Optimizing planning decisions in the fruit supply chain

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TESI DOCTORAL

Optimizing Planning Decisions in the Fruit Supply Chain

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I dedicate this research to my wife Paola, my children, Pía and Gonzalo,
and my future son; to my parents, Carlos and Norma, my sister Karina and my brother Carlos,
and to my grandparents, Irma and Hernán.

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Abstract

The Chilean agro-industry has experienced a steady increase of industrialized fruit exports over the last decade, reaching a total volume increase of 107% and 185% in value. This growth means that the fresh fruit supply chain, either for preserved, frozen, dehydrated, fresh fruit or juices, requires support in order to make management increasingly more efficient. So far, some problems directly related to the need to improve the sector´s competitiveness have not yet been addressed. In the last few years production costs have risen mainly due to labor shortage and poor quality of raw material (fresh fruit). That is why, improving the supply chain efficiency and thus the agro-industry competitiveness, particularly in the center-south region of the country, requires new tools that could support decisions making regarding the fresh fruit supply chain. Within this context, the general objective of this research was to develop a set of tools aiming to support tactical decisions that could enhance management of fresh fruit purchasing, cold storage, transport, and opening of cold chambers.

Three important contributions are made in this research study. The first one has to do with the state-of-the-art of supply chains management, by reviewing optimization models applied to fresh fruit supply chains. The second one consists in providing four tools to support tactical decisions regarding fresh fruit supply chains, specifically, three mathematical models for the optimization of decisions that support the selection of growers and the purchasing of fresh fruit, their subsequent storage and transportation, and the proposal of a mathematical model for cold storage management. The third contribution is the proposal of a Decision Support System (DSS), which aids in decisions about growers selection and purchasing of fresh fruit, as well as its subsequent storage and transportation.

Finally, there is an important additional contribution that involves the application of the models to real cases. All models proposed were created and validated with the support of agro-industries from the center-south region of the country having problems with their supply chain, which were addressed in this research study.

Content

Chapter 1:

General Introduction

1.1 Background

Agro-industries are spread out throughout the whole country in Chile, with more than 4,000 small, medium, and large-size operations (Redagrícola, 2016). The food sector accounts for approximately 10% of the Gross Domestic Product (Bravo, 2010), 20% of employment and 18% of national exports (Central Bank, 2010). The Central Bank (2010) points out that fruit production, wine making, poultry, pork, red meat production, as well as processed foods are the main areas.

Furthermore, Chilean exports of industrialized fruit experienced a sustained growth between the years 2002 and 2012; processed fruit went up from US$ 272 million in the year 2002 to US$ 834 million in 2012, equivalent to 306% growth. In addition, Chile's share of world exports of these products has increased from 3.56% to 4.45% (Redagrícola, 2016).

Chile is the world's leading exporter of dehydrated apples, accounting for 33.3% of world exports. Similarly, Chilean agro-industry ranks second among exporters of dehydrated plums and third in frozen raspberries, generating one fifth of the world exports of these products. With respect to raisins exports, Chile is in third place and is the fourth exporter of canned peaches worldwide (Redagrícola, 2016).

Estimates made by Chilealimentos (2010) regarding the destination of fruits and vegetables production, allow us to conclude that approximately 52% of the national supply goes to agro-industrial processing and 57% of planted surface production intended for harvest is also predestined to processing plants.

In the agro-foodstuff industry, total fruit exports increased from 14.3% to 17.2% between 2000 and 2014 in volume, and from 17.8% to 23.1% in value, in the same period. The volume exported has doubled, increasing 107% in a decade, while the value of exports has gone up even more significantly (185%) (Redagrícola, 2016).

In each of the stages of the agriculture supply chain, decisions aiming to optimize resources associated with each stage should be considered, as shown in Figure 1.1.

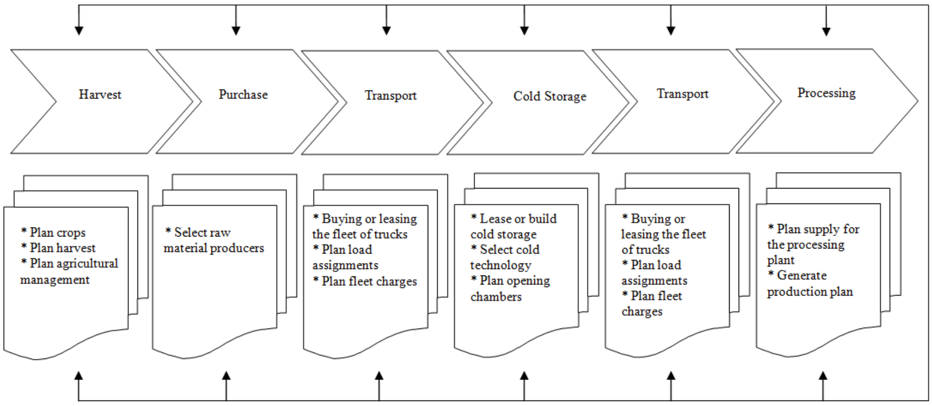

Figure 1.1 Decision map in the agriculture supply chain (Soto-Silva *at al.*, 2017)

There is research work that seeks to respond to each one of the decisions involved in every stage; for example, for harvest, Ferrer *et al.* (2007), Arnaout and Maatouk (2010), Morande and Maturana (2010), Bohle *et al.* (2010), Van der Merwe *et al.* (2011) and Ampatzidis *et al.(*2013); for suppliers selection (purchasing), Hammervoll (2009), Guneri *et al.* (2009), Chai *et al.* (2013) and Anojkumar *et al.* (2014); for transport, Eskigun et al. (2005), Kawamura et al. (2006), Gorman et al. (2010), Nadal-Roig and Pla (2015), Soto-Silva *et al.* (2016b) and Lamsal *et al.* (2016); for storage, Broekmeulen (1998), Wang *et al.* (2011) and Aung and Chang (2014); and for processing, Blanco *et al.* (2005), Masini *et al.* (2007), Cittadini *et al.* (2008), Catala *et al.* (2013) and Munhoz and Morabito (2013).

Nevertheless, some interesting, worth investigating gaps within the agriculture supply chain can be identified. Among them, the optimization of the selection process of fresh fruit suppliers and the subsequent cold storage. Final destination of this fruit is the processing plant, where keeping post-harvest fruit quality is an important concern. Furthermore, an appealing issue to tackle is management of the different cold storage regimes. Both problems have not received much attention in recent years (Soto-Silva *et al*., 2016b).

Although there is a sizable increase in optimization models in supply chain planning, this is not reflected in the agro-industrial sector (Catalá *et al.,* 2013). In addition to that, in their respective bibliographical reviews, Lucas and Chhajed (2004), Lowe and Preckel (2004), Weintraub and Romero (2006), Ahumada and Villalobos (2009), Audsley and Sandars (2009), and Soto-Silva *et al.* (2016a), note the lack of research in agro-industry, not only in the aforementioned topics, but also in issues related to the entire agriculture supply chain.

1.2 Problem Statement

As stated in the previous section, some gaps in the literature which have not been dealt with which would be interesting to address were found while working in conjunction with agribusinesses from the Maule and O'Higgins Regions, in Chile; at present, local companies do not have the necessary tools to make the processes involved more efficient.

Figure 1.2 shows the general structure of the supply chain for fruit destined for processing in Chile.

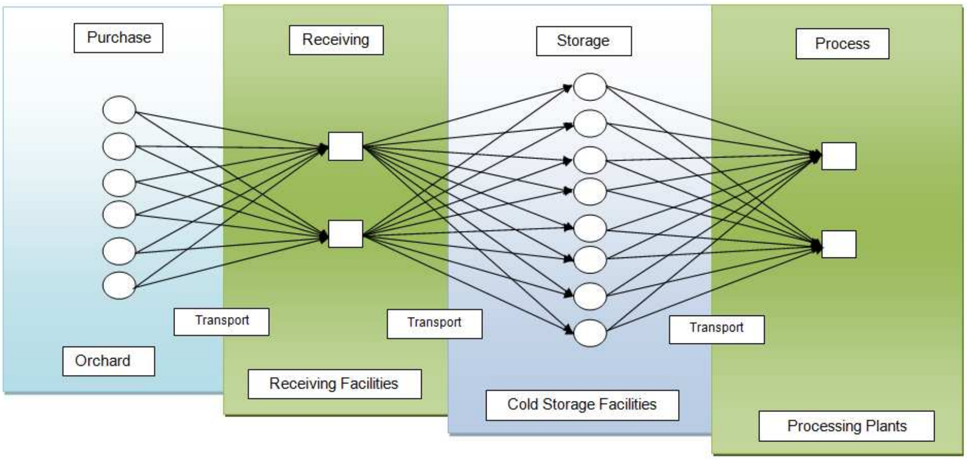

Figure 1.2 General structure of the supply chain for fruit destined for processing in Chile (Soto-Silva *et al.*, 2017)

Figure 1.2 shows the general structure of the supply chain of fresh fruit which has as its final destination a processing plant, be it for juice, frozen or dehydrated fruit, pulp, preserved or fresh fruit. The problems mentioned above can be found in this chain, namely, management of fresh fruit purchasing and storage, and handling of the opening of cold storage chambers in cold storage facilities.

The fresh fruit supply to a processing plant begins with the purchasing of fruit still in the orchard, from different growers. Companies owning orchards in Chile usually do not satisfy the fruit demand in the processing plants, so they must go out and buy fruit. Once the fruit is purchased, it is taken to the processing plant where physiological conditions are checked, and accounting and payment procedures to the growers are performed; then the fruit is sent to a cold storage facility, which can be owned or leased, as is the general case in the country.

The first problem was found in the fresh fruit purchasing and subsequent storage stage. This is because there is a pool of approximately 250 growers who provide fruit to the agro-industry; this is seasonal fruit whose quality needs to be maintained over time until it is processed in the plant. Due to the limited processing capability of processing plants in Chile, the processing season can take at least 9 months. During this period, the physiological conditions of the fruit must be kept stable, otherwise the yield conversion ratio in the processing plant will be directly affected. In order to achieve this, different cold storage technologies are available in the storage chambers which assure a 3-9 month post-harvest life.

The fruit quality invariability can be handled in two directly related ways; the first one is making a good purchasing, that is, selecting the growers who offer the best quality fruit; the second one is making sure that the cold storage conditions are the best for each type of fruit purchased.

Moving along the fresh fruit supply chain destined for processing, the in-plant processing stage comes next. This may be done to get juice, pulp, and dehydrated, preserved or fresh fruit. In a typical situation, one of the main features of this stage is the limited processing capacity of a plant, which makes it necessary to efficiently manage the opening of the cold chambers containing fresh fruit of the season, so as to avoid affecting the quality of the stored fruit and be able to deliver the best quality fruit and meet production goals as well.

This point is important because a conversion ratio which is periodically evaluated is used in the fruit agro-industry. This ratio indicates the amount of fresh fruit needed per kilogram of finished product. If during the purchasing process, cold storage, transport, and opening of the cold chambers, management or planning was poor, a larger amount of fresh fruit to be processed will be required in order to satisfy the demand for a finished product. In contrast, if all those stages were properly completed, a smaller amount of fruit will be required to meet such a demand.

Everything discussed above can translate into costs reduction and economic benefits for the company. If one takes into account that an average processing plant in Chile needs about 30,000 tons of fresh fruit per season in order to obtain approximately 3,000 tons of finished product, and, in addition, one considers that 1 ton of fresh fruit costs about US$45, and its average monthly storage is about US$7.89, savings resulting from management of purchasing, storage, transport, and opening of cold chambers during the processing season would be quite considerable, as long as those stages of the supply chain are optimally and efficiently managed.

