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.

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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 Río 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
biophysical growth of apple plants (Hester & Cacho, 2003) and to fruit farm activities scheduling (Vitoriano, Ortúñ, 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 (X₁), 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 (X₃) or cold stored for further processing (X₂). 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.

3. The fruit enters to the pre-classification (PC) stage (X₅) where non-tradable fruit is separated for juice production (W₁). Part of the fruit entering PC can come from NPFS (X₄) if required.

4. Pre-classified fruit (X₆) 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 X₇) 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 (X₈). Some waste is also produced at this stage (W₂).

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 X₉). Some waste is also produced at this stage (W₃).

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 X₁₀).

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 (X₁₁).

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
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 1
Fruit income data per variety

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

Table 2
Average and standard deviation for fruit quality

<table>
<thead>
<tr>
<th>v</th>
<th>g1 (%)</th>
<th>g2 (%)</th>
<th>g3 (%)</th>
<th>SDev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>0.58</td>
<td>0.27</td>
<td>0.15</td>
<td>0.063</td>
</tr>
<tr>
<td>v2</td>
<td>0.50</td>
<td>0.35</td>
<td>0.16</td>
<td>0.077</td>
</tr>
<tr>
<td>v3</td>
<td>0.58</td>
<td>0.27</td>
<td>0.15</td>
<td>0.07</td>
</tr>
<tr>
<td>v4</td>
<td>0.58</td>
<td>0.34</td>
<td>0.08</td>
<td>0.106</td>
</tr>
<tr>
<td>v5</td>
<td>0.40</td>
<td>0.27</td>
<td>0.33</td>
<td>0.043</td>
</tr>
<tr>
<td>v6</td>
<td>0.58</td>
<td>0.29</td>
<td>0.13</td>
<td>0.092</td>
</tr>
<tr>
<td>v7</td>
<td>0.45</td>
<td>0.32</td>
<td>0.23</td>
<td>0.091</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>v</th>
<th>DPC (%)</th>
<th>DQC (%)</th>
<th>DGC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>0.11</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>v2</td>
<td>0.14</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>v3</td>
<td>0.12</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>v4</td>
<td>0.13</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>v5</td>
<td>0.10</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>v6</td>
<td>0.11</td>
<td>0.04</td>
<td>0.07</td>
</tr>
<tr>
<td>v7</td>
<td>0.13</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>v8</td>
<td>0.12</td>
<td>0.03</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 4
Average and standard deviation for fruit gauge

<table>
<thead>
<tr>
<th>v</th>
<th>g1 (%)</th>
<th>g2 (%)</th>
<th>g3 (%)</th>
<th>g4 (%)</th>
<th>g5 (%)</th>
<th>SDev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>0.12</td>
<td>0.11</td>
<td>0.23</td>
<td>0.14</td>
<td>0.40</td>
<td>0.004</td>
</tr>
<tr>
<td>v2</td>
<td>0.11</td>
<td>0.16</td>
<td>0.19</td>
<td>0.24</td>
<td>0.30</td>
<td>0.004</td>
</tr>
<tr>
<td>v3</td>
<td>0.20</td>
<td>0.12</td>
<td>0.18</td>
<td>0.21</td>
<td>0.29</td>
<td>0.004</td>
</tr>
<tr>
<td>v4</td>
<td>0.18</td>
<td>0.12</td>
<td>0.22</td>
<td>0.22</td>
<td>0.26</td>
<td>0.004</td>
</tr>
<tr>
<td>v5</td>
<td>0.30</td>
<td>0.22</td>
<td>0.20</td>
<td>0.21</td>
<td>0.09</td>
<td>0.004</td>
</tr>
<tr>
<td>v6</td>
<td>0.21</td>
<td>0.26</td>
<td>0.12</td>
<td>0.26</td>
<td>0.16</td>
<td>0.004</td>
</tr>
<tr>
<td>v7</td>
<td>0.10</td>
<td>0.23</td>
<td>0.16</td>
<td>0.13</td>
<td>0.38</td>
<td>0.004</td>
</tr>
<tr>
<td>v8</td>
<td>0.27</td>
<td>0.16</td>
<td>0.16</td>
<td>0.14</td>
<td>0.28</td>
<td>0.012</td>
</tr>
</tbody>
</table>
• 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>
<thead>
<tr>
<th>Table 6</th>
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<tbody>
<tr>
<td>Delivery dates for the different markets</td>
</tr>
<tr>
<td>Overseas</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>80</td>
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<tr>
<td>110</td>
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<tr>
<td>140</td>
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<td>170</td>
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<td>190</td>
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<td>215</td>
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<tr>
<td>270</td>
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<td>300</td>
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<td>330</td>
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<td>360</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging plant products</td>
</tr>
<tr>
<td>$v_1$</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>P1</td>
</tr>
<tr>
<td>P2</td>
</tr>
<tr>
<td>P3</td>
</tr>
<tr>
<td>P4</td>
</tr>
<tr>
<td>P5</td>
</tr>
<tr>
<td>P6</td>
</tr>
<tr>
<td>P7</td>
</tr>
<tr>
<td>P8</td>
</tr>
<tr>
<td>P9</td>
</tr>
<tr>
<td>P10</td>
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<td>P11</td>
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<td>P12</td>
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<td>P13</td>
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<td>P15</td>
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<td>P16</td>
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<td>P17</td>
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<tr>
<td>P18</td>
</tr>
<tr>
<td>P19</td>
</tr>
<tr>
<td>P20</td>
</tr>
<tr>
<td>Set</td>
</tr>
</tbody>
</table>
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-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.

