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Operations management of a packaging plant in the fruit industry

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Abstract

The production of fresh fruit (apples and pears) and concentrated juice is one of the major regional economic activities of Argentina, which has traditionally been one of the world's main fresh fruit and concentrated juice producers. Due to market reasons, there is a strong need to count with reliable decision tools to manage the whole business. In order to tackle this problem, advantages can be taken from developments on formulations of planning and scheduling models. In this work, a realistic planning model of a packaging plant, the most important instance within the fresh fruit supply-chain industry from a tactical point of view, is developed. The model can be applied to estimate the fruit processing capacity of the facility in order to establish future sales policies.

Keywords: Fruit industry; Packing plant; Operations management

1. Introduction

The production of fresh pip fruit (apples and pears) and concentrated juice is one of the major regional economic activities of Argentina. The "Alto Valle de Rio Negro y Neuquén" area of Argentina (AVRNN), located across two states southwest of the country, is the region where apples and pears are grown.

During the 90s, fruit companies made important capital investments on new machinery for efficiency improvement. More recently, due to new worldwide competitors from South West Asia, local economic problems and volatile international markets, companies were compelled to improve even more their competitiveness to keep on business.

There are a few large companies that operate along the complete fruit industry supply chain (FISC), and concentrate the largest part of the business in the AVRNN region. A typical FISC of one of these companies involves one or more packaging and concentrated juice plants. Raw material for these plants can be supplied from own and/or third party farms. Final customers involve overseas, regional and local markets. Previous work (Masini, Petracci, & Bandoni, 2003) has addressed the Argentinean FISC planning problem.

Packaging plants (PP) represent the core of the FISC from a tactical point of view. At a PP, after raw material reception a decision has to be made whether the fruit is sent to cold storage for later processing or directly to the processing line. The processing line involves 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.

In the last decade there has been and increasing effort in developing and applying planning models in different instances of the food industry and in particular in the fruit industry. Mathematical programming planning models have been proposed for example for pip fruit orchard replacement (Kearney, 1994), to address the

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biophysical growth of apple plants (Hester & Cacho, 2003) and to fruit farm activities scheduling (Vitoriano, Ortuño, Recio, Rubio, & Alonso-Ayuso, 2003). According to the authors' knowledge, however, no contributions have addressed the operations management issues of PPs as described. Close related work is Broekmeulen (1998), where a tactical decision model for distribution centers for vegetables and fruits has been proposed. The main objective of that model is to provide an optimal assignment of the different perishables to the diverse storage zones within the center in order to minimize the so-called keeping quality loss.

It is the purpose of this contribution to present a detailed planning model of the operation of a PP, which includes its storage and processing activities, as described for the FISC. The model is intended to operate in a *profit mode*, this is to estimate the amount of products that the installed capacity can process provided a historical profile of fruit income. In such a mode of operation, the proposed model is considered to be a valuable tool in order to establish future sales policies.

2. Packaging plant description

The following activities take place in a typical PP of the FISC in the AVRNN area. The flow diagram for a single processing line PP is roughly sketched in Fig. 1.

1. Warm fresh fruit from woods is fed to the processing line (X_1), floating in a stream of water treated with fungicides. These fruits receive a treatment with pesticides, in a module for fruit washing called Drencher (DR), where dirt and fungus spores are eliminated.
2. After the Drenching stage, a decision has to be made whether the fruit is processed (X_3) or cold stored for further processing (X_2). In general non-processed fruit storage (NPFS) is undesirable due to economic reasons but it could be necessary if the income of fruit exceeds the processing capacity of the line.

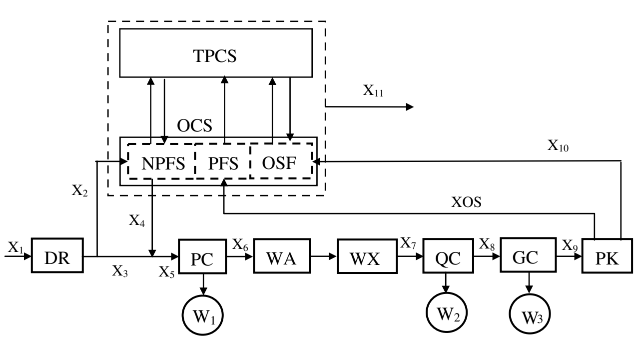

Fig. 1. Scheme of a packaging plant.

