AN OPTIMIZATION MODEL FOR PLANNING FRUIT TRANSPORT FROM COLD STORAGES TO PACKING PLANTS

Wladimir E. Soto-Silva
Programa de Doctorado en Ingeniería y Tecnologías de la Información, Universidad de Lleida
Investigador visitante del Centro de Estudios en Alimentos Procesados
Av. San Miguel N° 3425, Talca, Chile
wsoto@utalca.cl

Marcela C. González-Araya
Departamento de Modelación y Gestión Industrial, Facultad de Ingeniería, Universidad de Talca, Merced 437, Curicó, Chile
mgonzalez@utalca.cl

Lluis M. Pla-Aragones
Departamento de Matemática, Universidad de Lleida, Universidad de Lleida
73, Jaume II 25001 Lleida, Spain
lmpla@matematica.udl.cat

ABSTRACT

Aiming to support fruit transport planning from cold storages to processing factory, an optimization model that considers cold storages opening is developed. This model aims to minimize transportation and cold storages opening costs, in order to reach processing factories demand, don not ultra pass factories capacities and fruit quantities kept in cold storages. This model is applied to a study case from a processing factory located in O'Higgins Region, Chile.

KEYWORDS. Integer Linear Programming, Transport Planning, Fruit Industry.

1. Introduction

Chile expects to become a food power until the end of this decade. In this sense, to develop researches for improving agribusiness transport and warehousing logistics is necessary.

Nowadays, processing plants have storage constraints, especially in the peak of the season, being necessary outsource this resource, in order to guarantee a constant fresh fruit flow to processing plants.

The fresh fruit supply chain can have different configurations, but the participants in each stage are the same (Verdouw et al., 2010). A review of optimization models for supporting agribusiness decisions can be found in France and Thornley (1984), Glen (1987), Lucas and Chhajed (2004), Ahumada and Villalobos (2009), Weintraub and Romero (2006) and Audsley, Sandars (2009) and Bjorndal et al. (2012)

The Chilean fruit supply chain is represented in Figure 1, which is adapted from Jang et al. (2002).

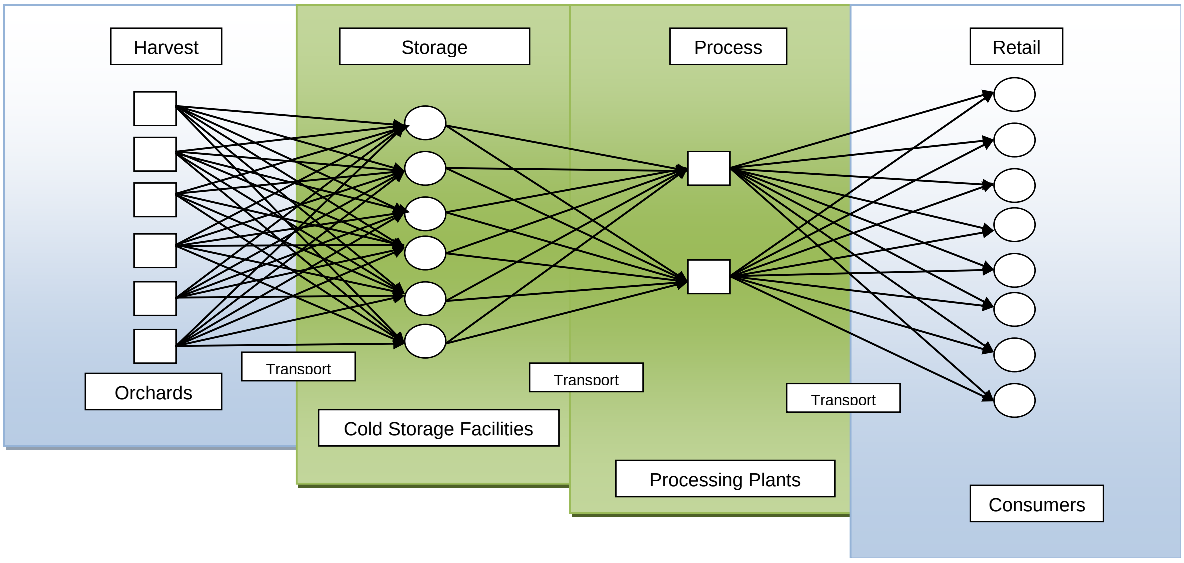

FIGURE 1 CHILEAN FRUIT SUPPLY CHAIN

The fruit harvest is done by producers (orchards owners) and it is transported from the orchards to either processing plants or cold storages. In both cases, the owners of the fruit are the processing plants, which decide where to send it according its quality.