1.3 Research Objectives

This research on the supply chain of fresh fruit was carried out in Chile, particularly in processing plants from the center-south region of the country in areas where the agro-industry is the main economic activity, and where there is little support for decision making through the use of optimization models.

The general objective of this research was to develop a set of tools to support tactical decisions in the fresh fruit supply chain. The main focus of these tools is to improve management of purchasing, cold storage, transport, and opening of cold chambers.

The specific objectives of the research were the following:

a) To identify management optimization models in the literature aiming to support decision making regarding the fresh fruit supply chain.
b) To formulate a mathematical programming model to support tactical decisions on purchasing, storage, and transport of fresh fruit in order to minimize costs associated with the selection of growers and storage of purchased fruit.
c) To formulate a mathematical programming model to support tactical decisions on the opening of cold chambers and fruit transport from storage facilities to processing plants, in order to minimize storage and transportation costs, as well as quality deterioration of the fresh fruit stored.
d) To develop a Decision Support System (DSS) for the purchasing, storage and transport of fresh fruit, in order to facilitate decision makers´ selection of growers, purchasing, storage, and transport of the fruit at the lowest cost.

These specific objectives were set based on the methodology described below.

1.4 Methodology

The following working methodology was utilized in this research:

a) ***Information Survey.*** First, an information survey on the issues to be addressed was carried out. This information was elicited through interviews made to personnel working in the supply chain of fresh fruit, particularly in the supply, reception, logistics, and production sections. In addition, guided visits to the processing plants were made in order to examine the current situation; analyses of reports containing data on the processes involved in the problem were made on site.
b) ***Diagnostics.*** After the information gathering, a diagnosis of the situation was made taking into consideration the data collected during the process, the information given by the processing plant personnel, and the information picked up during the guided visits to various agro-industries.

c) ***Literature Review***. Subsequently, once the information was gathered and the diagnosis made, a bibliographic review of optimization models applied to a fresh fruit supply chain was done using primary sources, such as books and scientific journals in the field. This was done in order to characterize both the optimization models which have been developed to date, and the possible existing tools used to tackle the problem in question.

d) ***Mathematical Modeling***. As there are two main problems, namely, purchasing, storage and transport of fruit, and the optimal management of cold chambers, both part of the fresh fruit supply chain, mathematical models aimed to find optimal solutions to each of these were developed. Simultaneously, the necessary data gathering was carried out in order to perform the runs utilized while testing the proposed models. The parameters used had to be pre-processed so as to meet the entry requirements of each model.

e) ***Application and Validation.*** To test the proposed model, two case studies were done in two different regions of Chile. In the first one, the proposed solution to the problem of fresh fruit supply and storage management was implemented and validated in a dehydrated apples fruit plant in the Maule Region. In the second one, the solution to the problem of cold storage and transport management was validated in a plum dehydrating plant in the O'Higgins Region. Besides, the opinions of fruit fresh purchasers, distribution managers, post-harvest personnel, and owners of storage facilities and processing plants were also considered during validation.

f) ***DSS Development.*** Finally, a Decision Support System (DSS) was developed that allowed the efficient management of purchasing, storage, and transport of fresh fruit destined to processing plants. In addition to evaluating its functionality and correct operation in a case study, by applying it in an apple dehydrating plant in the Maule Region, this system was also validated by personnel responsible for other fruit processing plants.

1.5 Structure of the thesis

This doctoral thesis consists of six chapters; four of them have the structure of research articles. The first chapter corresponds to the introduction and the last one provides the general conclusions drawn from the investigation. The chapters are briefly summarized below:

Chapter 1 provides an introduction and the problematics to be tackled, as well as the objectives, the methodology, and the contributions of the study. Finally, the general structure of the thesis is presented.

Chapter 2 presents a literature review of optimization models applied to fresh fruit supply chains. The main objective of this chapter is to provide a theoretical framework for this research study and to analyze different gaps in the field of optimization models used in the fruit agro-industry.

Chapter 3 has to do with mathematical programming models to optimize the logistics of the fresh fruit supply chain. On site, it was noted that to date there are no models that can support decision making regarding fresh fruit purchasing, storage, and transport. The problem is solved through the use of entire mixed linear programming models, whose results were compared with traditional planning methods in a fruit dehydrating plant.

Chapter 4 introduces an optimization model for the opening of cold storage chambers and the transportation of stored fruit. The model was born out of the need to optimize the use of different cold chambers available for the storage of fresh fruit. The problem is solved with an entire mixed linear programming model, where the planning provided by the proposed model is compared with the current one, in a fresh fruit processing plant.

Chapter 5 shows a computational tool, a Decisions Support System (DSS), designed to support decisions for the purchasing, storage, and transport of fresh fruit. This was developed in the NetBeans IDE programming platform, in conjunction with the ILOG OPL Development Studio IDE, Cplex and Excel optimization software.

Chapter 6 deals with the general conclusions of the thesis work related to the importance of optimization models in the agro-industry supply chain. Future research studies are presented at the end of this chapter.

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Chapter 2:

Operational Research Models Applied to the Fresh Fruit Supply Chain

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Abstract

The fresh fruit supply chain is characterized by long supply lead times combined with significant supply and demand uncertainties, and relatively thin margins. These challenges generate a need for management efficiency and the use of modern decision technology tools. We review some of the literature on operational research models applied to the fresh fruit supply chain. It is an attempt to gain a better understanding of the OR methods used in the revised papers apparently independent and oriented towards problem solving rather than theory developing. We conclude by outlining what we see as some of the significant new problems facing the industry like the lack of holistic approaches for the design and management of fresh FSC. Finally, some future research directions are indicated.

Keywords. Fruit Operations Research. Supply Chain Fresh Fruit. Agricultural Planning

2.1 Introduction

In the recent years the fresh fruit sector has grown significantly fueled by an increasing demand of customers concerned in healthier diets, food quality requirements and all year around availability of fruit (Reynolds *et al.,* 2014). Fresh fruit is defined by the Food Agricultural Organization's (FAO, 2014) as: the portion of a plant housing seeds commonly eaten as dessert (i.e. tomatoes are considered vegetable). The previous definition is important for this review to avoid the inconsistencies in segmenting fruits, flowers and vegetables reported by Shuckla and Jharkharia (2013). Fresh fruit are consumed raw, whether whole or prepared. Prepared refers to minimally processed such as peeling, slicing or shredding, having not undergone any treatment (chemical, physical or biological) to ensure preservation other than chilling. According to FAOStat (2012) the fresh fruit production has been increasing worldwide by a 20% between 2003 and 2012. It is observed a notable trading activity during the same period, doubling the overall imports, being the European Union (EU) who dominates the import/export market. Other aspects affecting such development are the industrialization of the production process, governmental food safety regulations and price variability. The industrialization refers to the use of mechanical means, the adoption of good agricultural practices and the automatization of sorting, selecting and packaging fruits including sometimes some minor minimal processing tasks. As a consequence of the globalization, competitors, regulations and the increasing demand for high quality, value-added and customized products, the fresh fruit sector tends to be specialized and integrated vertically in Fruit Supply Chains (FSC) to become more competitive and dynamic. The fast handling and seasonable attributes of fruits in relation to high volatility of supply and demand makes the storage a critical activity to manage robust FSC. In addition, fresh fruits quality is related with parameters like sweetness, crunchiness and strengthens, connected in some way with the optimal ripeness of the fruit. Hence, special considerations to preserve freshness and product quality require more limited delivery deadlines, more controlled storage conditions, better quality of end-products and minimize losses due to deterioration (Dabbene *et al*., 2008; Verdouw *et al.,* 2010), making the underlying supply chain more complex and harder to manage than other supply chains (Ahumada and Villalobos, 2009). These challenges generate a need for management efficiency and the use of modern decision technology tools (Lowe and Preckel, 2004; Akkerman *et al.,* 2010). As FSC comprise all the activities to procure, produce and distribute fruits to the end customers, production, transport and distribution planning needs to be integrated in order to be optimized simultaneously (Mula *et al.,* 2010).

The present review aims at determining current state of the art in operational research models applied to the fresh FSC in an attempt to gain a better understanding of the mathematical modelling methods used in these applications. Future trends are pointed out to provide a basis for future research. Hence, we intend to do that (1) reviewing the literature on planning models for fresh FSC, (2) classifying the literature by different criteria (3) considering other planning models of interest to fresh FSC and (4) outlining the fresh FSC perspectives in the future. To achieve this, we did an extensive research of scientific papers including optimization or operational research (OR) models for fresh fruit regardless the modeling approach and covering all or part of the FSC.

2.1.1 **Taxonomy**

In view of the proposed classification of the literature done by Mula *et al.* (2010) and Ahumada and Villalobos (2009), a synthesis of both has been performed including additional criteria used to organize and present this review. In this sense, as shown in Figure 1, we have proposed different taxonomies to classify the revised papers and giving a multidimensional approach of each one. So that, the proposed taxonomy in this paper considers the following six classification criteria:

Decision level: regarding the scope of decisions there are three levels: strategic, tactical or operational corresponding to long, medium and short time horizon respectively. Ahumada and Villalobos (2009) identified activities such as financial planning and network design as strategic; the harvest planning, crop selection and scheduling and labor as tactical; and activities such as production scheduling, transportation planning and storage as operational. Such a classification might become a bit difficult when dealing with activities moving between strategic and tactical decisions, or between tactical and operational (Shukla and Jharkharia, 2012; Farahani *et al.*, 2014).

Analytical modeling approach: considering the mathematical methods or mathematical relationships used to model and solve the problem within the context of fresh FSC.

Purpose: models are classified based on the type of decision variables related to different activities: sowing, production, harvesting, distribution or inventory. The nature of the objective function (revenue, profit, cost or other function) to optimize (maximize or minimize) and whether the objective involves one or more criteria are also revised.

Practical application: the existence of a real problem inspiring the paper or a case study are important to value the applicability and interest of the model beyond the theoretical approach. Furthermore, we register other relevant information such as the type of fruit and the country of origin where the case study was developed.

Novelty: This aspect is interesting to highlight the author's contribution and originality of the paper to the fresh FSC with respect to contemporary literature, i.e at the moment the revised paper has been published.

Research segmentation by journal: the scope of the journals where revised papers are published may be useful to understand the motivation of the research and the multidisciplinary approach.

Works done in non-perishable, processed and long shelf life fruit like canned, dried or transformed in juice or wine overlapping part of the fresh FSC have been discussed apart in this review. The decisional problems regarding fresh FSC for canning or processing plants or wineries are similar to human consumption of fresh fruit as all of them are consumers.