3. The fruit enters to the pre-classification (PC) stage (X_5) where non-tradable fruit is separated for juice production (W_1). Part of the fruit entering PC can come from NPFS (X_4) if required.
4. Pre-classified fruit (X_6) proceeds to the washing module (WA), where it is washed with water containing special chemical products. The fruit is then rinsed and dried before further processing.
5. If required, washed fruit enter the waxing module (WX) where it is sprayed with wax, which is further dried with hot air. To process fruit without wax, WX is simply by-passed.
6. The fruit (stream X_7) enters the quality classification sector (QC) where it is separated in several categories, according to the degree of defects or damage that the pieces present (X_8). Some waste is also produced at this stage (W_2).
7. Once the fruit has been classified by quality, it is further classified by size or weight (depending on the available technology) in several types at the gauge classification module (GC) (stream X_9). Some waste is also produced at this stage (W_3).
8. Each sized or weighted fruit enters to the packaging section (PK) where it is packed according to the characteristics of the container specified by the client. There is a variety of crate possibilities which determines an amount of final products (stream X_{10}).
9. Containers of the same type are stowed in pallets according to their sizes in refrigerating chambers (Processed Fruit Storage, PFS).
10. Finally, processed fruit is sent to port cold storage facilities if overseas products are involved, or dispatched by trucks to regional and local markets (X_{11}).

In the following a brief description of several important issues are discussed to present a more complete picture of the activity.

2.1. Fruit income

During the harvest a regular income of the different fruit varieties occurs according to the particular harvest period. Based on historical records, an income profile in terms of amount, waste, quality and gauge for each fruit variety can be established. The parameters of such a profile are stochastic in nature. Average and standard deviation values for such parameters are reported in Tables 1–4. By means of Monte Carlo simulation, deterministic fruit income profile scenarios are generated to feed the proposed deterministic planning model.

2.2. Waste

A fraction of the income fruit is non-tradable due to esthetic issues (damage, imperfections, size, etc.). Such a

Table 1
Fruit income data per variety

v	Variety	SD	HP	A (kg/day)	SDev (kg/day)	CR ($/kg)
v1	Williams pear	12	12–36	45560	2000	0.07
v2	Beurre D'Anjou pear	45	45–69	27400	1500	0.10
v3	Beurre Bosc pear	72	72–96	35960	2200	0.07
v4	Red apple 1	78	78–102	24240	780	0.08
v5	Packams Triumph pear	91	91–115	33200	2100	0.09
v6	Red Delicious apple	95	95–119	38600	3000	0.08
v7	Red apple 2	123	123–147	39040	2800	0.07
v8	Granny Smith apple	133	133–157	48360	3500	0.08

Table 2
Average and standard deviation for fruit quality

v	A (%)			SDev (%)		
	q_1	q_2	q_3	q_1	q_2	q_3
v1	0.58	0.27	0.15	0.063	0.045	0.025
v2	0.58	0.26	0.16	0.094	0.045	0.02
v3	0.50	0.35	0.16	0.077	0.045	0.019
v4	0.58	0.27	0.15	0.07	0.03	0.029
v5	0.58	0.34	0.08	0.106	0.057	0.013
v6	0.40	0.27	0.33	0.043	0.049	0.038
v7	0.58	0.29	0.13	0.092	0.041	0.023
v8	0.45	0.32	0.23	0.091	0.055	0.023

Table 3
Average and standard deviation for fruit waste in each classification stage

v	A (%)			SDev (%)		
	DPC	DQC	DGC	DPC	DQC	DGC
v1	0.11	0.05	0.06	0.014	0.003	0.007
v2	0.14	0.03	0.06	0.011	0.004	0.006
v3	0.12	0.03	0.07	0.012	0.005	0.005
v4	0.13	0.04	0.06	0.014	0.004	0.007
v5	0.10	0.05	0.07	0.011	0.003	0.006
v6	0.11	0.04	0.07	0.011	0.005	0.006
v7	0.13	0.04	0.05	0.013	0.004	0.007
v8	0.12	0.03	0.07	0.013	0.003	0.006

fruit is eliminated from the system in the different classification modules and sold for concentrated juice production.

2.3. Cold storage policy

The cold-storage facility represents a major operability cost within the process. It receives fruit from two sources during the whole fruit season: bins from woods that exceed the processing capacity of the line (NPFS) and pallets of crated fruit produced in the packaging machines (PFS). If the capacity of own cold storage (OCS) is exceeded, third party cold storage (TPCS) has to be rented. Processed fruit, rather than non-processed fruit is sent first to TPCS if required.