For deciding the cold storage technology it is important to determine the fruit maturation and deterioration quality process (Plà y Nadal, 2013).

In Chile, three kind of cold storage technology is used:

- Conventional Cold Storage (CC): the temperature control is done by a thermostat, allowing to keep fruit for three months;
- Smart Fresh Storage (SF): a diffusion system of Smart Fresh (a phytoregulator) is incorporated for diminishing fruit deterioration, allowing to keep fruit for six months;
- Controlled Atmosphere Storage (CA): the storage atmosphere is controlled, i.e., oxygen, carbon dioxide and nitrogen concentrations are regulated as well as humidity and temperature, allowing keeping fruit for nine months.

Every processing plant need to plan the fruit transport from each cold storage to its facility, so, this plan must be done according to available trucks and drivers (Hsiao *et al*., 2010).

In Chile is common that every processing plant has more than one warehouse to storage fruits (own or rented).

2. Proposed Model

The mathematical formulation of proposed model for minimizing transport and storage opening costs is presented in this section. A review of optimization models developed to support transport planning can be found in Mulá et al. (2006) y Mulá et al. (2010).

Sets

P: Set of processing plants,
F: Set of fruit varieties,
V: Set of trucks,
I: Set of warehouses,
G: Kind of cold storages, where $G = \{f = \text{CC}, s = \text{SF}, a = \text{CA}\}$,
C_i: Set of different cold storages in warehouse i,
C_{ig}: Cold storages of type g, $g \in G$, in warehouse i, $i \in I$, where $C_{if} \cup C_{is} \cup C_{ia} = C_i$.

Parameters

D_{fp}: Daily demand of fruit f, $f \in F$, from processing plant p, $p \in P$,
A_v: Capacity of truck v, $v \in V$,
TT_{cp}: Travel times from cold storage c of warehouse i, $c \in C_i$, and processing plant p, $p \in P$.

H_v: Maximum daily driving hours of truck v, $v \in V$,
M_v: Maximum daily number of trips for truck v, $v \in V$,
R_v: Minimum daily number of trips for truck v, $v \in V$,
W_g: Penalty cost for opening a cold storage of type g, $g \in G$,
N: Maximum number of trucks that can daily transport fruit from each warehouse,
S_{icf}: Stock of fruit f, $f \in F$, in cold storage c, $c \in C_i$, of warehouse i, $i \in I$.

Decision Variables

X_{icvfp} = Kilograms of fruit f, $f \in F$, transported from cold storage c, $c \in C_i$, of warehouse i, $i \in I$, to processing plant p, $p \in P$, in truck v, $v \in V$,

Y_{icvp} = Number of trips from cold storage c, $c \in C_i$, of warehouse i, $i \in I$, in truck v, $v \in V$, to processing plant p, $p \in P$.

Mathematical Formulation

$$\sum_{i \in I}\sum_{c \in C_i}\sum_{v \in V}\sum_{p \in P} C_{cvp} * Y_{icvp} + \sum_{i \in I}(W_f * \sum_{c \in C_{if}}\sum_{f \in F}\sum_{v \in V}\sum_{p \in P} X_{icfvp} + W_s * \sum_{c \in C_{is}}\sum_{f \in F}\sum_{v \in V}\sum_{p \in P} * X_{icfvp} + W_a * \sum_{c \in C_{ia}}\sum_{f \in F}\sum_{v \in V}\sum_{p \in P} * X_{icfvp}) \tag{1}$$

s.t.

$$\sum_{i \in I}\sum_{c \in C_i}\sum_{v \in V} X_{icfvp} \geq D_{fp} \qquad \forall p \in P, f \in F. \tag{2}$$

$$X_{icfvp} \leq A_v * Y_{icvp} \qquad \forall i \in I, c \in C_i, f \in F, v \in V, p \in P. \tag{3}$$

$$\sum_{i \in I}\sum_{c \in C_i} TT_{cvp} * Y_{icvp} \leq H_v \qquad \forall v \in V, p \in P. \tag{4}$$

$$\sum_{v \in V} Y_{icvp} \leq N \qquad \forall i \in I, c \in C_i, p \in P. \tag{5}$$

$$\sum_{i \in I}\sum_{c \in C_i}\sum_{p \in P} Y_{icvp} \leq M_v \qquad \forall v \in V. \tag{6}$$

$$\sum_{i \in I}\sum_{c \in C_i}\sum_{p \in P} Y_{icvp} \geq R_v \qquad \forall v \in V. \tag{7}$$

$$\sum_{v \in V}\sum_{p \in P} X_{icfvp} \leq S_{icf} \qquad \forall i \in I, c \in C_i, f \in F. \tag{8}$$

$$Y_{icvp} \in Z^+ \quad \forall i \in I, c \in C_i, v \in V, p \in P. \tag{9}$$

$$X_{icfvp} \geq 0 \qquad \forall i \in I, c \in C_i, f \in F\ v \in V, p \in P. \tag{10}$$

The objective function (1) aims to minimize costs associated to fruit transport from warehouses to processing plants and related costs for opening different kind of cold storages (*f* = CC, *s* = SF, *a* = CA).

