Transport Planning in Processing Plants for the Fruit Industry

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Abstract: Processing plants are central for the operation of fruit supply chains. One of the main aspects to consider is fruit transportation to the processing plant. Hence, this work proposes a mixed integer linear programming model to support the fruit transport planning from the storage facilities to the processing plant. The aim of the model is to minimize the daily transportation costs and associated costs of different storage facilities from where fruits are supplied to the plant in order to meet the demand. The model considers plant processing capacity, fruit demand, number and type of trucks available and the inventory of fruit in each type of storage facilities. The model was applied to a real case study of a processing plant located in the O'Higgins Region (Chile), where reported savings only in transport costs reached about 23 percent.

1 INTRODUCTION

Catalá et al. (2013) agreed that in the recent years, there has been an increase in the development of optimization models to support decision making regarding supply chain management (SCM) in manufacturing industries. However, this increase in proposals has not been observed in the agribusiness sector (Plà et al., 2014). This is also confirmed by reviews on models applied to the agribusiness sector done by France and Thornley (1984), Glen (1987), Lucas and Chhajed (2004), Weintraub and Romero (2006), Ahumada and Villalobos (2009), Audsley and Sandars (2009), Bjorndal et al. (2012) and Soto-Silva et al. (2015).

The review of Ahumada and Villalobos (2009) presented a classification of optimization models proposed for the agri-food industry into two categories: models for perishable agricultural products (fresh products) and models for non-perishable products. The fruit industry embraces both products because as most of the fruit production is consumed in fresh, there are another important part processed (e.g canned) and consumed as long life product.

In supply chains, storage plays an important role; however, in the supply chain of perishable products, this activity is critical. Hence, it is common to find the fruit industry organized as fruit supply chains with three main stages: production, storing and processing-distribution (Nadal-Roig and Plà, 2015). In this regard, Verdouw et al. (2010) stated that the management of the supply chain of fresh fruit requires special considerations to maintain freshness and product quality, involving more limited delivery times and more controlled storage conditions (low temperature, less punts, etc.). Farmers perform actions to minimize losses due to quality deterioration like cool storage. Pittia et al. (1999) and McHugh and Senesi (2000) discussed different techniques of preserving the raw material quality over time. These techniques refer to microbiological and blanching treatments for preserving fruit quality in cold storages facilities.

The development of optimization models to support fruit supply chain management and coordination, Blanco et al. (2005) presented a model for production scheduling in an apples and pears packing plant. The authors proposed a mixed integer programming model to plan the production process, in order to maximize profit estimated by fruit sale incomes less raw material purchase, cold storage and labor costs. As result, an annual schedule considering packaging plant constraints was

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developed. In a related research, Blackburn and Scudder (2009) presented a mathematical model to determine the loss in value of perishable agricultural products depending on the type of storage. This research corroborated that cold storages allow fruit industry for a better fruit quality during postharvest.

In the literature, there are also optimization models to support decisions in distribution and transportation for supply chains of perishable and non-perishable agricultural products. For instance, Mula et al. (2006) and Mula et al. (2010) presented reviews of the different optimization models applied to transportation planning in supply chains. More recently, Nadal-Roig and Plà (2015) proposed a linear programming model that minimizes the associated costs to transport from cooperatives to a fruit logistic center. The model scheduled the daily transport routes in order to satisfy the demand of the logistic center, at a minimal cost. Furthermore, the authors emphasized another complex task in fruit supply chain like the planning and coordination of different agents involved in production, processing, storage and distribution.

Thus, it seems from literature that managing fruit storages of different types and the coordination of a fruit supply chain requires a sound transport planning. Currently, optimization models to decision support for daily transportation planning from warehouses or storage centers, with different types of cold storages, to the processing plants has not been yet proposed. Even less, there are such optimization models used in practice to the knowledge of authors. Surprisingly, transportation models for nearby industries of the primary sector like forestry (Weintraub et al., 1996) or sugar industry (Lopez-Milan and Plà-Aragonés, 2014) have been developed successfully, but not to the fruit industry (Oliva, 2011). So that, to cover this gap in this paper, a mixed integer linear programming model to find the optimal transport planning from warehouses with different cooling technologies to a fruit processing plant is proposed. The model minimizes the total cost associated with transport and proposes the opening of the cold storage facilities grouped in warehouses. Finally, we applied the model to a real case study in a processing plant of Japanese plums and canned peaches.