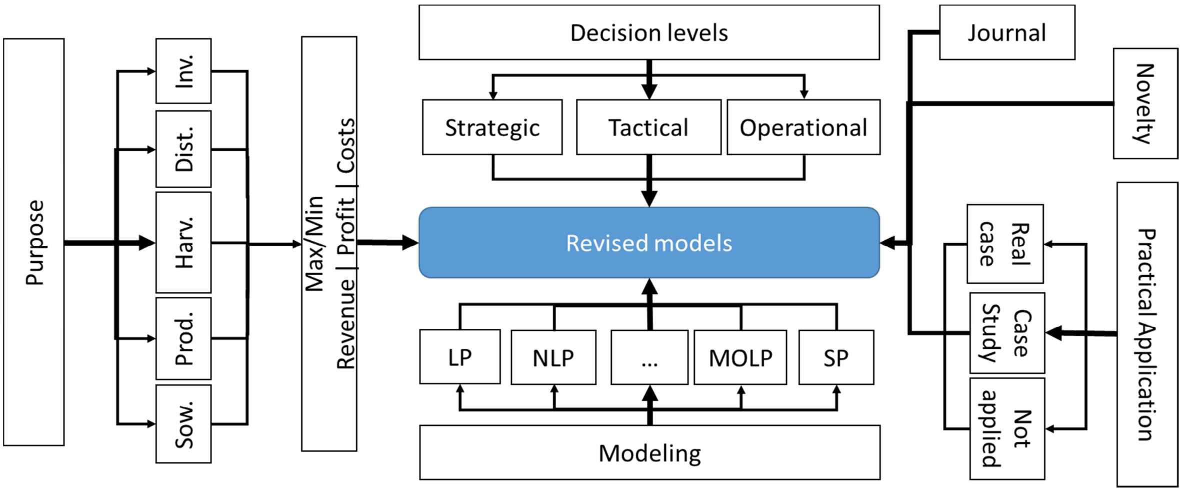

Figura 2.1. Classification criteria of the revised papers for this review

2.1.2 Review Methodology

A comprehensive search of related research papers from last decades was applied to produce a synthesis of peer-reviewed literature. We searched papers published in international peer-reviewed journals or books from the main electronic bibliographical sources (Scopus, Web of Science) using different keywords. We have used the following keywords to do the search: “Fresh fruit” AND “Supply chain” AND (“Optimisation” OR “Operational Research” OR “Operations Research”). The outcome depended on which fields are performed the search. For instance, only 9 papers were found in Scopus searching the proposed keywords within the Title, Abstract or Keyword’s list of the paper. However, 127 were found if the keywords appeared in whatever part of a paper. This keywords’ set was difficult to be fixed because always there were listed many irrelevant papers. In the end, an individual examination paper by paper was necessary to make a final decision. Other keywords like (“harvesting” OR “scheduling” OR “management”) were also used to catch susceptible papers of being included. From the collected material, we filtered the papers according to the following rules: (i) the papers should be written in English language, (ii) they include decision variables modeling the production planning or logistics of fresh FSC, (iii) the papers satisfying the previous rule but dealing with other perishable agricultural product like vegetables instead of fruit were also selected but processed apart. From the second rule, we included some articles dealing with the production planning of fresh fruit regardless they are not for fresh consumption. This is the case, for example, in the paper by Ferrer *et al.* (2007), in which the authors present a scheduling model for grape harvesting for wine production. The third rule enabled us to consider several papers in the field of perishable products. Double checking with keywords in the Title, Abstract or Keyword’s list was done arising few references more. We use back-tracking to find earlier relevant sources (e.g. Willis and Halon, 1976), and forward-tracking in Web of Science to find literature that are referring to the central sources. We also looked for recent surveys in related domains in order to find additional sources excluding conference papers.

We can classify the revised papers in two categories. The first category gathers papers dealing with Fresh FSC or one fruit or family of fruits. In these papers, fruit is not processed, just packaged and delivered to retailers for marketing. The second category regroups papers either sharing or overlapping part of the FSC, or in neighboring domains or perishable products with similar problems to the FSC (e.g. vegetables). Examples of that would be Munhoz and Morabito (2001) who illustrate problems related with the processing of juicy fruits, or Ahumada and Villalobos (2011a, 2011b) who show similar problems in the tomato industry.

The organization of this paper is as follows: in the next section we introduce some background about the fresh FSC, decision levels and some examples. In section 3 we present supply chain models that have been developed for fresh fruit, and we classify them according to the different criteria presented in figure 1. Later on, in section 4, we present some related models to fresh FSCs and in section 5 we outline a view of OR in FSCs. In the last section we provide a summary of the review and conclusions.

2.2 Fresh fruit supply chains

2.2.1 Background

It is only during the last ten years that the agri-food industry in general and the fresh fruit sector in particular has recognized and started embracing SCM as a key concept for its competitiveness (Lucas and Chajed, 2004; Tsolakis *et al*., 2014). Ahumada and Villalobos (2009) performed one of the first reviews about planning models in agricultural supply chains (ASC), however the lack of holistic proposals to ASC was evident. Their revision included papers since 1985 focusing on different agricultural products, perishable and non-perishable, mostly vegetables. Other SCs related to livestock production such as cattle, pig, milk or meats were not included. Even though, given the broad spectrum of products FSC had a limited coverage. Audsley and Sandars (2009) revised also OR models in agriculture but limiting the review to British developments. This revision did not include the perspective of FSC, but gave interesting arguments to explain observed shortcomings when approaching the modelling of the agricultural sector in the past. More recently, Zhang and Wilhelm (2011) presented an interesting revision of OR models in specialty crops industry covering fruits, vegetable, grapes and wine, ornamentals, tree nuts, berries and dried fruits. However, they included products out of the scope of this review according to the FAO’s definition of fresh fruit and the SC perspective was lacking too.

On the other hand, Shukla and Jharkharia (2012) summarized the existing literature from 1991 to 2011 in fresh production such as fruits, flowers and vegetables. The main characteristic of the review is that all papers were focused in perishable, deteriorate, edible, and fresh production. They also categorize literature by geographic region and journal, but do not emphasize the decision problems nor OR methods.

Focusing more on supply chain characteristics, Farahani *et al*. (2014) presented examples of the typical decisions taken in general SCs, while Tsolakis *et al.* (2014) presented the kind of decisions in agricultural SCs. These decisions are divided into strategic, tactical and operational, linked to a temporary horizon. Hence, operational decisions are more related to pricing and demand; tactical decisions are related to mid-term contracts in purchasing, transportation, IT and facilities; and strategic decisions are related to the long term assets, operations and company’s vision and mission.

2.2.2 Structure of the fresh FSC

The fresh fruit sector is competitive and dynamic, with many uncertainties related to fruit biology, diseases, climate and market, plus added logistical complexities. A newly planted fruit tree takes years to start producing fruits and the strategic decision of planting must be made before demand and selling prices are known (Zhang and Wilhem, 2011). Therefore, operational and tactical decisions need to be taken more accurately and permitting tactical adjustments rapidly. In this context, flexible decision support and models play an important role to help managers through the entire FSC which are in continuous change because of the different sources of uncertainty to cope with. The structure of the FSC is not static but it can be diverse regarding the number of agents taking part in the different activities involved ranging from farming (i.e. land cultivation, fruit production and harvesting), processing, packaging, warehousing, transportation and distribution to marketing. Changes in the industrialization of activities, stakeholders, uncertainty in production, legal regulations and new trends in markets and demand make this sector being more unforeseen than others whose SC designs have been consolidated and used for years (Huang, 2004). Because of the wide variety of FSCs structures, Verdouw *et al.* (2010) presented a basic model with templates for the design of fresh and processed FSCs in a deep detail. Nadal-Roig and Plà (2015) formulated a transportation planning model for a FSC in which a fruit logistic center was supplied of fruit by different storing centers on demand during the non-harvesting season. The general structure of the FSC described by Nadal-Roig and Plà (2015) is common in modern FSCs, although the actors taking part may vary. Therefore, as problems and needs in terms of modelling can be different, slight variations in the structure can be found in literature. For instance, Canavari et al. (2010), emphasized the role of producers and considered three different FSCs (1) where a producer sends the fruit to a small retailer who selects their suppliers on the basis of the price (2) where a producer sends the fruit to large retailers and (3) called “ho.re.ca” by the authors where the producer sends the fruit to driving actors such as hotels, restaurants and catering companies. Similarly, Srimanee and Routray (2012) modeled the FSCs in Thailand as a network of five different FSCs linked by the producer who established a percentage of production according to the final consumer (local market, local collectors, cooperatives, assemblers and export agents). A different approach was presented by Zang and Fu (2010) who presented four different FSCs designs existing in China (worldwide 1st fruit producer) with different characteristics, stakeholders and limitations. All the revised FSCs had different emphasis in some part of the design or in one or several components, therefore there are some specificities not shared between them.

2.3 Fresh fruit Supply chains, supply chain planning and modeling approaches

A summarized overview of the twenty-eight revised papers is presented in Table 2.1 including a brief description and the goals to achieve for each one.

Table 2.1. *Summary of all the revised papers dealing with fresh FSC*

Author	Description of the research
Willis and Halon (1976)	A mathematical model based on dynamic programming, which optimizes the resources needed in the apples fields. Furthermore, the model plans the kind of variety to plant on the farm
Starbird (1988)	A dynamic programming model to sequence the loading of storage facilities at an apple packing plant.
Maia (1997)	A mixed integer linear programming model to support fruit preservation planning.
Broekmeulen (1998)	A mixed integer linear programming model to improve the effectiveness of the operations of a distribution center for fruits and vegetables. The model seeks the optimal production planning for the allocation and storage at tactical level. To verify the correctness of the model, a one year simulation is performed.
Gigler *et al.* (2002)	A dynamic programming model to optimize agri chains.
Hester and Cacho (2003)	A dynamic simulation model representing bio-economic characteristics of an orchard. The evaluation of different alternatives allows the user to identify the management strategy maximizing the net present value over a period of 15 years.
Vitoriano *et al.* (2003)	Two mathematical formulations are presented to plan and organize the inputs necessary for crop production in a certain time horizon. Discrete time and continuous time approaches are compared.
Blanco *et al.* (2005)	A planning model to maximize the profit of an apple and pears packaging plant. The costs considered are the raw material purchase, storage and labor costs. Income is calculated from different selling prices according to the varieties of fruit.
Caixeta-Filho (2006)	A linear programming model to manage orange orchards to maximize the total profit. A fractional decision variable to represent the part of the orange grove to be harvested each time period. Quality measures to determine the suitability for fresh consumption or to the juice industry is balanced.
Ortmann *et al.* (2006)	Two models (a graph theoretical model of a single product and a mathematical programming model with multiple products) to determine the maximum weekly flow or yield fresh fruit through the national export infrastructure in South Africa are introduced.
Masini *et al.* (2007)	An extension of the model presented by Masini *et al.* (2003). It combines the optimal production of fresh fruit and juice concentrate introducing a penalty for unmet demand of customers.
Ferrer *et al.* (2007)	A mixed integer linear programming for scheduling grape harvesting operations to wine production. The model takes into account the costs of harvesting, and loss of quality of the grapes to delay the harvesting and processing.
Cittadini *et al.* (2008)	A multi-objective model to plan the production of fruit. The model optimizes manpower utilization and maximizes fruit production. The model explores the robustness of solutions against price variations focusing on cherries.
Bai *et al.* (2008)	A practical fresh produce inventory control and shelf space allocation model was built and presented upon the situation as described by a UK retailer.
Van Der Vorst *et al.* (2009)	The authors propose an integrated approach towards logistics, sustainability and food quality analysis by introducing a new simulation environment, ALADIN^{TM}. A case example of pineapple illustrates the benefits of its use relating to speed and quality of integrated decision making.
Blackburn and Scudder (2009)	A hybrid model to design a supply chain of perishable foods, based on optimizing the value of marginal product over time was developed. The model considers the changing value of perishable foods over time that tends to decline according to quality deterioration.