2.4. Labor policy

PPs have a permanent labor staff, which covers a single eight-hour working shift along the whole year. However, temporary labor staff may be required to cover two or three eight-hour working shifts during certain periods in order to satisfy commercial commitments. In this work, the year has been divided in 26 fourteen-days periods, which according to labor regulations, is the minimum amount of time to hire temporary staff. During any of these periods, the PP can operate with two or three working shifts if convenient.

2.5. Final products

Many final products are possible depending on the particular combination of fruit variety, waxing, quality, gauge and crate:

Table 4
Average and standard deviation for fruit gauge

v	A (%)					SDev (%)				
	g_1	g_2	g_3	g_4	g_5	g_1	g_2	g_3	g_4	g_5
v1	0.12	0.11	0.23	0.14	0.40	0.004	0.004	0.008	0.005	0.015
v2	0.11	0.16	0.19	0.24	0.30	0.005	0.008	0.009	0.009	0.012
v3	0.20	0.12	0.18	0.21	0.29	0.009	0.005	0.008	0.009	0.009
v4	0.18	0.12	0.22	0.22	0.26	0.008	0.005	0.008	0.009	0.012
v5	0.30	0.22	0.20	0.21	0.09	0.009	0.007	0.008	0.007	0.003
v6	0.21	0.26	0.12	0.26	0.16	0.010	0.012	0.005	0.011	0.007
v7	0.10	0.23	0.16	0.13	0.38	0.004	0.008	0.005	0.005	0.012
v8	0.27	0.16	0.16	0.14	0.28	0.012	0.007	0.005	0.005	0.011

- Fruit variety: Eight typical varieties are considered.
- Waxing: Waxed fruit may be required by certain clients.
- Fruit quality: Fruit quality has to do with sanitary (fungus presence) and esthetic (color, shape and imperfections) issues. Three categories can be distinguished:
  – First quality: Fungus and imperfections free fruit.
  – Second quality: Fungus free and some degree of imperfection fruit.
  – Third quality: Fungus free and a high degree of imperfection fruit.
- Fruit gauge (size or weight): It has to do with the amount of same gauge pieces that can be packed in standard 20 kg packs. Five different gauges are considered in this work.
- Crate: It has to do with client preferences, which vary depending on the market (overseas, regional and local). They involve different types of boxes, plates, wrapping paper, etc. For the sake of simplicity, only one crate for all products is considered in this work.

There also exists an amount of products regarding variety, quality and gauge that do not have a particular demand in the different markets. However, they are necessarily produced (XOS) and need to be stored (OSF). These are called *out-of-specification products* and are usually allocated in the local market. Table 5 reports the 20 different products considered in this contribution and their respective sale prices.

2.6. Market operation

Overseas market only demands certain first quality products. The available amount of the required fruit has to be sent to the port cold storage facilities prior ship arrivals, which follow a rather fixed yearly schedule. Regarding the regional market, where other certain products are consumed, periodic deliveries are considered as well as for the local market. The rest of the possible out of specification products has a lower average price and is usually allocated in the local market as soon as available. Market schedules and market products are reported in Tables 6 and 7 respectively.

2.7. Business strategy and planning models

Previously the beginning of the fruit season, PP managers establish sales commitments with different markets. Their objective is to allocate as much processed

Table 6
Delivery dates for the different markets

Overseas	Regional	Local
25	30	31
50	60	54
80	90	78
110	120	102
140	150	126
170	180	150
190	210	174
215	240	198
	270	222
	300	246
	330	270
	360	294
		318
		342
		360

Table 5
Packaging plant products

	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	w_1	w_2	q_1	q_2	q_3	g_1	g_2	g_3	g_4	g_5	p_1	PP ($/kg)
*P*1	1									1	1			1					1	0.33
*P*2			1							1	1				1				1	0.39
*P*3		1							1				1			1			1	0.26
*P*4				1						1		1					1		1	0.28
*P*5					1					1			1					1	1	0.24
*P*6								1	1		1							1	1	0.34
*P*7						1			1			1						1	1	0.27
*P*8							1		1			1				1			1	0.29
*P*9	1									1	1				1				1	0.32
*P*10			1							1			1	1					1	0.36
*P*11						1			1				1	1					1	0.28
*P*12								1		1			1			1			1	0.31
*P*13		1							1			1				1			1	0.28
*P*14				1						1	1						1		1	0.29
*P*15							1			1	1					1			1	0.29
*P*16					1				1			1		1					1	0.29
*P*17		1								1		1		1					1	0.29
*P*18						1				1			1		1				1	0.26
*P*19	1								1		1						1		1	0.31
*P*20				1						1	1				1				1	0.31
Set					VP				WP			QP				GP			SP	

Table 7
Products for the different markets

Overseas	$P1$, $P2$, $P6$, $P9$, $P14$, $P15$, $P19$, $P20$
Regional	$P4$, $P7$, $P8$, $P13$, $P16$, $P17$
Local	$P3$, $P5$, $P10$, $P11$, $P12$, $P18$

fruit as possible in order to maximize profit, particularly in the overseas market.