Therefore, this paper is structured as follows. In section 2, the description of the problem of transport and storage in Chile is presented. In section 3, the proposed mathematical model for transportation planning in the fruit industry is presented. In section 4, a case study obtained from a Chilean company for establishing fruit transportation planning is carried out. In section 5 are presented the conclusions as well as further research.

2 FRUIT STORAGE AND TRANSPORT TO PROCESSING PLANTS

The planning and coordination of different agents involved in production, processing, storage and distribution are unavoidable tasks in a fruit supply chain. In the network of fruit supply chains, each stakeholders transport the fruit downstream to the next level in the chain. The activities developed at each level are briefly described below.

Harvesting is done by producers who are generally the farms' owners. Crops are collected using containers, which are transported from the farm to the storage facilities (cold storages), or directly to the process plant. Note that the plant is responsible for assigning the fruit destination. Each plant purchases the fruits and takes care of his retirement from the orchards.

The storage time depends on the fruit and variety. For example, apples and pears, depending on the variety, may be stored for up to 9 months. On the contrary, cherries are not stored. They must be processed the same day they are harvested. However, for all stored fruit, the cooling system must be considered to control the ripening process of these (Nadal-Roig and Plà, 2015).

Processing is performed in processing plants with a different degree of complexity. The simplest process is exhibited in packing plants where fruit is intended for fresh consumption. Minimal processing is gaining popularity as a way to diversify the production offered to the market.

Retailing varies depending on product quality, added value and amount sent to the market. Although the usual way is that retailing firms place orders to processing plants and distribute the fruit among consumers, it is also common for small and local production the access to the market from storage facilities hold by producers.

In general, the fresh fruit arrives to processing plants from different cold storage facilities, according to the plants and retail demands. So, an important issue for managers is to decide which and when a cold storage facility must be opened in order to pick the fruit up for satisfying the demands. This decision depends on the stored fruit and technology of the cold storage facilities.

The structure of the fruit supply chain can have different configurations, but the basic elements inherent in the stakeholders remain the same (Verdouw et al., 2010). For example, at the bottom of the fruit supply chain in Chile are the farmers, who sell their products to processing plants. The processing plants either store the fruit in storage centers (which are owned or rented) or process the fruit immediately in the plant. This approach is different from other countries like Spain, where farmers usually are grouped in cooperatives owning storages centers supplying to the processing plants. In this case, there is not a change of ownership for the fruit, because these stages are managed by a cooperative of producers integrated in a sole company.

Different types of cold storage facility are available, and these are: the Conventional Cold technology storage facility (CC), where the temperature control is performed by a thermostat, thereby maintaining the fruit for a period approximately of 3 months; The Smart Fresh technology storage facility (SF), which has a built-diffusion system phytoregulator for protecting the fruit from the effects of ethylene during storage, allowing the fruit to maintain a period approximately of 6 months; and Controlled Atmosphere technology storage facility (CA), where the concentrations of oxygen, carbon dioxide and nitrogen are controlled as well as the temperature and humidity. That is, the atmosphere in the storage facility is controlled, thereby maintaining the fruit for a period approximately of 9 months. Generally, plants have more storage, in order to have fruit for processing throughout the year. There is also possible some changes between types of storages. For instance, the transformation of a conventional cold storage facility into a Smart Fresh depends on the demand and need for each company according to their estimated time of fruit supply.

In Chile, in each cold storage facility is only possible to store one type of fruit at a time (Oliva, 2011). According to the Center for Natural Resource Information (CIREN, 2005), in 2004, Chile had approximately 201 agro-companies and 2,349 cold storage facilities.