Arnaout and Maatouk (2010)	This research presents a mixed integer linear programming for scheduling grape harvesting operations to wine production. Two heuristics are applied and compared to reduce the computational time. The model is based on that of Ferrer et al (2007) but adapted to be applicable in Europe.
Bohle *et al.* (2010)	Extension of a mixed integer linear programming model to a stochastic one in which the productivity of labor is an uncertain parameter. The study analyzes how labor affects the quality and quantity of fruit to harvest.
Morande and Maturana (2010)	A DSS aimed at allowing winemakers to make decisions like when to pick grapes, allocates processing vats and wine presses, and manage operations within the warehouse. The DSS was designed and validated with the assistance of winemakers in a collaborative research.
Amorim *et al.* (2012)	Production and distribution of perishable foods are integrated to optimize the freshness of fruit based on minimizing stocks of stored raw material. Two cases are compared depending on whether life’s products are fixed or variable.
Yu *et al.* (2012)	This paper studies a food-industry vendor management inventory system where a common replenishment policy is used to manage the inventories of a fast deteriorating raw material and a slow deteriorating product. An integrated model to obtain the total inventory and deterioration costs is given in a closed form and an exact algorithm to find the optimal solution of the model is developed.
Banaeian *et al.* (2012)	A nonparametric method, data envelopment analysis (DEA) was used to study the technical efficiency of producers with regard to effective resource allocation like energy utilization on greenhouse strawberry yield.
Ampatzidis *et al.* (2013)	Use of queuing theory to analyze the performance, and find optimal resource allocation such as machinery and labor in a harvest of fresh fruit.
Catalá *et al.* (2013)	A strategic planning model to analyze investment decisions in the fruit industry. Decisions variables are variety and density of fruit to plant, and different scenarios related to types of financing plans over time.
Velychko (2014)	The development of integrated methods and a model of preparing decisions in the logistics of fruit and vegetable servicing cooperative is presented. Possible alternatives and existing limitations in separate technological, logistical and marketing business processes are explored.
Lambert *et al.* (2014)	Impact on the Persian lime supply chain of orchard yield and fruit quality predictions.
González-Araya *et al.* (2015)	A mixed integer linear programming model to support planning decisions in an orchard, aiming to minimize the amount of resources used and ensuring the production of fruit with highest quality.
Nadal-Roig and Plà (2015)	A linear programming model for planning daily transport of fruit from warehouses to processing plants is presented, aiming to minimize transport costs.

2.3.1 Decision Level

The classification of the revised papers according to the decision level is presented in Table 2.2. As it is shown, there are six papers dealing with strategic decisions, nineteen related to tactical decisions and also fourteen at the operational level. While fifteen papers are devoted to one specific decision level, there are twelve papers that combine decisions at different levels like strategic-tactical or tactical-operational. Most of the strategic decisions consider the optimal mix of varieties to plant and how to replace them over time. These studies where presented as an analysis of the investment project in fruit production.

Table 2.2. *Decision levels for the papers analyzed*

Author	Decision level		
	Strategical	Tactical	Operational
Willis and Halon (1976)		X	X
Starbird (1988)		X	
Maia (1997)		X	
Broekmeulen (1998)		X	
Gigler *et al.* (2002)		X	
Hester and Cacho (2003)	X		
Vitoriano *et al.* (2003)			X
Blanco *et al.* (2005)	X	X	
Caixeta-Filho (2006)		X	X
Ortmann *et al.* (2006)	X	X	
Ferrer *et al.* (2007)		X	X
Masini *et al.* (2007)		X	X
Cittadini *et al.* (2008)	X	X	
Bai *et al.* (2008)			X
Van Der Vorst *et al.* (2009)	X	X	
Blackburn and Scudder (2009)		X	
Arnaout and Maatouk (2010)		X	X
Bohle *et al.* (2010)		X	X
Morande and Maturana (2010)			X
Amorim *et al.* (2012)		X	X
Yu *et al*. (2012)			X
Banaeian *et al*. (2012)		X	
Ampatzidis *et al*. (2013)			X
Catalá *et al.* (2013)	X		
Velychko (2014)		X	
Lambert *et al.* (2014)		X	
González-Araya *et al.* (2015)		X	X
Nadal-Roig and Pla (2015)			X

2.3.2 Analytical modeling approach

There is a variety of mathematical approaches used to model and solve decision problems related to revised fresh FSC. Table 2.3 displays the acronyms and corresponding meaning of the different mathematical modeling approaches considered for this review.

Table 2.3.- *Nomenclature used to classify the papers according the modeling approach*

Notation	Modeling Approach
ILP	Linear programming Mixed integer/Integer linear programming
NLP	Non-linear programming
MOLP	Multi-objective linear programming
SM	Simulation models
DP	Dynamic Programming
SP	Stochastic optimisation
HEU	Heurıstics algorithms and metaheurıstics
HYB	Hybridmodels

Table 4 is composed using the acronyms introduced in Table 2.3. As shown in Table 2.4, most of the papers preferred linear programming as modeling technique. From twenty-eight papers, sixteen are included in this category being the larger. This is due to the ability of ILP to model and solve real-life instances. The rest of papers used other methodologies less popular with three, two or one representatives. Also, most papers employed just one method and it was strange to find more than one method in a paper. Only, eight papers combined different methodologies either to compare them (Vitoriano *et al.*, 2003) or as an alternative to an unsuitable first approach to the problem (Ferrer *et al.*, 2007; Arnaout and Maatoukw, 2010; Bohle *et al.*, 2010) or just to refine and complement first approaches (Broekmeulen,1998; Hester and Cacho, 2003; Bai *et al.* 2008). Special mention deserves the hybrid approach of Lambert and al. (2014), who developed an expert system for predicting orchard yield and fruit quality of Persian lime making use of fuzzy logic. Later on they develop a simulation model to see the impact on the Persian lime supply chain.

Table 2.4.- *Modelling approaches used by the analyzed papers*

Author	Modeling approach of the reviewed works							
	ILP	NLP	MOLP	SM	SP	DP	HEU	HYB
Willis and Halon (1976)	X							
Starbird (1988)						X		
Maia (1997)	X							
Broekmeulen (1998)	X			X				
Gigler *et al.* (2002)						X		
Hester and Cacho (2003)		X					X	
Vitoriano et al. (2003)	X							X
Blanco et al. (2005)	X							
Caixeta-Filho (2006)	X							
Ortmann *et al*. (2006)	X							
Masini *et al*. (2007)	X							
Ferrer *et al*. (2007)	X						X	
Cittadini *et al.* (2008)			X					
Bai *et al*. (2008)							X	X
Van der Vorst *et al.* (2009)				X				
Blackburn and Scudder (2009)								X
Arnaout and Maatouk (2010)	X						X	
Bohle *et al.* (2010)	X				X			
Morande and Maturana (2010)				X				
Amorim *et al*. (2012)			X					
Yu *et al.* (2012)		X						
Banaeian *et al*. (2012)	X							
Ampatzidis *et al.* (2013)				X				
Catalá *et al*. (2013)	X							
Velychko (2014)	X							
Lambert *et al*. (2014)				X				X
González-Araya *et al.* (2015)	X							
Nadal-Roig and Plà(2015)	X							

2.3.3 Purpose

Depending on the FSC different production processes may be involved. In this section we pay attention to the coverage of the different stages involved in the proposed PSC models. The decision variables are taken into account to verify the stages considered along the production process of the PSC. For such purpose, we identified four types of decision variables related to: Planting (i.e. decisions on fruit and variety), Production (i.e. decisions on production planning and scheduling), Harvesting (i.e. decisions on harvesting means and season), Distribution (i.e. decisions on transport) and inventory (i.e. decision variables associated with the inventories in different storing places and systems). As seen in Table 2.5, revised papers considered in decreasing order decision variables associated to production, distribution and harvesting, respectively. Regarding the variables associated with inventory and sowing, the number of studies is lesser. However, seventeen of the papers presented a combination of decision variables, and only eleven papers focus on optimizing a single production stage.

Table 2.5. *Classification according the decision variables considered*

Author	Production stages or decision variables related to				
	Planting	Harvesting	Production	Distribution	Inventory
Willis and Halon (1976)	X	X			
Starbird (1988)		X			
Maia (1997)				X	X
Broekmeulen (1998)				X	
Gigler *et al.* (2002)				X	
Hester and Cacho (2003)	X	X	X		
Vitoriano *et al.* (2003)		X	X		
Blanco *et al.* (2005)			X		
Caixeta-Filho (2006)		X	X		
Ortmann *et al.* (2006)			X	X	
Masini *et al.* (2007)			X	X	X
Ferrer *et al.* (2007)		X			
Cittadini *et al.* (2008)	X	X	X		
Bai *et al.* (2008)				X	X
Van Der Vorst *et al*. (2009)				X	X
Blackburn and Scudder (2009)			X	X	
Arnaout and Maatouk (2010)		X		X	
Bohle *et al.* (2010)		X			
Morande and Maturana (2010)		X	X		
Amorim *et al.* (2012)			X	X	
Yu *et al.* (2012)					X
Banaeian *et al.* (2012)			X		
Ampatzidis *et al.* (2013)		X			
Catalá *et al*. (2013)	X		X		
Velychko (2014)			X	X	
Lambert *et al.* (2014)			X		
González-Araya *et al.* (2015)		X			
Nadal-Roig and Plà(2015)				X	X

Regarding the coverage of the fruit supply chain, there are two remarkable papers: Masini *et al.* (2007) and Cittadini *et al.* (2008). The former integrated production, inventory and distribution decisions. The latter considered decisions regarding growing, harvesting and production.

The objective function in most of the papers consisted in maximize the profit, net revenue or net present value. Fewer papers considered the minimization of costs (Starbird, 1988; Yu *et al.* 2012; Velychko, 2014, González-Araya *et al.* 2015). However, when calculating the income almost all the papers used constant prices ignoring variations over time in the market. This procedure is useful to compare different alternatives in the long term, but may reduce the applicability in the short or medium term. Only Broekmeulen (1998) simulated different scenarios of prices to test his model.

2.3.4 Practical application

Although there were three papers emphasizing modelling or resolution aspects by using numerical examples, all the rest were either based on real cases or case studies. Even though, not all of them were applied in a later stage. An important aspect for practical applications is the availability of real data and the collaboration with the sector. It is important to disclose whether the modeling approach presented in the revised papers relies on practical or theoretical data. Besides the practical applicability, Table 2.6 displays also the type of fruit and the country where the project is developed.

Table 2.6. *Applicability of the revised paper*

Author	Data		Other traits		
	Real Case	Case Study	Crops	Fruit	Country
Willis and Halon (1976)	X		Fruit	Apple	US
Starbird (1988)	X		Fruit	Apple	US
Maia (1997)	X		Fruit	Banana	Brazil
Broekmeulen (1998)		X	Fruit	-	Netherlands
Gigler *et al.* (2002)		X	Fruit	Banana	Netherlands
Hester and Cacho (2003)	X		Fruit	Apple	Australia
Vitoriano *et al.* (2003)	X		Grape	Grape	Spain
Blanco *et al.* (2005)	X		Fruit	Apple - Pear	Argentina
Caixeta-Filho (2006)	X		Citrus	Orange	Brazil
Ortmann *et al.* (2006)	X		Fruit	-	South Africa
Masini *et al.* (2007)	X		Fruit	Apple - Pear	Argentina
Ferrer *et al* (2007)	X		Grape	Grape	Chile
Cittadini *et al.* (2008)	X		Fruit	Cherry	Argentina
Bai *et al.* (2008)	-	-	Fruit	-	UK
Vander Vorst (2009)		X	Fruit	Pineapple	Netherlands
Blackburn and Scudder (2009)	X		Fruit	Melon	US
Arnaout and Maatoukw (2010)	X		Grape	Grape	Lebanon
Bohle *et al.* (2010)	X		Grape	Grape	Chile
Morande and Maturana (2010)	X		Grape	Grape	Chile
Amorim *et al.* (2012)		X	Fruit	-	Portugal
Yu *et al.* (2012)	-	-	Fruit	-	China
Banaeian *et al.* (2012)	X		Fruit	Strawberries	Iran
Ampatzidis *et al.* (2013)	X		Grape	Grape	US
Catalá *et al.* (2013)	X		Fruit	Apple - Pear	Argentina
Velychko (2014)	-	-	Fruit	-	Ukraine
Lambert *et al.* (2014)	-	X	Fruit	Persian lime	Mexico

González-Araya *et al.* (2015)	X	Fruit	Apple	Chile
Nadal-Roig and Plà (2015)	X	Fruit	Apple - Pear	Spain

Only five papers (see Table 2.6) included a case study based on existing databases to test the proper operation of corresponding proposed model (Broekmeulen, 1998; Gigler *et al.*, 2002; Van Der Vorst *et al.*, 2009; Amorim *et al.*, 2012; Lambert *et al.*, 2014). The rest of the papers just described the application to real cases.