In this *negotiation instance*, estimates of quality and amount of future available fruit, based on historical profiles of fruit income, are required.

During the fruit season, it is desired to operate the PP in such a way that the sales schedule established in the negotiation instance is fulfilled as close as possible. This schedule is established on the base of the actual fruit income profile.

A second important objective of this *operation instance* of the PP, is to manage in an optimal fashion the non-previously allocated produced fruit. Such an optimal management mainly involves the tradeoff between cost and time of keeping the fruit in cold storage, which represents a major operability cost, while expecting better levels of sale prices.

Due to the rather complex interactions among the resources in the PP and to the uncertainty associated to the income of fruit in terms of amount and quality, optimal (or even good enough) solutions of the *negotiation* and *operation* instances of the business are hard to implement without the assistance of planning tools.

In the following, a planning model for the negotiation instance of the PP is developed. Such a model is intended to operate in a *sales oriented* fashion in order to maximize the sales income by allocating as much packed fruit as possible while minimizing operating costs.

3. Packaging plant planning model

The planning model for the PP mostly involves mass balances in each node of the system (Fig. 1). The numerical data for the proposed model are presented in Tables 1–8. In the following the detailed set of equations is developed.

Table 8
Model parameters

STKMX	4×10^6	kg
MPC	118×10^4	kg/day
CC	1.35	\$/1000 kg
MC	0.28	\$/1000 kg
LCS	40,600	\$/shift/day
POS	0.14	\$/kg
PWF	34	\$/1000 kg

3.1. Income fruit scenario

In order to generate a deterministic income fruit scenario, a Monte Carlo simulation (MCS) is performed on each parameter of the stochastic income profile in terms of amount of fruit per variety, quality of fruit per variety, gauge fruit per variety, and waste of fruit per variety in the different classification stages (Tables 1–4):

$$X_{1t,v} = \text{MCS}\{X_{1t,v}[A(X_1), \text{SDev}(X_1)]\}$$
$$t \in \text{HP}_v\ \forall v$$
$$q_{it,v} = \text{MCS}\{q_{it,v}[A(q_i), \text{SDev}(q_i)]\}$$
$$t \in \text{HP}_v,\ i \in \{1,2,3\}$$
$$g_{jt,v} = \text{MCS}\{g_{jt,v}[A(g_j), \text{SDev}(g_j)]\}$$
$$t \in \text{HP}_v,\ j \in \{1,2,3,4,5\}$$

$$\text{DPC}_{t,v} = \text{MCS}\{\text{DPC}_{t,v}[A(\text{DPC}), \text{SDev}(\text{DPC})]\}$$
$$t \in \text{HP}_v$$
$$\text{DQC}_{t,v} = \text{MCS}\{\text{DPC}_{t,v}[A(\text{DQC}), \text{SDev}(\text{DQC})]\}$$
$$t \in \text{HP}_v$$
$$\text{DGC}_{t,v} = \text{MCS}\{\text{DGC}_{t,v}[A(\text{DGC}), \text{SDev}(\text{DGC})]\}$$
$$t \in \text{HP}_v$$

3.2. Mass balance in drencher (DR)

Part of the incoming fruit (X_1) feeds the processing line (X_3) and if the production capacity is exceeded the rest is derived to cold storage (X_2).

$$X_{1t,v} = X_{2t,v} + X_{3t,v} \quad t \in \text{HP}(v)\ \forall v$$

3.3. Mass balance in pre classification stage (PC)

Fruit entering PC (X_5) if conformed by fresh fruit entering the system (X_3) and non-processed cold stored fruit (X_4) if required. The fruit leaving PC is the fraction of non-wasted pieces entering the module. Two different time period sets are considered, SD_v (t') and HP_v (t''), for those periods after the starting day of the variety and those that belong to the whole harvest period, respectively.

$$X_{5t',v} = X_{3t'',v} + X_{4t',v} \quad t' \geqslant \text{SD}_v,\ t'' \in \text{HP}_v\ \forall v$$
$$X_{6t,v} = (1 - \text{DPC}_{t,v}) \cdot X_{5t,v} \quad t \geqslant \text{SD}_v\ \forall v$$