Quite often, the fruit transportation from warehouses is coordinated by processing plants to satisfy subsequently the orders they receive at the same time from retailers. This transport must be planned according to the availability of trucks and / or drivers (Hsiao et al., 2010), in order to meet the demand of different varieties. Also, it is important to consider daily variations of processed fruit quantities, because of unforeseen changes in demand or in order priorities. Moreover for the fruit transportation, a fleet of trucks is rent and the payment thereof is made according to the number of daily trips made. On the other hand, the availability of a fixed number of trucks is necessary to ensure a minimum and maximum number of daily (Oliva, 2011).

3 MODEL FOR PLANNING THE DAILY TRANSPORTATION STORAGE FACILITIES TO THE PROCESSING PLANTS

The formulation of the proposed model for planning the daily transport from the storage facilities to processing plants model is presented. The indices, parameters and decision variables of the model can be found in the Appendix.

Mathematical formulation

$$\begin{aligned}&\sum_{i\in I}\sum_{v\in V}\sum_{p\in P} C_{ivp}Y_{ivp}\\ &+\sum_{i\in I}(W_f\sum_{c\in C_{if}}\sum_{f\in F}\sum_{v\in V}\sum_{p\in P}X_{icfvp}\\ &+W_s\sum_{c\in C_{is}}\sum_{f\in F}\sum_{v\in V}\sum_{p\in P}X_{icfvp}\\ &+W_a\sum_{c\in C_{ia}}\sum_{f\in F}\sum_{v\in V}\sum_{p\in P}X_{icfvp})\end{aligned}\tag{1}$$

s.t

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

$$\begin{aligned}&\sum_{f\in F}\sum_{c\in C}X_{icfvp}\\ &\leq A_vY_{ivp}\qquad \forall i\in I, v\in V, p\in P.\end{aligned}\tag{3}$$

$$\sum_{i\in I}\sum_{p\in P}TT_{ivp}Y_{ivp}\leq H_v\qquad \forall v\in V\tag{4}$$

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

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

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

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

$$X_{icfvp} \geq 0 \qquad \forall\, i \in I, c \in C_i, f \in F\; v \in V, p \in P. \tag{9}$$

$$Y_{ivp} \in \mathbb{Z}^+ \qquad \forall\, i \in I, v \in V, p \in P. \tag{10}$$

The objective function minimizes the costs associated with transport from cold storage to processing plants and the fixed costs for the opening of the different types of storage facilities. Thus, the objective function can be decomposed as follows:

Minimize: transportation cost + fixed cost for opening conventional cold storage facilities + fixed cost for opening *Smart Fresh* storage facilities + fixed cost for opening controlled atmosphere storage facilities.

The aim of the fixed costs is to prioritize the quality of the fruit to be processed, where the technology of cold storage facility opening is relevant. For this reason, the model has to consider that in conventional cold storage facilities fruit quality deteriorates before than fruits stored in controlled atmosphere. Thus, the fixed for opening conventional cold storage facilities is lower than that for Fresh and controlled atmosphere. Likewise, fixed for opening Smart Fresh storage facilities is lower than that for controlled atmosphere.

Constraint (2) states that the amount of fruit removed from storages by trucks should be greater than or equal to processing plant demand. Constraint (3) restricts the amount of fruit transported daily from a warehouse to a plant by a truck must be less or equal to the capacity of the truck by the number of trips made on the day between the warehouse and plant. Constraint (4) shows that each truck must not exceed the maximum number of usage hours. The TT_{ivp} parameter counts the total hours of a trip between a warehouse and a plant, where it is considered the truck travel time, holding time, the loading and unloading time in both the plant and store. The restriction (5) shows that must not exceed a certain amount of trips per each truck, between a store and a plant, because the production capacity of the plants. Constraint (6) limits the maximum number of truck trips and the constraint (7) limits the minimum number of truck trips. Thus, the constraints 6 and 7 balance the number of trips that can make the trucks and therefore, maintaining a fixed number of trucks available for transportation daily. Constraint (8) states that shipped weight in kg for a certain kind of fruit to a processing plant, from a particular cold storage must be less or equal to the stock of fruit available. Constraints (9) and (10) correspond to no negativity and integrality of the decision variables, respectively.