2.3.5 Novelty

The novelty associated with each of the papers is presented in Table 2.7 that illustrates roughly how the interest of the fruit industry has been evolving over time.

Table 2.7. *Novelty associated with revised papers*

Model	Novelty in research
Willis and Halon (1976)	One of the first attempts to optimize processes associated with agricultural supply chain, particularly in apple production.
Starbird (1988)	Use of dynamic programming to sequence the loading of storage facilities considering quality deterioration in apple fruit.
Maia (1997)	Similar objective than Starbird to plan facilities to better preserve fresh fruits, but different approach.
Broekmeulen (1998)	An analysis of results from a planning model in a fresh fruit storage center. Results are verified with a simulation for a year of operation.
Gigler *et al.* (2002)	General approach to agri chains illustrated with a case of bananas
Hester and Cacho (2003)	Bio- economic approach to analyze production plans of an apple orchard.
Vitoriano *et al.* (2003)	Discussion about the suitability of discrete or continuous time models for fresh fruit production optimization.
Blanco *et al*. (2005)	Versatility of a model that can be oriented either to sales or to production.
Caixeta-Filho (2006)	Consideration of biological aspect of growing oranges, to ensure the quality of the concentrated orange juice in the industry.
Ortmann *et al.* (2006)	A comprehensive analysis of the maximum flow of fresh fruit in South Africa.
Masini *et al.* (2007)	Introduction of a penalty to not meet the demand of the customers and a modeling of the entire Apple and pear supply chain for juice.
Ferrer *et al* (2007)	Consideration of a penalty associated with the loss of quality by a lack or excess of the grape ripeness.
Cittadini *et al.* (2008)	Consideration of variations in the sale’s price of fruits.
Bai *et al.* (2008)	Effort to propose an efficient algorithm to solve the inventory problem considering the allocation of fresh produce to shelf space.
Van der Vorst (2009)	Redesign of food supply chains when logistic uncertainties regarding product quality and sustainability are in place.
Blackburn. and Scudder (2009)	Use of the marginal value of a perishable fruit that quality deteriorates over time.
Arnaout And Maatouk (2010)	The contribution of this research is the comparison of two

	heuristics to decrease the computational time of the execution of the model presented by Ferrer *et al.* (2007).
Bohle *et al.* (2010)	Strengthening the model by Ferrer *et al.* (2007), considering a couple of parameters under uncertainty, and analyze the behavior of the model.
Morande and Maturana (2010)	A DSS for the management of the grape, and subsequent process of using this in winemaking.
Amorim *et al.* (2012)	Consideration of the freshness of fruit, to minimize the stocks of facilities.
Yu *et al.* (2012)	Explicit consideration of the deterioration of perishables in the inventory supply chain model for a retailer
Banaeian *et al.* (2012)	Attempt to identify sources of inefficiency for greenhouse strawberry production with emphasis on energy.
Ampatzidis *et al*. (2013)	Operational planning for fruit harvesting optimizing the use of inputs.
Catalá *et al.* (2013)	Strategic decisions on which trees to plant in a field to optimize the net present value of the investment.
Velychko (2014)	General approach to a distribution logistic problem of a fruit and vegetable cooperative.
Lambert *et al*. (2014)	Use of an expert system to predict yield and quality of Persian lime.
González-Araya *et al.* (2015)	Use of an optimization model for supporting harvest planning decisions in orchards, aiming to minimize resources costs and loss of fruit quality cost.
Nadal-Roig and Plà(2015)	Operational optimization for reducing daily truck trips, aiming to supply fruit from warehouses to processing plants

2.3.6 Research segmentation by journal

Research projects dealing with decisional problems in fresh fruit supply chains produce papers usually published in OR journals. Then, the fruit characteristics may not be of much concern as the main objective of OR journals rely on the method excellence. On the other hand, there is very less interest in Agricultural journals to address decision making issues as only four papers where published in such journals. In such scenario, the chances of theory development, specifically for fresh FSC had been very less (Shukla and Jharkharia, 2013).

Model	Journal	Type
Willis and Halon (1976)	Canadian Journal of Agricultural Economics	AGR
Starbird (1988)	Journal of the Operational Research Society	OR
Maia (1997)	International Journal of Production Economics	OR
Broekmeulen (1998)	International Transactions in Operational Research	OR
Gigler *et al*. (2002)	European Journal of Operational Research	OR
Hester and Cacho (2003)	Agricultural Systems	AGR
Vitoriano *et al.* (2003)	European Journal of Operational Research	OR
Blanco *et al.* (2005)	International Journal of Food Engineering	ENG
Caixeta-Filho (2006)	Journal of the Operational Research Society	OR
Ortmann *et al.* (2006)	Orion	ENG
Masini *et al.* (2007)	Springer	Book
Ferrer e*t al* (2007)	International Journal of Production Economics	OR
Cittadini *et al.* (2008)	Agricultural systems	AGR
Bai *et al.* (2008)	Journal of the Operational Research Society	OR
Vander Vorst (2009)	International Journal of Production Research	OR
Blackburn. and Scudder (2009)	Production and Operations Management	OR

Arnaout and Maatouk (2010)	International Transactions in Operational Research	OR
Bohle *et al.* (2010)	European Journal of Operational Research	OR
Morande and Maturana (2010)	Revista ICHIO	OR
Amorim *et al.* (2012)	International Journal of Production Economics	OR
Yu *et al.* (2012)	International Journal of Production Economics	OR
Banaeian *et al.* (2012)	Energy Efficiency	ENG
Ampatzidis *et al.* (2013)	Biosystems Engineering	ENG
Catalá *et al.* (2013)	Agricultural Systems	AGR
Velychko (2014)	Business: theory and practice	ENG
Lambert *et al.* (2014)	Engineering applications of artificial intelligence	ENG
González-Araya *et al.* (2015)	Springer	Book
Nadal-Roig and Plà(2015)	Springer	Book

On the other hand, if we pay attention to the year of publication, clearly, the interest in fresh FSC is rather recent. There is a scarce number of references, but most of them have been published this century and more than a half in less than ten years ago. However, the increment in references is expected to increase even more in the following years by two main reasons: changes in the diet leading to a higher consumption of fruit and vegetables (Reynolds *et al.* 2014) and the increasing competition of the sector pointing to OR methods as a way to cope the uncertainties of flexible FSC (Van der Vorst *et al.*, 2009, Plà *et al.*, 2014).

2.4 Other OR models related to fresh FSC

Major characteristics of other OR models related to fresh FSC are listed and presented in Table 8. The final product of the SCs considered in this section is not a fresh fruit. These papers are devoted to processed fruits (twelve papers) or vegetables (six papers), two of them covering both products at a time. Most of these models are concerned in good quality management and product freshness to get optimal products. Processed fruits differ from fresh fruits in the last stage of the chain, but they share the production, harvesting, storing and transportation of the raw material.

Table 2.8. *Characteristics of Process Oriented Models*

Authors	Decisions level	Decision Variables	Participants	Modeling approach	Product	Country
Shuster and Allen (1998)	O	P-I	P-PP	ILP	Wine	US
Munhoz and Morabito (2001)	O	P-D-I	P-PP-D-S	MOLP	Orange-juice	Brazil
Leven and Segerstedt (2004)	T	P	S	HEU	Frozen Berries	US
Kolympiris *et al.* (2006)	T-O	P	PP	ILP	Wine	US
Cholette (2007)	T-O	D	PP-D	ILP	Wine	US
Munhoz and Morabito (2010)	T-O	H-P	P-PP	ILP	Orange-juice	Brazil
Parthanadee and Buddhakulsomsiri (2010)	O	P	PP	SM	Canned Pineapple	Thailand
Van der Merwe *et al.* (2011)	O	H-P	P-PP-S	ILP-HEU	Wine	South Africa
Rong *et al.* (2011)	T-O	P-D	PP-D	ILP	Peppers	Denmark
Ahumada and Villalobos (2011a)	O	H-P	P-PP	ILP	Tomato	US

Ahumada and Villalobos (2011b)	T	S-P-D	P-PP-D	ILP	Tomato	US
Ahumada and Villalobos (2012)	T	S-P-D	P-PP-D	SP	Tomato	US
Tan and Çömden (2012)	S	H-P	P-PP-D	NLP	Fruits & Vegetables	Turkey
Teimoury *et al.* (2013)	S	O	D	SM - DP	Fruits & Vegetables	Iran
Munhoz and Morabito (2013)	T-O	H-P	P-PP	SP	Orange-juice	Brazil
Munhoz and Morabito (2014)	T-O	H-P	P-PP	ILP	Orange-juice	Brazil

***Decision Level**: Strategical=S, Tactical=T, Operational=O. **Decision Variables**: Sowing=S, Harvesting=H, Production =P, Distribution=D, Other: O. **Participants**: Producer=P, Process Plant=PP, Storage= S, Distributor=D. **Modeling Approach**: Classification according to Table 4.*

Among the sixteen papers listed in Table 2.8, fourteen were focused on tactical and/or operational decisions and only two analyzed strategic issues. Regarding the decision variables, only eleven papers analyzed production or production plus another process while seven included decisions on distribution and five in harvesting. Few papers considered the whole FSC but most of them included the producers or processing plants. Only Teimoury *et al.* (2013) focused on the last stage of the chain: distribution at national level to support agricultural policy decisions, aiming to analyze the interactions of price, demand and supply, for applying the best import quota policy. With respect to mathematical methods (coded according to Table 2.3), pure or mixed linear programming models are the most common followed by stochastic programming models. Other methodologies were multi-objective linear programming and simulation. Finally the studies presented were developed mainly in USA and Brazil, being the rest testimonials of other countries. The products concerned were orange juice, grape for wine, tomato, canned pineapple, peppers, and banana.

Cholette (2007) formulated a mixed ILP model to help match transports between wineries and distributors. Parthanadee and Buddhakulsomsiri (2010) developed a simulation model to solve a real scheduling problem. They model the system accounting for dimensions shared by many fresh FSC like uncertainty in raw material, multiple types of finished products and the share of the same resources. However, they fit the model for the canned pineapple industry, a final product that does not correspond to a fresh fruit product. The paper of Rong *et al.* (2011) focused on the management of fresh food quality modelling quality degradation. The authors gave a general approach to fresh food and the problem of preserving the quality as happens with fresh fruit, but they select bell peppers as illustrative case study. Tan and Çömden (2012) made an important contribution to show the benefit of considering uncertainties when planning production of annual plants. In particular they consider random demand and supply (yield risk).

Six papers composed two series of three papers each of the same authors devoted to a particular crop. Ahumada and Villalobos (2011a, 2011b, 2012) focused on tomatoes and Munhoz and Morabito (2001, 2010, 2013, 2014) on orange juice production. It is important to highlight the contribution of Ahumada and Villalobos (2011a, 2011b, 2012) formulated an operational planning, a tactical planning, and a robust tactical planning model for tomato ranging from cultivation to production and distribution. They accounted for variations in cultivation and productivity rates. Munhoz and Morabito (2001, 2010, 2013, 2014) intended to optimize the orange supply chain, taking oranges as raw material for producing different juice related products. The first paper analyzed the operational planning, the second one presented a model of aggregated production planning, and the third and fourth ones presented a robust optimization of an aggregated planning, giving robustness indices of fruit ripening. In these investigations the harvesting of oranges with a prestated maturity degree was of great importance for the production of juice. A good conversion of oranges into juice is related to a good quality of the fruit which depends on the control of optimal maturation indices.