3.4. Mass balance in waxing stage (WA)

Fruit leaving the WA module (X_7) is conformed by the fraction of waxed fruit and non-waxed fruit.

$$\sum_w X_{7t,v,w} = X_{6t,v} \quad t \geqslant \text{SD}_v\ \forall v, w$$

3.5. Mass balance in quality classification stage (QC)

Fruit leaving the QC module (X_8) is conformed by the fractions of non-wasted fruit of the different qualities.

$$X_{8t,v,w,q} = (1 - \mathrm{DQC}_{t,v}) \cdot Q_{t,v,q} \cdot X_{7t,v,w}$$
$$t \geqslant \mathrm{SD}_v \ \forall v, w, q$$
$$\sum_q Q_{t,v,q} = 1 \quad \forall t, v, q$$

3.6. Mass balance in gauge classification stage (GC)

Fruit leaving the GC module (X_9) is conformed by the fractions of non-wasted fruit of the different gauges.

$$X_{9t,v,w,q,g} = (1 - \mathrm{DGC}_{t,v}) \cdot G_{t,v,g} \cdot X_{8t,v,w,q}$$
$$t \geqslant \mathrm{SD}_v \ \forall v, w, q, g$$
$$\sum_g G_{t,v,g} = 1 \quad \forall t, v, g$$

3.7. Mass balance in packaging (PK)

Fruit leaving the PK module (X_{10}) is conformed by the fractions of the different fruit products.

$$X_{9t,v,w,q,g} = \sum_p X_{10t,v,w,q,g,p} \quad t \geqslant \mathrm{SD}_v,\ v \in \mathrm{VP},\ w \in \mathrm{WP},\ q \in \mathrm{QP},\ g \in \mathrm{GP},\ p \in \mathrm{SP}$$

3.8. Mass balances in cold storage

Classic inventory equations are applied to model the stock of the different classes of processed and non-processed fruit in the cold chamber. Two different time period sets, $\mathrm{SD}_v(t')$ and $\mathrm{HP}_v(t'')$, for those periods after the starting day of the variety and those that belong to the whole harvest period respectively, are applied when required.

Non-processed fruit mass balance in cold storage—per variety (NPFS)

$$\mathrm{NPstk}_{t',v} = \mathrm{NPstk}_{t'-1,v} + X_{2t'',v} - X_{4t',v}$$
$$t' \geqslant \mathrm{SD}_v,\ t'' \in \mathrm{HP}_v \ \forall v$$

Non-processed fruit mass balance in cold storage (total)

$$\mathrm{NPstkT}_t = \sum_v \mathrm{NPstk}_{t,v} \quad t \geqslant \mathrm{SD}_v \ \forall v$$

Processed fruit mass balance in cold storage (per product)

$$\mathrm{Pstk}_{t,v,w,q,g,p} = \mathrm{Pstk}_{t-1,v,w,q,g,p} + X_{10t,v,w,q,g,p} - X_{11t,v,w,q,g,p}$$
$$t \geqslant \mathrm{SD}_v,\ v \in \mathrm{VP},\ w \in \mathrm{WP},\ q \in \mathrm{QP},\quad g \in \mathrm{GP},\ p \in \mathrm{SP}$$

Processed fruit mass balance in cold storage (total)

$$\mathrm{PstkT}_t = \sum_v \sum_w \sum_q \sum_g \sum_p \mathrm{Pstk}_{t,v,w,q,g,p}$$
$$t \geqslant \mathrm{SD}_v,\ v \in \mathrm{VP},\ w \in \mathrm{WP},\ q \in \mathrm{QP},\ g \in \mathrm{GP},\ p \in \mathrm{SP}$$

Out of specification fruit mass balance

$$\mathrm{XOS}_{t,v,w,q,g} = X_{9t,v,w,q,g} - \sum_p X_{10t,v,w,q,g,p} - X_{11t,v,w,q,g,p}$$
$$t \geqslant \mathrm{SD}_v,\ v \notin \mathrm{VP},\ w \notin \mathrm{WP},\ q \notin \mathrm{QP},\ g \notin \mathrm{GP},\ p \in \mathrm{SP}$$

Stock of fruit out of specification

$$\mathrm{OSstk}_t = \mathrm{OSstk}_{t-1} + \sum_v \sum_w \sum_q \sum_g \mathrm{XOS}_{t,v,w,q,g} - \sum_v \sum_w \sum_q \sum_g \sum_p X_{11t,v,w,q,g,p}$$
$$t \geqslant \mathrm{SD}_v,\ v \notin \mathrm{VP},\ w \notin \mathrm{VW},\ q \notin \mathrm{QP},\ g \notin \mathrm{GP},\ p \in \mathrm{SP},\ t \in \mathrm{CDM}$$

