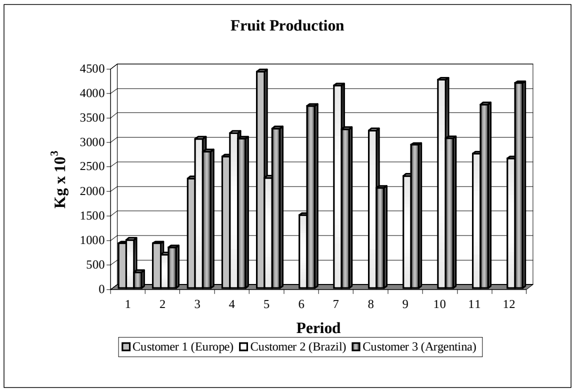

Figure 5. Optimal plan for packed fruit delivery to the three fruit markets.

The optimal planning allocates a balanced operation for the 4 packaging plants, assigning approximately 25 % of the fruit to each one, while the 41 % of the juice production is assigned to plant 1 and 59 % to plant 2. The reason for this production assigning policy comes from the differentiated yields, production costs and transportation costs at the different plants.

The total fruit production of the company does not fully satisfy customer demands, and then a penalty must be paid. In the case of concentrated juice all customer order can be satisfied and no penalties exist.

Product demand is not constant along the year, and then an optimal cold storage policy must be calculated for fruit and juice. Figure 6 shows the optimal stock profile of fresh fruit in cold storage at each packaging plant. Several costs (transportation to and from the storage plants, unitary cost of storage, etc.), maximum storage availability and production yield at each plant affect the optimal level of storage. Plant 1 result in the cheapest one for all the periods, and then it has the largest stock level. Meanwhile, mixed profiles result for the other plants along the year as a results of the combination of these factors.

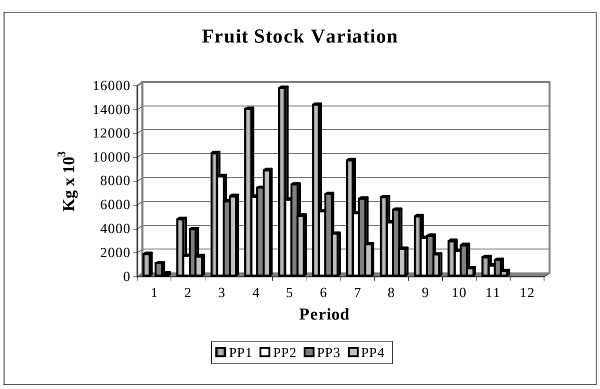

Figure 6. Fruit storage profile at packaging plants.

Figure 7 presents similar results for concentrated juice storage. Mixed profiles for storage in Plant 1 and 2 also result as combination of the different factors affecting the level of storage. However it can be observed that in average, less storage is allocated to Plant 2, being zero for some periods.

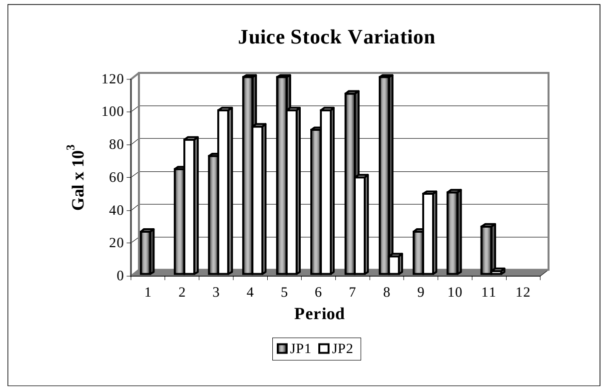

Figure 7. Juice storage profile at juice plants.

On January 2002 there was an important devaluation of the Argentinean currency against the U$S. The U$S to A$ rate changed from 1:1 to 1:3.5 in 4 months. This variation produced a quite different effect on costs, which are expressed in local currency, and on the selling prices in the foreign markets, which are expressed in U$S. This situation, favored the increase in the juice production which is fully commercialized in U$S at foreign markets. The net profit for the new scenario, after all costs and prices were realistically updated is U$S 62,628,842. The resulting production plan for fruit and juice are similar to the previous case, while the stock profiles are quite different.

Conclusion

A model was developed to optimize the supply chain planning of a typical fruit company in the HV area of Argentina. The model realistically represents the current economic scenario in the country. It optimally decides production plans for fruit and juice to satisfy customer orders form different markets, while it optimally allocates sources of raw material and processing plants, based on capacities and costs. Current research is under way to complete the sensitivity analysis and incorporates uncertainties in demands and harvest estimations.

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