2.5 Perishable or fresh food supply chains other than fresh FSC

Along the revision process, we had found papers dealing with other agricultural supply chains (ASC) out of the scope of the present review. However, we judged the interest of papers including optimization models of other perishable or fresh food supply chains where the modelling technique, the relevance or the meaningfulness in the context of our review is easily transferable to the fresh FSC industry. For instance, a similar SC to fresh FSC is that related with floriculture as it deals with a cultivated and perishable product. For example, Caixeta-Filho *et al.* (2002), Rantala (2004) and Widodo *et al.* (2006) are papers interested in the optimization of the supply chain management of flowers. Thus, they considered harvesting, distribution and inventory management. The agricultural nature and the perishable aspect of flowers are common traits also present in fresh fruits. Furthermore, preserving the quality and durability of these products till the moment they are purchased by the final costumer is also of interest for SC managers.

Other papers dealing with different agricultural supply chains sharing similar characteristics with fresh fruits are presented in Table 2.9. Hsiao *et al.* (2010), explored outsourcing to reduce logistic costs of SC, but they found the relationship between levels of outsourcing, performance and supply chain characteristics is complex. Cai and Zhou (2014) and Agustina *et al.* (2014) considered the transport of food products while Tsao (2014) focused on non linear optimization appliend in fresh food supply chain design. Ketzenberg *et al.* (2015) considered the management of sustainable food supply chain and transport alternatives to reduce greenhouse gas (GHG) emissions.

Table 2.9. *Other papers related to ASC*

Paper	Problem	Product
Arbib *et al.* (1999)	Scheduling	Perishable
Higgins *et al.* (2007)	Value chain	Sugar cane
Dabbene *et al.* (2008)	Supply chain	Fresh-food
Hsiao *et al.* (2010)	Outsourcing	Food
Haddad and Shahwan (2012)	Risk	Crops
Moccia (2013)	Planning	Wine
Tsao (2013)	Designing SC	Perishable
Cai and Zhou (2014)	Inventory	Fresh food
Agustina *et al.* (2014)	Routing	Food
Ketzenberg *et al.* (2015)	Management	Perishable

There are reviews more focused on a product like Moccia (2013) who presented a survey of researches related to wine production, because of that he also included several studies on grape production but always linked with the main interest of his review. Although grape production techniques for wine are different from that for table grapes, many considerations of the papers revised by Moccia (2013) are shared by both productions.

2.6 Perspectives of OR in FSC management

New models and tools for improving farming, harvesting and production plans along the FSC are required because the intrinsic characteristics of fresh fruits industry have not yet been handled properly (Soysal *et al.* 2012). The SC in the agri-food industry in general and in the fresh fruit sector in particular is characterized by long supply lead times combined with significant supply and demand uncertainties, and relatively thin margins. According to Lowe and Preckel (2004), these challenges generate a need for management efficiency and the use of modern decision technology tools. Moreover, fresh FSC requires a new generation of decision models in which new variables like quality deterioration or wastage should be integrated (Rong *et al.*, 2011; Ketzenberg *et al.*, 2015) and new decisions like outsourcing activities be considered (Hsiao *et al.,* 2010). Most of the perspectives of OR in FSC management were pointed out for ASC by Pla *et al.* (2014) and are also valid for fresh FSC. Hence, operational research in large FSC can make important new contributions at middle management levels to: optimization of production planning; scheduling; and logistics across a large integrated industry, and the optimal exploitation of an increasingly sophisticated business environment. Specifically, for developing competitive and sustainable FSC, a number of critical issues need to be tackled in order to create added value for all the involved stakeholders with respect to: (i) the definition of key performance indicators of the unique characteristics of fresh FSC that differentiate them from traditional SC networks, (ii) the decisions that should be made on the strategic, operational and tactical levels under different dimensions, e.g. efficiency, quality, safety, etc, (iii) the policies which are required to ensure traceability and sustainability of the fresh FSC, (iv) the appropriate innovative interventions to foster radical advances and competitiveness within the changing FSC context (Tsolakis *et al.,* 2014), and (v) the promotion of consumer culture to manage risk and dissemination of standards across FSC actors (Manzini and Accorsi, 2013).

Because of product proliferation, fresh FSC face significant inventory and fruit-variety management challenges (Lowe and Preckel, 2004). The increasing scale and integration of supply and demand chains creates a need for optimization across a number of previously autonomous businesses, which may be operating in different regulatory environments. However, there is a lack of holistic approaches for the design and management of ASCs. This research gap is even more evident in the case of perishable goods and fresh FSC. The growing scale of the fruit industry together with increasing opportunities or responsibilities for traceable, environmental, and ethical goods means that primary producer decisions form part of overall decision making. A development in this field is the emergence of modelling frameworks that include existing and accepted decision models, such as optimal harvest scheduling and logistical discrete-event simulation, and optimal process scheduling enhancing the scalability of developed models (Higgins *et al*, 2007, Shukla and Jharkharia, 2013).

Regulation, social responsibility and consumer values create a more complex business planning environment. There are new dimensions contributing to differentiate new products like Genetically Modified Organisms (GMOs) or production of organic fruit very limited at present. Specific data relating to the extent of organic fruits or on-farm processing of fruit for sale to consumers through catering or retail establishments is currently unavailable. However, few models that are found in the literature address these challenges roughly as Ahumada and Villalobos (2009) mentioned. Another remarkable trend is the convergence of sustainability and supply and demand chains, emphasizing the growing importance of environmental issues when managing an entire supply chain involving consumers, production, customer service, and traceability (Linton *et al*, 2007). Sustainability is controversial since international trade can now be economically achieved for a large number of fresh fruits raising green-house gas emissions and waste management issues. At the same time, increasing global competition creates pressure for lower prices. So, efficient management of the transportation, distribution, and inventory management of fresh fruit, is essential to profitability and provides additional research opportunities. But Soysal *et al.* (2012) claimed for taking from practice specific sustainable requirements into consideration to support business decisions and capture fresh FSC dynamics. Hence, research efforts should focus more on the configuration of sustainable fresh FSC networks (Tsolakis *et al*., 2014; Eskandarpour *et al.*, 2015).

Climate adaptation and food security are two major research frontiers for the OR community but with a limited impact on fruit production at the moment. There are issues with changes in water availability and its seasonal variability, extreme weather events, viability of processing infrastructure in the case of reduced production, changes in crop maturity and time windows of harvest and competition with other land uses. To this respect, uncertainty and risk should also be better considered in FSC. Just considering the water availability aspects, Haddad and Shahwan (2012) show an optimization modelling approach to agricultural production under financial risk of water constraint.

New information technologies (precision agriculture, global-positioning-system, etc.) in conjunction with inexpensive computers and sensor technology should allow FSC managers to monitor yields and so develop detailed and more precise production plans. As result, the coordination between different stages can be strengthened raising the efficiency of the entire FSC. There is a challenge with the development of integrated planning models capable of capturing data or updating parameters from such information systems and permitting an easy adoption by managers (Gunasekaran and Ngai, 2004; Lehmann *et al.*, 2012).

2.7 Conclusions

In this paper we have revised the optimization models to solve decision problems related to fresh FSCs. It is an attempt to gain a better understanding of the OR methods used in the revised papers apparently independent and oriented towards problem solving rather than theory developing. Although there are some reviews done by previous researchers regarding ASCs, there is no review focused on fresh FSCs. We have stated the rapid growth and technification of the sector in the last years to satisfy the increasing demand, regulations and competiveness present in the sector. As a consequence, the number of papers published in this last years has been growing. Despite of this, few papers are focused in SCs structures and there is a lack of holistic approaches for the design and management of fresh FSC.

Among the papers revised, most of them were focused in tactical and operational decisions and less considered strategic decisions. In particular, the problems attracting more attention were transport, routing, planning and allocation problems involving the production and distribution stages. Regarding modeling techniques and mathematical methods, linear programming, integer or mixed integer are the most dominant methods. Other techniques are not so used and it is a consequence of the novelty of the proposals or the solvers available. Although the common objective of the papers were the maximization of the benefit, only cost function was described in detail and income was calculated from averaged prices considering roughly uncertainty in sale prices over time. Most of the papers were based in real cases and became real applications tailored to particularities of specific fresh FSCs.

Finally, we also extend and reinforce the work done by previous authors in regard to the perspective of OR in agri-fruit industry pointing out new opportunities. For instance, the challenge of dealing with organic fruit production, or proposing sustainable fresh FSCs, climate adaptation, food security and seasonability’s issues. At methodological level, the integration of complementary methods like optimization and simulation, or changing the perspective from a monocriterion to a multicriteria approach related to multi-echelon FSC.

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Chapter 3:

Optimizing Fresh Food Logistics for Processing: Application for a Large Chilean Apple Supply Chain

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Abstract

This research paper presents optimization models that deal with three kinds of related decisions in horticulture, which are purchasing, transporting and storing fresh produce. The study is intended to assist in decision making in a fresh apple processing plant in order to ensure its annual supply. First, a fresh produce purchasing model is proposed to minimize purchasing costs, producer administration costs and costs for transport to the classification center while taking into consideration the fresh produce offered by each producer, storage capacity and the type of storage for the fruit. These parameters will aid in selecting the producers providing the best price-storage time-distance combination for the purchase. Second, a fresh produce storage model is proposed for minimizing the cost of storage and transport to the classification center (located in the actual processing plant) for each fresh product purchased. Finally, a third integrated model is proposed to give a joint solution to purchasing, transporting and storing the fresh produce. The models are applied in a real case study in an apple dehydration plant in the Maule region of Chile, where average savings were obtained of about 8% with respect to the real costs of purchasing, storing and transporting the fresh produce during the processing period.

Keywords. Fresh produce purchase; fresh produce storage; mixed integer linear programming; tactical planning; agricultural supply chain.

3.1. Introduction

During 2010, Chilean horticulture product exports rose to US$ 700 million of which dehydrated products represent 36% (Chilealimentos, 2010). The Chilean dehydrated product exports have grown rapidly over the last three decades, increasing from approximately US$ 20 million and 13 thousand tonnes shipped at the beginning of the 80s to more than US$ 251 million and 122 thousand tonnes shipped in 2010 with 7% of the total corresponding to dehydrated apples (Chilealimentos, 2010). Chile has the largest exports of dehydrated apples in the world (2016) totaling 33.3% of total world exports (Redagrícola, 2016).

Eight of the country’s largest agro industry processing plants are found in the O’Higgins and Maule regions located in the central zone of the country. Over the last five years the annual demand for fresh apples from these companies accounts for approximately 35% of the production (INE, 2010) which has remained constant at approximately 1 million tonnes between 2005 and 2010 (Oliva, 2011). This makes for strong competition in the purchase of fresh apples and requires making quick decisions as well as planning for storage for later processing throughout the year.

Choosing suppliers for the purchase of fresh apples is an important stage in the agro industrial supply chain in that it represents the main cost of the production process (Oliva, 2011). Therefore, among the direct costs in obtaining dehydrated apples, the fresh apples (raw material for the process) represent 85%, materials 5%, energy 5%, and labor the remaining 5%. The costs related to fresh apples include their purchase (70%), storage (25%) and transport (5%).

In the fruit dehydration industry the purchase and subsequent storage of an excellent fresh product are crucial to the supply chain since both activities are related to obtaining a good final product and economic return (Oliva, 2011).

Figure 3.1 presents an outline of the main decisions involved in different stages of the agricultural supply chain up to the production stage.