Total mass balance in cold storage

$$\mathrm{stkT}_t = \mathrm{NPstkT}_t + \mathrm{PstkT}_t + \mathrm{OSstk}_t \quad t \geqslant \mathrm{SD}_v$$

Third party storage

$$\mathrm{TPstk}_t = \mathrm{stkT}_t - \mathrm{STKMX} \quad t \geqslant \mathrm{SD}_v$$

3.9. Maximum processing capacity

The maximum processing capacity of the processing line has to do with the amount of fruit that can be handled at the entrance of the PC module, which is in turn dependent on the number of working shifts and the processing capacity per shift.

$$\left.\begin{array}{l} \sum_v X_{5t,v} \leqslant \sum_s y_{m,s} \cdot \mathrm{MPC} \cdot s \\ \sum_s y_{m,s} = 1 \end{array}\right. \quad t \geqslant \mathrm{SD}_v, t \in \mathrm{CDM}\ \forall m, v, s$$

3.10. Objective function

In the proposed *profit oriented* mode of the model, a total profit objective function is considered for minimization:

$$\mathrm{PROFIT} = \sum_t (\mathrm{ISP}_t + \mathrm{IWF}_t + \mathrm{IOSF}_t) - \sum_t \mathrm{RMC}_t - \sum_t (\mathrm{WFCC}_t + \mathrm{CMC}_t) - \sum_t \mathrm{TLC}_t \quad t \geqslant \mathrm{SD}_v$$

where

Income per product sale:

$$\mathrm{ISP}_t = \sum_v \sum_w \sum_q \sum_g \sum_p \mathrm{PP}_p \cdot X_{11t,v,w,q,g,p}$$
$$t \geqslant \mathrm{SD}_v,\ v \in \mathrm{VP},\ w \in \mathrm{WP},\ q \in \mathrm{QP},\quad g \in \mathrm{GP},\ p \in \mathrm{SP}$$

Income per waste fruit sale:

$$\mathrm{IWF}_t = \mathrm{PWF}\cdot\left[\sum_v \mathrm{DPC}_{t,v}\cdot X_{5t,v} + \sum_v \mathrm{DQC}_{t,v}\sum_w X_{7t,v,w} + \sum_v \mathrm{DGC}_{t,v}\cdot\sum_w\sum_q X_{8t,v,w,q}\right]$$

$t \geqslant \mathrm{SD}_v\ \forall v,\ w \in \mathrm{WP},\ p \in \mathrm{SP}$

Income per out of specification product sale

$$\mathrm{IOSF}_t = \mathrm{POS}\sum_v\sum_w\sum_q\sum_g \mathrm{XOS}_{t,v,w,q,g}$$

$t \geqslant \mathrm{SD}_v,\ v \notin \mathrm{VP},\ w \notin \mathrm{WP},\ q \notin \mathrm{QP},\ g \notin \mathrm{GP}$

Cost per raw material purchase

$$\mathrm{RMC}_t = \sum_v \mathrm{CR}_v\cdot X_{1t,v} \quad t \in \mathrm{HP}_v\ \forall v$$

Cost per fruit cooling

$$\mathrm{WFCC}_t = \mathrm{CC}\cdot\left[\sum_v X_{2t',v} + \sum_v\sum_w\sum_q\sum_g X_{9t,v,w,q,g}\right]$$

$t' \in \mathrm{HP}_v,\ t \geqslant \mathrm{SD}_v\ \forall v,w,q,g$

Cost per cold fruit maintenance

$$\mathrm{CMC}_t = \mathrm{MC}\cdot\sum_t \mathrm{Tstk}_t \quad t \geqslant \mathrm{SD}_v$$

Labor cost

$$\mathrm{TLC}_t = \sum_m\sum_s y_{m,s}\cdot \mathrm{LCS} \quad t \in \mathrm{CDM}\ \forall m,s$$

Where

Indices

v	fruit variety
t	day
w	waxing option
q	fruit quality
g	gauge (size or weight)
p	packing type
m	fixed periods when additional shifts are possible
s	shifts

Sets

HP	harvest period
SD	starting day of the harvest
VP	product to variety assignation
WP	product to waxing assignation
QP	product to quality assignation
GP	product to gauge assignation
SP	selling product packing
CDM	dates in each period m of 14 days