The set of constraints (2) establishes fruit demand of each processing plant must be satisfied. Set of constraints (3) limits the maximum daily fruit kilograms transported per truck, according to its number of daily trips. Set of constraints (4) states the maximum driving hours per truck. Set of constraints (5) represents the maximum number of daily trips that can be managed by each warehouse. Set of constraints (6) and (7) refers to the maximum and minimum number of daily trips per trucks, respectively. Set of constraints (8) limits the daily fruit kilograms transported from a warehouse to processing plants according to its available stock. Set of constraints (9) and (10) are related to the nature of decision variables, integer and continuous, respectively.

3. Case Study

The model was applied to a fruit processing plant located in O'Higgins Region, Chile, using date from 2013 season.

The model was run in CPLEX Optimization Studio v.12.3, in a personal computer with AMD Turion (tm) 64x2 Processor Mobile Technology TL-60 2.00 GHz. Memory: 2 G. Hard disk: 512 G.

The company has 6 warehouses, with 47 cold storages, and processes 5 fruit varieties. For fruit transport has 6 trucks, where two trucks (1 and 2) have a capacity of 8,100 kg, two trucks (3 and 4) have a capacity of 18,900 kg, and two trucks (5 and 6) have a capacity of 21,600 kg.

The result obtained for a day in 2013 season is shown in Table 1.

TABLE 1. FRUIT TRANSPORT PLANNING FROM WAREHOUSES TO THE PROCESSING PLANT

			Trucks					
Warehouses	Storages	Kind of Cold Storage	1	2	3	4	5	6
1	1	CC	1	1	0	0	0	0
2	7	CC	0	0	0	1	1	0
3	17	SF	2	0	0	0	0	0
4	19	CC	0	2	0	2	0	0
5	26	CC	0	0	1	0	0	2
6	36	CC	1	0	2	0	0	0
Total Trips per Truck			4	3	3	3	1	2

The results show that, for satisfying daily plant demand, a total of 16 truck trips are necessary, where fruits from the six warehouses are collected; which are divided in 5 conventional cold storages and 1 Smart Fresh storage. In addition, only truck 1 reaches the maximum number of trips and, on the other hand, only truck 5 reaches the minimum.

The fruit kilograms transported by variety are detailed in Table 2.

TABLE 2. TRANSPORTED FRUIT KILOGRAMS BY VARIETY

		Variety 1		Variety 2		Variety 3		Variety 4		Variety 5	
		Trucks		Trucks		Trucks		Trucks		Trucks	
Warehouses	Storages	1	2	3	6	1	3	4	5	2	4
1	1	6,900	8,100	0	0	0	0	0	0	0	0
2	7	0	0	0	0	0	0	18,900	21,300	0	0
3	17	15,000	0	0	0	0	0	0	0	0	0
4	19	0	0	0	0	0	0	0	0	16,200	37,800
5	26	0	0	18,900	41,100	0	0	0	0	0	0
6	36	0	0	0	0	8,100	36,900	0	0	0	0
Transported Kilograms		30,000		60,000		45,000		40,200		54,000	
Plant Demand		30,000		60,000		45,000		40,200		54,000	

According to table above, total of transported fruit kilograms is 229,200 kg, satisfying the processing plant demand.

The model prioritizes to pick fruit from cold storages with lowest penalty costs. For this reason, in the analyzed day the model suggests to open 5 conventional cold storages. Additionally, as the demand of variety 1 is not totally satisfied with the stock of fruit in cold storage 5, the model proposes opening the closest cold storage with this variety, being this the Smart Fresh cold storage 17. Finally, the model does not suggest opening a controlled atmosphere cold storage because fruit demand can be covered by less expensive opening cold storages.

The obtained solution will change according to the analyzed period of season, so it is expected, at the end of the season, the model suggests to open more controlled atmosphere cold storages, because they will keep more fruit stock.

4. Conclusions

In this research was developed a mathematical model to optimize daily fruit transportation planning from several warehouses to different processing plants, considering opening selection of cold storages, in order to reduce operational costs. In this sense, it is relevant to consider each kind of cold storage technology; because of they have different opening costs and different maximum times for maintaining fruit in stock.

The computational time consumed by the model is low, so its implementation is feasible for supporting transportation planning decisions.

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