4 CASE STUDY OF A CHILEAN COMPANY

The studied company is currently one of the fruit leading exporters of Chile. Their orchards are located in the Metropolitan Region and the Region of O'Higgins.

The company stores two types of fruits in cold, with these Japanese plums and canning peaches.

In 2013, a total of 642.0 t of Japanese plums and 9392.2 t of canning peaches stored in cold storage facilities, which must be transported during the season to the plant for processing. In addition, the company has six warehouses with 62 cold storage facilities, of which 23 have a capacity of 400 bins, 30 have a capacity of 600 bins, and nine have a capacity of 1000 bins. It should be noted that one bin is a reservoir with a capacity of about 400 kg. The distribution of cold storage in warehouses according to their cold technology is presented in Table 1.

Table 1: Number of cold storage facilities in the warehouses according to its technology.

	Storage facilities' type			
Warehouse	**CC**	**SF**	**CA**	**Total**
#1	5	-	-	5
#2	2	8	-	10
#3	-	4	-	4
#4	2	7	6	15
#5	2	2	2	6
#6	10	6	6	22
Total	**21**	**27**	**14**	**62**

As it is seen in Table 1, the company has 21 CC storage facilities (Conventional Cold), 27 SF storage facilities (Smart Fresh) and 14 CA storage facilities (Controlled Atmosphere). The company performs the distribution of the fruit to cold storage warehouses, based on the experience of the charge of the process, taking into account the distance between each field and warehouse, plus the availability of cold storage facilities.

For the transportation of fruit, the company has four trucks. These trucks are assigned to different warehouses based on the experience of the plant manager and production manager of the company.

Transportation decisions to the plant are made daily, based on the orders of costumers accepted for the day. Three different instances are considered for

Table 2: Processing plant demands for each analyzed day.

				Day 0		Day 30		Day 90	
Fruit	**Type**	**Variety**	**Variety**	**Bins**	**t**	**Bins**	**t**	**Bins**	**t**
Plum	Japanese plums	**V1**	Angeleno	80	32	0	0	0	0
	Japanese plums	**V2**	Black Diamond	0	0	0	0	0	0
	Japanese plums	**V3**	Larry Anne	0	0	0	0	0	0
	Japanese plums	**V4**	Saphiro	0	0	0	0	0	0
Peach	Canning peaches	**V5**	Andross	40	16	80	32	50	20
	Canning peaches	**V6**	Ross Peach	20	8	40	16	30	12
	Canning peaches	**V7**	Loadell	0	0	0	0	25	10
	Canning peaches	**V8**	Bowen	0	0	40	16	40	16
	Canning peaches	**V9**	Carson	40	16	35	14	35	14
	Canning peaches	**V10**	Klampt	40	16	0	0	0	0
	Canning peaches	**V11**	Everst	0	0	0	0	20	8
	Canning peaches	**V12**	Hesse	0	0	15	6	15	6
	Canning peaches	**V13**	Kakama	0	0	0	0	0	0
	Canning peaches	**V14**	Tirrenia	40	16	0	0	0	0
	Canning peaches	**V15**	Rizzi	0	0	0	0	0	0
			Total	**260**	**104**	**210**	**84**	**215**	**86**

Table 3: Scheduled trips from the warehouses to processing for each analyzed day.

	Day 0 Truck				Day 30 Truck				Day 90 Truck			
From	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4
W1	0	1	1	0	1	1	0	0	0	1	0	0
W4	2	0	0	0	2	0	0	0	2	0	0	0
W5	0	0	0	1	0	0	1	1	0	0	0	1
W6	2	0	0	0	0	0	0	0	0	0	1	0
# Trips	4	1	1	1	3	1	1	1	2	1	1	1
Tons	41.6	12.8	26.4	23.2	31.2	11.6	14.8	26.4	20.8	12.8	26.0	26.4

the analysis of the case study. These instances correspond to the production planning of the processing plant in three different days. The first instance is the starting day of the processing fruit period, day 0, where all the stock is available. For the second instance, we consider the data of the day 30th after the beginning of operations at the plant. At this time, the stock of stored fruit has decreased a 25%. The third instance is the day 90th after the beginning of operations at the plant. At this time, fruit available in cold storage has decreased a 59% compared to the beginning of the season.