Variables

$X_{1t,v}$	fruit supply to the plant from farms (kg/day)
$X_{2t,v}$	fruit to cold storage for future processing (kg/day)
$X_{3t,v}$	fruit to processing line (kg/day)
$X_{4t,v}$	fruit to processing line from cold storage (kg/day)
$X_{5t,v}$	fruit to pre classification stage (kg/day)
$X_{6t,v}$	fruit to waxing stage (kg/day)
$X_{7t,v,w}$	fruit to quality classification stage (kg/day)
$X_{8t,v,w,q}$	fruit to gauge classification stage (kg/day)
$X_{9t,v,w,q,g}$	fruit to packaging stage (kg/day)
$\mathrm{XOS}_{t,v,w,q,g,p}$	out of specification fruit (kg/day)
$X_{10t,v,w,q,g,p}$	fruit to cold storage (kg/day)
$X_{11t,v,w,q,g,p}$	fruit delivery (kg/day)
$\mathrm{NPstk}_{t,v}$	non-processed fruit stock per variety (kg)
NPstkT_t	total non-processed fruit stock (kg)
$\mathrm{Pstk}_{t,v,w,q,g,p}$	processed fruit cold stock per product (kg)
PstkT_t	total processed fruit stock (kg)
OSstk_t	out of specification stock (kg)
stkT_t	total fruit stock (kg)
TPstkT_t	third party storage
$Y_{m,s}$	binary variables which model one, two or three shifts per period
ISP_t	income from product ($/yr)
IWF_t	income from waste fruit ($/yr)
IOSF_t	income from out of specification fruit ($/yr)
RMC_t	raw material cost ($/yr)
WFCC_t	warm fruit cooling cost ($/yr)
CMC_t	cooling maintenance cost ($/yr)
TLC_t	total labor cost ($/yr)
PROFIT	annual profit ($/yr)

Parameters

A	average value
SDev	standard deviation
$\mathrm{DPC}_{t,v}$	fraction of waste in pre classification
$\mathrm{DQC}_{t,v}$	fraction of waste in quality classification
$\mathrm{DGC}_{t,v}$	fraction of waste in gauge classification
$Q_{t,v,q}$	fraction of different qualities in quality classification stage
$G_{t,v,g}$	fraction of different gauges in gauge classification stage
STKMX	maximum own cold storage capacity (kg)
MPC	maximum processing capacity per shift (kg)
CR_v	raw material cost per variety ($/kg)
PP_p	product price ($/kg)
PWF	waste fruit price ($/kg)
POS	out of specification fruit price ($/kg)
CC	energy cost related to fruit cooling ($/kg)
MC	energy cost related to maintain cool fruit ($/kg)
LCS	labor cost per shift per day ($/shift/day)

4. Results

The model described in the previous section can be applied in a *profit oriented* fashion as previously suggested:

Provided a historical profile of fruit income (in terms of amount, waste, quality distribution and gauge distribution) generate a processing plan in order to maximize total profit:

$$\text{Total profit} = \text{sales income} - \text{raw material cost} - \text{labor costs} - \text{cooling costs}$$

In this mode of operation a plan that maximizes the production of each particular product for the installed capacity is obtained. The resulting volumes of products allow the prediction of the potential production of the facility in order to establish sales commitments.

The proposed mixed integer linear programming model was solved with GAMS (Brooke, Kendrick, & Meeraus, 1996) for the provided data. For a certain deterministic Monte Carlo simulated scenario of fruit income, the total profit is maximized by allocating as much as product as possible in the different markets. The profiles in the time of each term of the objective function are graphically reported in Fig. 2. Cost of raw material is determined by the fruit income profile, and lasts for the whole harvest period (days 12–157). The term of energy cost, which comprises fruit cooling and cool maintenance, reflects the evolution of the stock of fruit in storage chambers, which verify high values within the harvest and decreases in time as raw fruit income decreases and processed fruit leaves the system. Labor cost, which depends on the number of working shifts (one, two or three), presents high value plateaus in early periods when fruit income is important and large amounts of fruit need to be processed. It decreases later in the year when the harvest finishes and the remaining stored fruit feeds the processing line, which is operated with only one working shift. Regarding income from sales, it can be seen that a rather low-income plateau exists along practically the whole horizon, which correspond to the regular selling in local market of out of specification fruit. High-income peaks correspond to the selling of overseas products according to the established schedule.