### 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, and waste of fruit per variety in the different classification stages (Tables 1–4):

\[ X_{1, t, v} = \text{MCS}\{X_{t, v} \cdot A(X_{1}), \text{SDev}(X_{1})\} \]

\[ t \in \text{HP}_v \ \forall v \]

\[ q_{i, t, v} = \text{MCS}\{q_{i, t, v} \cdot A(q_{i}), \text{SDev}(q_{i})\} \]

\[ t \in \text{HP}_i, \ i \in \{1, 2, 3\} \]

\[ g_{j, t, v} = \text{MCS}\{g_{j, t, v} \cdot A(g_{j}), \text{SDev}(g_{j})\} \]

\[ t \in \text{HP}_j, \ j \in \{1, 2, 3, 4, 5\} \]

\[ \text{DPC}_{i, t, v} = \text{MCS}\{\text{DPC}_{i, t, v} \cdot A(\text{DPC}), \text{SDev}(\text{DPC})\} \]

\[ t \in \text{HP}_i \]

\[ \text{DQC}_{i, t, v} = \text{MCS}\{\text{DQC}_{i, t, v} \cdot A(\text{DQC}), \text{SDev}(\text{DQC})\} \]

\[ t \in \text{HP}_i \]

\[ \text{DGC}_{i, t, v} = \text{MCS}\{\text{DGC}_{i, t, v} \cdot A(\text{DGC}), \text{SDev}(\text{DGC})\} \]

\[ t \in \text{HP}_i \]

### 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 \( X_2 \).

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

### 3.3. Mass balance in pre classification stage (PC)

Fruit entering PC \( X_3 \) 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, \( \text{SD}_v(t') \) and \( \text{HP}_v(t') \), for those periods after the starting day of the variety and those that belong to the whole harvest period, respectively.

\[ X_{5, t, v} = X_{3, t, v} + X_{4, t, v} \quad t' \geq \text{SD}_v, \ t' \in \text{HP}_v \ \forall v \]

\[ X_{6, t, v} = (1 - \text{DPC}_{t, v}) \cdot X_{5, t, v} \quad t \geq \text{SD}_v \ \forall v \]

### 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.

\[ \sum_{w} X_{7, t, v, w} = X_{6, t, v} \quad t \geq \text{SD}_v \ \forall v, w \]
3.5. Mass balance in quality classification stage (QC)

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

\[
X_{st,w,q} = (1 - DQC_{t,v} \cdot G_{t,v,q} \cdot X_{t,v,w})
\]

\[
t \geq SD_v \quad \forall t, v, w, q
\]

\[
\sum_q G_{t,v,q} = 1 \quad \forall t, v, g
\]

3.6. Mass balance in gauge classification stage (GC)

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

\[
X_{st,w,q,g} = (1 - DGC_{t,v} \cdot G_{t,v,q,g} \cdot X_{t,v,w})
\]

\[
t \geq SD_v \quad \forall t, v, w, q, g
\]

\[
\sum_g G_{t,v,q,g} = 1 \quad \forall t, v, g
\]

3.7. Mass balance in packaging (PK)

Fruit leaving the PK module (\(X_t\)) is conformed by the fractions of the different fruit products.

\[
X_{st,w,q,g} = \sum_p X_{10r,v,q,g,p} \quad t \geq SD_v, \ v \in VP,
\]

\[
w \in WP, \ q \in QP, \ g \in GP, \ p \in SP
\]

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, \(SD_v(t')\) and \(HP_v(t'')\), for those periods after the starting day of the variety and those that belong to the whole harvest period respectively, are applied when required.

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

\[
NP_{st,k,v} = NP_{st,k-1,v} + X_{2p,s} - X_{4f,v}
\]

\[
t' \geq SD_v, \ t'' \in HP_v \ \forall v
\]

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

\[
NP_{stk_t} = \sum_v NP_{st,k,v} \quad t \geq SD_v \ \forall v
\]

Processed fruit mass balance in cold storage (per product)

\[
P_{st,k,v,w,q,g,p} = P_{st-k-1,v,w,q,g,p} + X_{10r,v,w,q,g,p} - X_{11r,v,w,q,g,p}
\]

\[
t \geq SD_v, \ v \in VP, \ w \in WP, \ q \in QP, \ g \in GP, \ p \in SP
\]

Processed fruit mass balance in cold storage (total)

\[
P_{stk_t} = \sum_v \sum_w \sum_q \sum_g \sum_p P_{st,k,v,w,q,g,p}
\]

\[
t \geq SD_v, \ v \in VP, \ w \in WP, \ q \in QP, \ g \in GP, \ p \in SP
\]