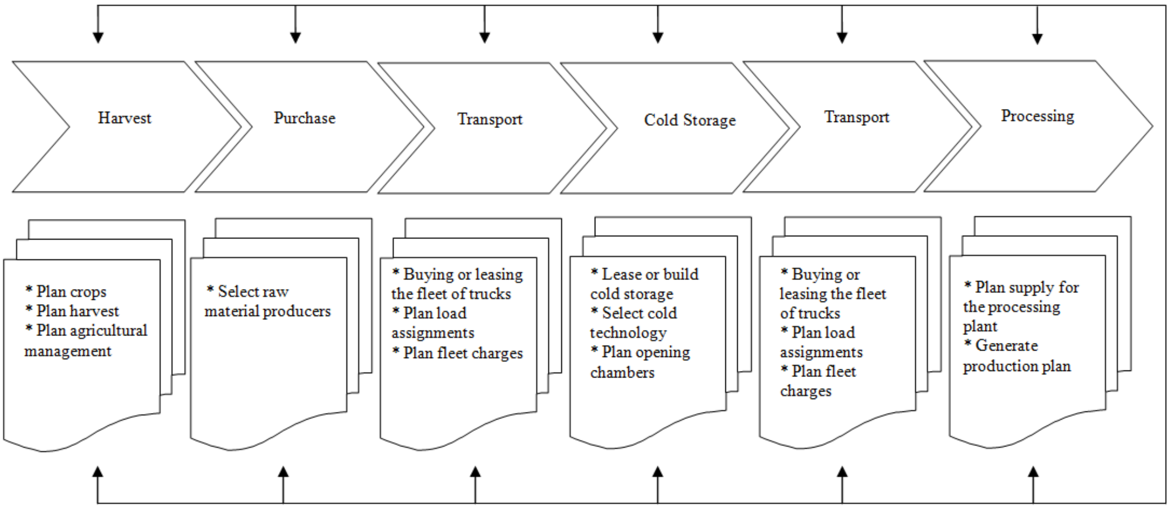


Figure 3.1. Decision map in agriculture supply chain (based on Higgins *et al.*, 2010)

As shown in Figure 1 the relevant decisions in the agricultural supply chain include harvest planning, transportation, supplier selection, cold storage selection, and production, as well as combinations of these decisions.

To support decisions at the harvest stage in the literature it is possible to find different optimization models for improving the coordination, planning and management of harvesting several horticulture products among which can be mentioned Ferrer *et al.* (2007), Arnaout and Maatouk (2010, Morande and Maturana (2010), Bohle *et al*. (2010), Van der Merwe et al (2011) and Ampatzidis et al (2013). All these authors proposed optimization models for grape harvesting. In addition, other authors who developed optimization models for horticulture products are Cittadini *et al.* (2008) who presented a model for cherry harvest planning; Caixeta – Filho (2006) and Munhoz and Morabito (2013) who developed models for orange harvest planning; Ahumada and Villalobos (2011) who proposed a tactical model for tomato harvesting; Higgins and Laredo (2006) who presented a model for sugar cane harvest; and González-Araya *et al.* (2015) who developed an optimization model for apple harvest planning. Among these researchers the work of Ferrer *et al.* (2007) and González-Araya *et al.* (2015), besides optimizing harvesting costs, seeks to reduce fruit loss due to not achieving the required quality when harvesting.

In agriculture supplier selection (farmers) is one of the main concerns before and/or during the harvest season. The processing plants need to identify producers with high quality raw material when planning the purchase of fresh produce. In this way, it would be possible to reduce loss, to store the raw material for more time and to obtain the best productivity rate during processing. About this issue, Narasimhan *et al.* (2004) and Chen and Li (2005) mention that a good long-term supply strategy can provide competitive advantages to companies because it allows ensuring quality and quantity over time. For this reason Zutshi and Creed (2009) state that the construction and management of the customer-supplier relationship is one of the main pillars for the creation of a sustainable competitive advantage. However, according to Anojkumar *et al.* (2014) this supplier selection is complex and requires considerable time to construct stable relationships.

Literature related to supplier selection has focused mainly on selection methods where different techniques have been used; among them are mathematical programming and multi criteria analysis (Hammervoll, 2009). In supplier selection many criteria are used to discriminate which ones are the most appropriate among a set of suppliers. Some of the main criteria used are the following: quality, delivery time, price, manufacturing capacity, service, management, technology, research and development, flexibility, reputation, relationship, risk, safety and environment (Guneri *et al*., 2009). Concerning this issue, Anojkumar *et al.* (2014) indicate that it is necessary to determine simple and logical selection criteria in order to make efficient decisions in the shortest time possible. A review of supplier selection methods with emphasis on the classification criteria that is used can be found in Guneri *et al.* (2009) and Terrazas *et al*. (2009). Later, Chai *et al.* (2013) did a review of 123 articles published between 2008 and 2012 regarding the techniques proposed for supplier selection. In this review the authors identified that most articles present multi criteria models (59%), followed by mathematical programming models (26%), and finally, artificial intelligence techniques (15%). On the other hand, Zimmer *et al.* (2015) carried out a literature review of supplier selection methods that incorporate social and environmental impact criteria into the evaluation. To the best of our knowledge, there is no mathematical model that supports the selection of fresh fruit suppliers for the dehydration processing industry.

Regarding cold storage decisions, a line of research on cold chain management (CCM) has emerged in the last few years and it involves planning, implementation and control of the efficient and effective flow of perishable products using cold storage (Bogataj *et al.* 2005). For this kind of product an efficient management of temperature conditions in all the chain stages will allow prolonging the quantity and quality of the product (Aung and Chang, 2014). Cold chain is mainly applied to the food industry involving agricultural products. In this area, Blackburn and Scudder (2009) mentioned that choosing a good refrigeration strategy for perishable foods increases their shelf-life and also their use at the end of the storage period. Verdouw *et al.* (2010) pointed out the necessity for good storage handling with more controlled conditions for fruit in order to prolong its shelf-life.

Some operations research models for supporting decisions in cold chain management can be found in the literature. For instance, Broekmeulen (1998) proposed a mathematical programming model for minimizing the loss of fruit quality when stored in different types of cold storage. Wang *et al.* (2011) presented a mixed linear mathematical programming model to optimize super chill product planning with different types of packaging and delivery times in order to improve product distribution through a conventional cold chain. Rong *et al.* (2011) proposed action plans in order to preserve fresh produce quality in its production and distribution. These authors presented a mathematical programming model which takes into account the degradation of quality in the supply chain. Aung and Chang (2014) developed a simulation model to determine the optimal temperature for perishable foods in cold storage in order to estimate storage times for maintaining product quality. As well, there are some researchers that aim to preserve the quality of frozen fruit when it is inside the cold chambers. In this area it is possible to find articles by Pittia *et al.* 1999, McHugh and Senesi 2000, Roth *et al.* 2007. In this literature review no research was found for supporting decisions for allocating fresh produce in cold storage considering different cold technologies.

With respect to transport decisions in agriculture or horticulture, Eskigun *et al.* (2005) suggested an integer linear programming mathematical model which sought to minimize transport costs associated with satisfying various demand points from a processing plant taking the distribution centers into consideration. Kawamura *et al.* (2006) presented a multiperiod linear programming model which sought to minimize transport and storage costs for the finished product. Osvald and Stirn (2008) proposed a routing model with time windows for the distribution of perishable foods. The model was used for planning the distribution of fresh vegetables where the perishable component represented a critical factor. Gorman *et al.* (2010) proposed a model that is a simplification of the model proposed by Eskigun *et al.* (2005) which was a mixed integer linear formulation that minimized distribution costs among distribution centers. In the fruit industry, Nadal-Roig and Pla (2015) proposed a linear programming model to minimize the costs associated with transporting fruit among various storage centers and a logistic distribution center but without taking into consideration the fresh fruit purchase. Moreover, these authors bring to light the degree of complexity in the coordination and planning among the different decision makers for production, processing, storage and distribution. Soto-Silva *et al.* (2016b) presented a mathematical model for planning daily fresh produce transport from different cold chambers to a processing plant aiming to satisfy the plant demand for fresh produce. These authors pointed out the relevance of coordinating chamber opening and closing according to the refrigeration technology. Lamsal *et al.* (2016) presented an optimization model for picking up perishable products from the producers and delivering them to processing plants in order to optimize the use of transport (number of truck trips). This model is useful in supply chains that have two main characteristics: there are multiple independent suppliers and the producers have no storage capacity. The model was applied to three cases of producers of sugar cane, beet and vegetables, respectively. Bortolini *et al.* (2016) proposed an optimization model for designing a perishable food distribution network to minimize operating costs, carbon footprint and delivery deadlines. This model was applied to a company that provides six varieties of fruit from Italian suppliers who need to distribute their products to European retailers. Nakandala *et al.* (2016) proposed an optimization model for maintaining the quality of perishable products while they are being transported from producers to retailers; it aims to minimize costs and to keep the product quality above a determined standard.

From a general overview about models for supporting transportation decisions, Mulá *et al.* (2010) presented research reviews where transport is optimized in supply chains. These authors highlighted that the majority of the reviewed models minimized total costs and that they were integer linear programming models. However, they did claim that none of the models included the suppliers of raw material for processing and they concluded that future studies should integrate both tactical and operative decision models. In a later review of transportation models, Díaz-Madroñero *et al.* (2015) concluded that models that integrate tactical decisions about production, transport and route planning were still scarce. Also, they mentioned that transportation models applied to real cases were even more limited.

Catalá *et al.* (2013) argue that in recent years there has been an increase in the development of optimization models for supporting supply chain planning, however, this increase has not been reflected in the research on the agro industrial area. This statement is corroborated in various bibliographic reviews on models applied to the general supply chain (Lucas and Chhajed, 2004) or to agro industry (Lowe and Preckel, 2004; Weintraub and Romero, 2006; Ahumada and Villalobos, 2009; Audsley and Sandars, 2009; Soto-Silva *et al.*, 2016a) that have mentioned the lack of research in this area. In particular, the agro industrial processing plants do not currently have tools that provide either for the selection of fresh fruit suppliers or for assigning the fresh produce to the most appropriate warehouses (Soto-Silva *et al.*, 2016b). Currently, these decisions are made according to the experience of the decision makers which often leads to system inefficiency (Oliva, 2011). For this reason, optimization models for assisting tactical decisions for buying, transporting and storing fresh produce with the purpose of minimizing the cost of these activities are proposed in this study. These models have been formulated by mixed integer linear programming.

The first model is intended to improve selecting producers from whom to purchase the fresh fruit, seeking to minimize costs for purchasing, producer administration, and fruit transportation. The second model will minimize the costs for storage and transportation of the fresh produce purchased from the various producers, assigning the cold chamber appropriate for maintaining the freshness of the fruit until it is processed. The third model integrates the two prior ones in order to minimize all the costs at once. The models have been developed for improving the logistics of an apple supply chain in Chile. However, these models can be used for any kind of fruit and vegetable supply chains that have to consider their storage in cold chambers before being processed so that their physiological characteristics do not deteriorate quickly over time. The models were used in an actual case study involving the operation of a dehydrated apple processing plant located in the Maule Region, Chile.

In Section 2 the activities involved in the purchase and storage of fresh produce aimed at the dehydration process in Chile are described. In Section 3 the mathematical models for the purchase and storage of fresh produce are formulated, and as well, the resulting integration of both. In Section 4 the results of the case study are presented showing the data obtained from a dehydration company in the Maule Region of Chile. Finally, Section 5 highlights the feedback from the Chilean company while in Section 6 the conclusions of the study are presented and suggestions given for future research.

3.2. Supply chain for Chilean apples destined for dehydration process.

Figure 3.2 is a diagram of the supply chain involving the purchase, transportation and storage of fresh apples destined for processing plants in Chile. This chain is similar to that of other fruit and vegetable products that are raw material for agro industry. The diagram presents all of the actors involved and the flows among them even though the last part of the chain that deals with dispatching the fruit from warehouses to processing plants is not included as an objective of this study.