Integrating the profiles in the time, total values for income and costs can be obtained in order to describe the whole business performance during the season. Total sales income is \$58,423,785 with a raw material cost of \$33,242,063, an operating cost of \$21,783,926, and a cooling cost of \$111,171. The net profit is \$3,331,623. Additional results, not reported here, have to do with the expected complex distribution of volumes of the different possible products and types of out-of-specification fruit. Such results are a valuable tool for the PP manager to estimate the PP processing capacity in order to establish sales commitments for the next business year.

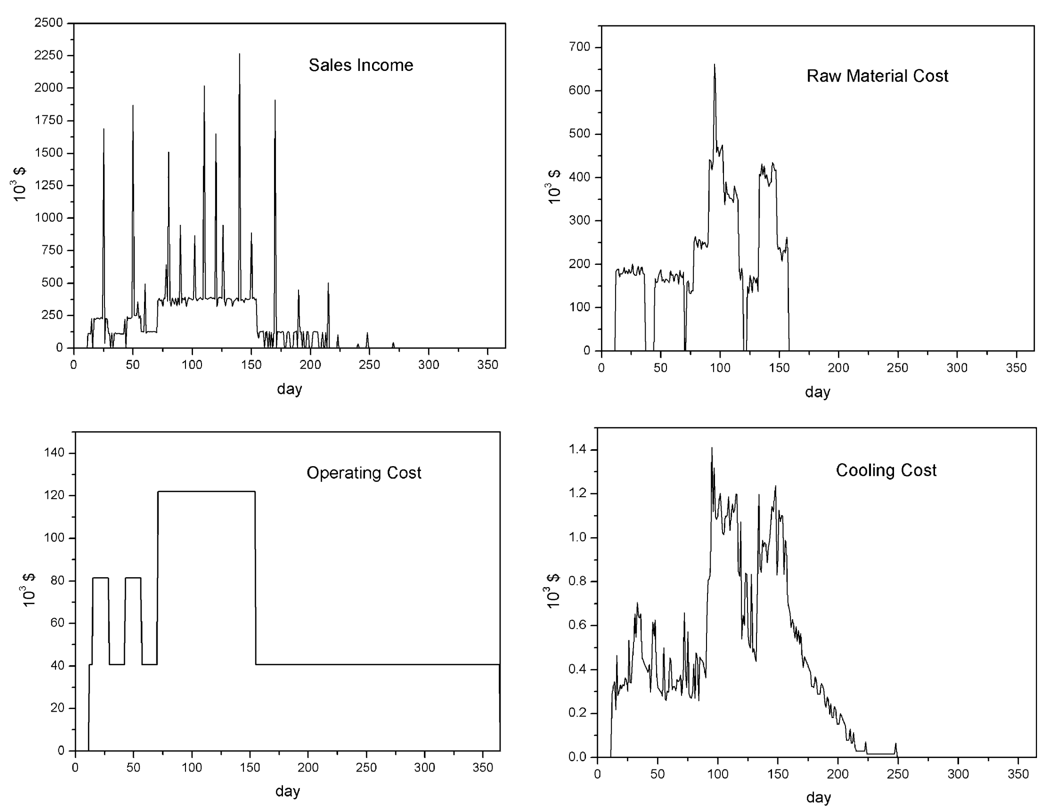

Fig. 2. Terms of the profit objective function.

5. Conclusions

In this work, the planning problem of a typical fresh fruit PP has been addressed. It has been applied in a *profit-oriented* mode in order to estimate the production capacity of the facility. Results were presented corresponding to a packaging plant operating one processing line, with seven fruit varieties and 20 final products.

Such a model constitutes a valuable tool for the PP manager at the negotiation instance of the business, when sales commitments are established with the different demanding markets.

Essentially the same model can be applied in another mode of operation in a *sales oriented* fashion: *provided a historical profile of fruit income and an established sales program, generate a processing plan in order to maximize total profit, while penalizing non-satisfaction of sales commitments in terms of volume of fruit and delivery deadlines*. In this mode of operation, a plan that accomplishes as close as possible the sales program, in terms of volumes and deadlines, results. It is also intended to address the often critical tradeoff between keeping non-allocated fruit in cold storage while expecting better sales prices. In such a mode, the model becomes a valuable tool to estimate future resources requirements (third party cold storage, labor, energy, etc.) and therefore to identify potential bottlenecks of the system. Future work will address the *sales oriented* fashion version of the model.

Several improvements to address more realistic versions of the system are possible and will also motivate future work. They imply for example, the consideration of PPs with several parallel processing lines, "partial harvests" effects for each variety, "batch" fashion processing of the fruit suppliers, detailed flows within the cold chambers, transportation issues, etc. A further natural extension of the present work which is under development, is the explicit consideration of the stochastic nature of the system under study.

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