In Table 2, the demands of the plant for each fruit varieties are presented in each of the proposed instances (analyzed days).

As it is seen in Table 2, the first instance (day 0) has a demand of 104 t, and 6 varieties of fruit are claimed. In the second instance (day 30) the demand is 84 t, where five types of fruit are demanded, and in the third instance (day 90) has a demand of 86 t, with a demand of 7 varieties of fruit.

Note that in all three scenarios some of the varieties of fruit were not shipped, because in the days analyzed were not required. However, these varieties were required on other days during planning.

The number of trips by trucks and the warehouses which trucks should be directed are presented in Table 3.

As it is seen in Table 3, a total of 7, 6 and 5 trips to the processing plant are required at day 0, 30 and 90 respectively. Considering the three instances, the truck #1 (truck type 1) is always performing most of the trips representing the 40%, 37% and 24% of the total number of tons transported at day 0, 30 and 90 respectively. The results concerning to the number of fruit tons to be transported from different warehouses to the processing plant in each truck are presented in Table 4.

As it is seen in Table 4, 104.0 t are transported from the storage facilities to the processing plant at day 0, satisfying the demand of each of the varieties. The model aims to use the fruit for those storage facilities whose are Conventional Cold type (CC), opening 5 cold storage facilities of this type, followed by the opening of Smart Fresh (SF) 3 storage facilities, and finally, gives 1 controlled atmosphere (CA) storage facilities, just to minimize

Table 4: Transport planning from warehouses to processing plant at day 0.

	Warehouse	**W1**		**W4**			**W 5**		**W 6**		
	Type	**CC**	**CC**	**CC**	**SF**	**SF**	**SF**	**CA**	**CC**	**CC**	
	Cold Storage #	**1**	**5**	**20**	**22**	**25**	**37**	**40**	**43**	**46**	
Variety	**Truck #**										**Total (t)**
V1	# 1	-	-	0.8	-	-	-	-	-	-	32.0
	# 2	12.8	-	-	-	-	-	-	-	-	
	# 3	18.4	-	-	-	-	-	-	-	-	
V5	# 4	-	-	-	-	-	16.0	-	-	-	16.0
V6	# 3	-	8.0	-	-	-	-	-	-	-	8.0
V9	# 1	-	-	-	-	4.0	-	-	-	4.8	16.0
	# 4	-	-	-	-	-	-	7.2	-	-	
V10	# 1	-	-	-	16.0	-	-	-	-	-	16.0
V14	# 1	-	-	-	-	-	-	-	16.0	-	16.0

the fixed costs of opening of different types of cold storage facilities. The opening of the CA storage facilities is influenced because the demand for the variety of fruit could not be satisfied with that was stored in the standard CC and SF storage facilities. In relation to transport costs and fixed opening costs of cold storage, in Table 5 the results for the three instances studied are presented.

Table 5: Transportation costs and opening fixed costs of cold storage facilities (in $USD*).

	Transportation costs	**Storage facility opening fixed**	**Total cost**
Day 0	317	91	**408**
Day 30	244	93	**337**
Day 90	285	104	**389**

* 1 USD = 555.15 CLP, exchange rate in February 21st of 2014 (www.bcentral.cl).

Note that the instances (days 0, 30 and 90) are real cases in the processing plant, so that the demand and stocks at the beginning of the day are real for the company.

Comparing the cost of transportation plans derived from the optimal solution of each instance versus actual planning that took place at each studied day in the company, the first instance reported savings of 22%, in the second scenario savings of 26% and in the third scenario 20% saving respectively representing an average savings of 23% during the season.

5 CONCLUSIONS

In this research, a mathematical optimization model with the aim to plan the daily transport from the storage centers in the fruit processing plant, minimizing the costs associated with transport is presented. The model also performs an optimal opening of the storage facilities depending on the type presented technology associated with the cooling of each of them. The processing plant makes both its own and leased storage to have fruit throughout the season progresses and thereby meets demand.