Out of specification fruit mass balance

\[
X_{OSstk_t,v} = X_{st,v,w,q,g} - \sum_p X_{10r,v,w,q,g,p} - X_{11r,v,w,q,g,p}
\]

\[
t \geq SD_v, \ v \notin VP, \ w \notin WP, \ q \notin QP, \ g \notin GP, \ p \in SP
\]

Stock of fruit out of specification

\[
OS_{stk_t} = OS_{stk_{t-1}} + \sum_v \sum_w \sum_q \sum_g X_{OSstk_t,v} - \sum_v \sum_w \sum_q \sum_g X_{10r,v,w,q,g,p} - \sum_v \sum_w \sum_q \sum_g X_{11r,v,w,q,g,p}
\]

\[
t \geq SD_v, \ v \notin VP, \ w \notin WP, \ q \notin QP, \ g \notin GP, \ p \in SP
\]

Total mass balance in cold storage

\[
stk_t = NP_{stk_t} + P_{stk_t} + OS_{stk_t} \quad t \geq SD_v
\]

Third party storage

\[
TP_{stk_t} = stk_t - STKMX \quad t \geq SD_v
\]

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.

\[
\sum_v X_{st,v} \leq \sum_s y_{mx,s} \cdot MPC \cdot S
\]

\[
t \geq SD_v, t \in CDM \ \forall m, v, s
\]

\[
\sum_s y_{mx,s} = 1
\]

3.10. Objective function

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

\[
PROFIT = \sum_r (ISP_r + IWF_r + IOSF_r)
\]

\[
- \sum_r RMC_r - \sum_r (WFCC_r + CMC_r)
\]

\[
- \sum_r TLC_r \quad t \geq SD_v
\]

where

Income per product sale

\[
ISP_r = \sum_v \sum_w \sum_q \sum_g \sum_p PP_{p,v,w,q,g,p} \cdot X_{11r,v,w,q,g,p}
\]

\[
t \geq SD_v, \ v \in VP, \ w \in WP, \ q \in QP, \ g \in GP, \ p \in SP
\]
Income per waste fruit sale:

\[ IWF_t = PWF \cdot \left( \sum_v \left[ \sum_w \left( \sum_{t'} \left[ \sum_q \sum_{g} X_{2t',v,w} + \sum_v \sum_{t'} \sum_q \sum_{g} X_{2t',v,w} \right] \right) \right] \]  

\[ + \sum_v \left[ \sum_t \left[ \sum_q \sum_{g} X_{3t,v,w} \right] \right] \]  

\[ t \geq SD_v \forall v, w \in WP, p \in SP \]

Income per out of specification product sale

\[ IOSF_t = POS \cdot \sum_v \sum_t \sum_q \sum_{g} \sum_{m} XOS_{i,v,t,q,m} \]  

\[ t \geq SD_v, v \notin VP, w \notin WP, q \notin QP, \ g \notin GP \]

Cost per raw material purchase

\[ RMC_t = \sum_v \sum_q \sum_{g} CR_v \cdot X_{1t,v} \]  

\[ t \in HP \forall v \]

Cost per fruit cooling

\[ WFCC_t = CC \cdot \left( \sum_{t'} \sum_v \sum_w \sum_{t'} \sum_q \sum_{g} X_{2t',v,w} \right) \]  

\[ t' \in HP_v, t \geq SD_v \forall v, w, q, g \]

Cost per cold fruit maintenance

\[ CMC_t = MC \cdot \sum_t Tstk_t \]  

\[ t \geq SD_v \]

Labor cost

\[ TLC_t = \sum_m \sum_{t} Y_{m,s} \cdot LCS \]  

\[ t \in CDM \forall m, s \]

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 assignment  
\( WP \): product to waxing assignment  
\( QP \): product to quality assignment  
\( GP \): product to gauge assignment  
\( SP \): 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)  
\( XOS_{i,v,t,q,m} \): out of specification fruit (kg/day)  
\( X_{10t,v,w,q,g} \): fruit to cold storage (kg/day)  
\( X_{11t,v,w,q,g,p} \): fruit delivery (kg/day)  
\( NPstkr_{t,v} \): non-processed fruit stock per variety (kg)  
\( NPstkrT \): total non-processed fruit stock (kg)  
\( Pstkr_{t,v} \): processed fruit stock (kg)  
\( OSstkr_{t,v} \): out of specification stock (kg)  
\( stkr_{t,v} \): total fruit stock (kg)  
\( TPstkr_{t,v} \): third party storage

Parameters

\( A \): average value  
\( SD \): standard deviation  
\( DPC_{t,v} \): fraction of waste in pre classification  
\( DQC_{t,v} \): fraction of waste in quality classification  
\( DGC_{t,v} \): 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  
\( STKMKX \): 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:

$$\text{Total profit} = \frac{\text{sales income}}{C_0} - \frac{\text{raw material cost}}{C_0} - \frac{\text{labor costs}}{C_0} - \frac{\text{cooling costs}}{C_0}$$

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.](image-url)
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 harvest” 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.

References