For the Chilean case, it is important to segment the cold storage facilities according the cool technology, since a plan about what cold storage facilities will be opened first for the season, in order to ensure the quality of the fruit that is sent to process is needed. The mathematical formulation presented by Nadal-Roig and Plà (2015) is the basis for the extension developed in this paper where various processing plants and different types of storing facilities are considered.

As the model is intended for practical use, the computational performance of the model is analyzed under two scenarios in which the amount of storage centers, trucks fleet, demand, availability of fruit in cold storage and quantity of plants vary, obtaining the optimal solution in both cases. For the smaller scenario (6 warehouses, 62 cold storage facilities with 10 million kilos of stored fruit and a processing plant), the model provided the optimal solution after 10 seconds, while for the scenario where the parameters mentioned increased twice, the optimal solution was reached in 3600 seconds. This shows that for the more complex cases that could be expected in the Chilean fruit industry, it would be possible to deliver an optimal solution in a reasonable computational time.

Finally, the model is applied to a real case of a fruit processing plant in the O'Higgins Region, Chile, which has 62 cold storage facilities, grouped into 6 warehouses. The company processes varieties of peaches and plums, having a total of 15 varieties. Each season holds approximately 10 million kilos of fruit. The model, when applied to three days observed in the 2013 season, achieved cost savings average transport of about 23 percent relative to the value observed transport cost. Regarding the reduction in the costs of opening cold storage, it has been possible to demonstrate the solution delivered by the model is consistent with the priority established in practice for opening storage facilities.

Future extensions of the model are exploring to incorporate the temporary nature in the transport planning, i.e. including tactical decisions like the transportation planning for the entire season. Hence, the optimal size of the fleet could be assessed. This research would require good estimates of both truck type's characteristics and the demand for each variety of fruit to be processed in a season.

Finally, it would be interesting to integrate this model into existing mathematical models that consider operations in the orchards or the filling of different types of cold storage, depending on the quality of harvested fruit.

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APPENDIX

Sets, parameters and variables used in the formulation

The sets used by the model are the following:

P: Processing plants set.

F: Varieties of fruit stored in different storage facilities available for the storage of products.

V: Set of trucks available.

I: Set of storages available for the fruit

C_{if}: Set of Conventional Cold storage facilities in the storage *i*

C_{is}: Set of 'Smart Fresh' storage facilities in the storage *i*

C_{ia}: Set of Controlled Atmosphere in the storage *i*.

C_i: C_{if} U C_{is} U C_{ia} : Set of storage facilities in the storage *i*

The parameters considered by the model are the following:

D_{fp}: Fuit demand f, $f \in F$, from the processing plant p, $p \in P$.

A_v: Maximum capacity for the truck v, $v \in V$.

TT_{ivp}: Travel time that warehouse i, $i \in I$, with the truck v, $v \in V$, with destination to the processing plant p, $p \in P$.

H_v: Maximum number of hours of driving for the truck v, $v \in V$.

M_v: Maximum number of trip for the truck v, $v \in V$.

R_v: Minimum number of trip for the truck v, $v \in V$.

W_f: Opening fixed cost for the storage facilities type *f (Type CC: Conventional cold).*

W_s: Opening fixed cost for the storage facilities type *s (Type SF: Smart Fresh).*

W_a: Opening fixed cost for the storage facility type *a (Type CA: Controlled atmosphere).*

C_{ivp}: Transportation cost from the warehouse i, $i \in I$, with the truck v, $v \in V$, with destination to the processing plant p, $p \in P$.

N: Number of trucks allowed removing fruit to the warehouses

S_{icv}: Stock available in the storage *i*, and storage facility c, $c \in C_i$, of the fruit f, $f \in F$.

The decision variables of the model are the following:

X_{icvfp} : kg transported from the storage *i*, from the storage facility c, $c \in C_i$, and fruit type v, $v \in V$, and truck f, $f \in F$, with destination to the processing plant p, $p \in P$.

Y_{ivp}= Number of trips from the storage *i* done by the truck $v, v \in V$, to the processing plant p, $p \in P$.