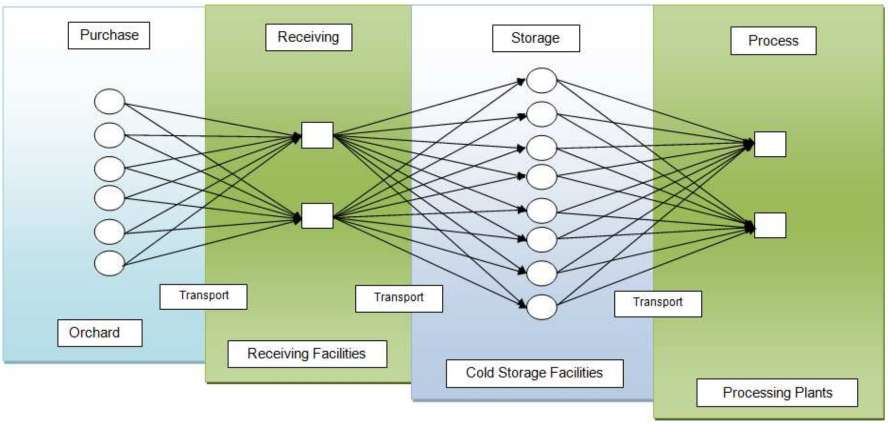


Figure 3.2. General structure of the supply chain for apples destined for processing in Chile

Next, the interaction among the supply chain elements (Figure 2) is briefly described. The harvest is carried out by the producers who are generally the orchard owners. This harvest is collected in bins whose load capacity is approximately 0.380 tonnes. The processing plant takes care of removing the bins from the orchard and receiving them at the plant where the payment, accounting and checking the condition of the apples are done (González-Araya *et al.*, 2014). Then, the fruit is placed in cold storage, either in refrigerated chambers within the plant or in rented ones. It is worth pointing out that the decision to store the fruit in refrigerated chambers within the plant or to send it to rented ones is made by the processing plant upon receiving the fruit. The purchase decisions are necessary when there are different owners of the plants, cold warehouses and orchards. This happens frequently in the Chilean fruit supply chain. On the other hand, in the Spanish fruit supply chain, many plants and cold storage units belong to agriculture cooperatives (many producers that work together for processing their fruit). These cooperatives manage their entire supply chain through a fruit logistic center belonging to them (Nadal-Roig and Pla, 2015). In the Spanish case, all the agents operate under the same umbrella: the so-called cooperative of second order; whereas in Chile fruit supply chain agents operate with autonomy and producers, logistics, cold storage providers and processing plants are commonly different companies. Then, from the perspective of a processing plant, there are operational issues to consider not present in the approach of Nadal-Roig and Pla (2015). For instance, when a plant purchases fruit from a producer, there is some administration cost associated with technical visits to the orchards by the plant professionals and with the processing of purchase documents. Hence, purchase decisions described in this paper do not fit the Spanish case.

The type of cold chamber in which the fruit has to be kept must also be selected and the fruit is divided up (segregated) according to the length of time it is deemed it can be stored (short, medium or long term storage). This segregation is done according to physiological indexes that are controlled by the quality control professionals in the receiving area of the plant. Among the most used indicators are the degrees Brix, pressure, starch index and physical damage. For example, considering the fruit pressure, the lesser it is, the longer the storage time will be; on the contrary, the greater the fruit pressure, the shorter the storage time. For the segregation it is also possible to use the historical behavior of the fruit quality for each producer assuming that it is unlikely that from one season to the next a producer will deliver fruit of a different quality. In Chile a processing plant usually has a demand of approximately 30,000 tonnes of fresh produce available for purchase from about 250 producers who offer six varieties of fruit with 3 different duration times (short, medium and long term).

Storage time depends on the type of cold chamber that is used. Moreover, for all the stored fruit the ripening process must be controlled by the refrigeration system (Nadal-Roig and Pla, 2015). A warehouse can have different types of refrigerated chambers, such as chambers with conventional refrigeration technology (CR), where the temperature is controlled by means of a conventional thermostat which permits keeping the fruit for about a 3-month period (short term); chambers with *Smart Fresh* (SF) technology having the Smart Fresh phyto-regulator diffusion system incorporated in them which minimizes the synthesis of ethylene in the fruit respiration during storage allowing the fruit to be kept for about 6 months (medium term); and chambers with controlled atmosphere (CA) technology where the concentrations of oxygen, carbon dioxide and nitrogen are regulated along with the temperature and humidity, that is, the chamber has a controlled climate allowing the fruit to be kept for a period of approximately 9 months (long term). Generally, the plants have more than one warehouse in order to have fruit available for processing throughout the year. In Chile it is possible to have only one type of fruit stored in a cold chamber at one time (Oliva, 2011). Of the national total 86% are conventional refrigeration chambers and 14% are controlled atmosphere chambers.

If a company does not have enough capacity for cold storage, as occurs regularly, it must lease.

Therefore, optimizing the fruit purchase leads naturally to anticipating whether it will be necessary to rent cold chambers.

Figure 3.3. Structure of a warehouse

Source: Based on www.frigopack.cl

A warehouse could have several cold chambers which may also have different refrigeration technologies. Figure 3.3 shows a possible configuration of a warehouse with 4 cold chambers (1, 2, 3 and 4 in the figure). It is important to note that a cold chamber can only store one kind of fruit variety because of the differences among fruit respiration rates (ripening rate) and the ethylene generation. As a result, mixing varieties would reduce the shelf-life of stored fruit.

The storage available for rent, as well as the purchase of fresh fruit, is required by many different agro industrial processing companies. Therefore, given this competition the decision to lease storage should be made promptly at the beginning of the season. The storage cost is usually charged per tonne of stored fruit depending on the cold technology in each chamber and, hence, corresponds to a variable cost. On the other hand, there is a fixed cost related to administrative costs of renting a cold chamber. Although this fixed cost is less than the variable costs, it is considered in the model proposed in this study in order to represent as effectively as possible the actual cost of storage.

In the apple dehydration process, as mentioned before, there is a segregation of fresh fruit into short, medium and long term according to its quality and estimated shelf-life. Thus, fresh fruit must be stored in cold chambers for short term (CR), medium term (SF) and long term (CA), accordingly. It should be noted that it is possible to store short-term quality fruit in a CA chamber; however storage cost would increase as CA technology is more expensive. On the other hand, long-term quality fruit should not be stored in short-term cold chambers unless plant demand is covered to the end of the processing season (which lasts approximately 270 days). Moreover, since fruit quality preservation depends on the cold technology used in the chamber, long-term quality fruit stored in short-term cold chambers will be processed at the beginning of the season, i.e. in the short term. The latter does not matter if cold storage management allows fruit to be available throughout the processing season without affecting the conversion rate performance of fresh fruit to dehydrated fruit.

Before the processing stage plants must make two types of decisions where the fruit quality is relevant. One decision corresponds to supplier selection and the purchase of enough raw material for long term storage, which implies that the initial quality of fruit has to be very good. The other decision corresponds to matching cold storage technology and fruit quality in order to maintain the fruit's initial quality as long as possible.

It is important to mention that the conversion rate of fresh fruit into dehydrated fruit is directly related to the purchased fruit classification or segregation. Therefore, a better conversion rate is obtained when processing long-term fruit than short-term fruit although this is done at the beginning of the season because the long-term fruit has better quality. This better conversion rate allows reducing the tonnes of fresh fruit to be purchased. However, the purchase of good raw material is not always attractive to processing plants because besides having a higher purchase cost, storage costs also increase. Consequently, long term quality fruit stored in long term cold chambers to be processed at the beginning of the season could be very expensive for plants.

Transportation for the supply chain from the producers to the plant for segregation and then from the plant to the warehouses is usually outsourced because it is too expensive to have a fleet of trucks and the cost of drivers and machine maintenance can be avoided (Gonzalez-Araya *et al.,* 2014). Payment policies vary; among the most common are payment by kilogram or by bin transported, by kilometer travelled or otherwise, a value for the whole season is negotiated. However, transport costs generally have two components: a variable cost that depends on the amount of transported fruit and the distance travelled; and a fixed cost corresponding to the freight realization. In practice, processing plant operators are in charge of logistics and transport of fresh fruit from suppliers to the plant and from the plant to the warehouses. They estimate a variable cost as a unit value per transported tonnes considering the distance between the plant and the suppliers, and from the plant to the warehouses. With regard to the fixed cost, the total load capacity of each type of truck is considered for its calculation.

In Chile, the apple harvest season begins at the end of January each year and ends in April. The processing season for apple dehydration plants is carried out each year between May and December. For this reason, fruit intended for processing must always be stored in cold chambers. Nonetheless, decisions to purchase fresh fruit must be made at the beginning of the season in order to ensure enough quantity and the best quality at the best price for the raw material. In consequence, at the beginning of the season there is a great demand for fresh fruit from the different processing and packing plants. The plants could buy fresh fruit outside of this period but risk paying higher prices and with a lesser fruit quality. In addition, when a plant purchases a fruit variety from a producer, it must buy the total production. This happens because if a producer were left with stock in his/her orchard, he/she would risk not selling the remaining fruit since quality decreases quickly over time. This is the only condition imposed by producers that a plant has to consider.

During the pre-harvest and post-harvest period managerial activities are carried out, such as visits to the fields by agricultural technicians in order to select and negotiate with producers, as well as processing the documents associated with the fruit purchase.

3.3. Model for planning the purchase, transport and storage of fresh produce for agro industrial processing plants

The objective of the models is to minimize total costs for purchasing, transporting and storing fresh apples for dehydration. The main constraints are those that include the availability of fresh produce from the producers, the processing plant demand and its production capacity, and the storage type and capacity. Since the plant removes the bins from the orchard to its receiving area where the fruit condition is checked and, according to this information, is stored in different chambers, it is not necessary to incorporate an analytical formulation of perishability into the planning models.

The optimization models proposed in this study have been formulated in order to support decisions at different links in the supply chain. The first model seeks to assist in decisions at the purchasing stage where the fresh produce is bought from the producers and transported. The second model permits establishing in which cold chamber to store the purchased produce and its transport. The third model integrates these stages into a single model.

3.3.1 Model for purchasing the fresh produce

The objective function (1) seeks to minimize costs associated with the fruit purchase, transport from the producers to the processing plant for segregation, the maintenance and administrative costs for the producers from whom the fruit is purchased. Table 3.1 presents the indices, parameters and decision variables used in each of the model formulations, respectively.

As was commented in Section 2, the transport costs have two components: one calculated according to the distance travelled and the quantity of fruit transported from the orchards to a processing plant, and the other one is a fixed cost charged for using a truck. Also, for every producer there is an administration cost associated with the technical visits to the orchards done by the plant professionals and with the processing of purchase documents.

Table 3.1 Model indices, parameters and decision variables of the model for purchasing the fresh produce

Indices	
p	Apple producer index
q	Fruit type index
t	Fruit storage time index (3 = short term, 2 = medium term, 1 =long term)
l	Type of truck available for transport
Parameters	
CC_{pqt}	Purchase cost for producer p of the fruit type q with storage time t (US$ /tonnes)
O_{pqt}	Fruit supply from producer p of type q with storage time t (tonnes)
CT_p	Transport cost from producer p to the plant by tonnes of fruit (US$ /tonnes)
CFT_l	Fixed cost of transport using truck type l
CA_p	Administration cost for producer p
M	Big M
D_{qt}	Demand for fruit type q with storage time t (tonnes)
QM_l	Maximum load for truck type l (tonnes)

Decision Variables

W_{pqtl}	Tonnes of fruit to buy from producer p, of type q, with storage time t transported by truck type l
Y_{lpq}	Quantity of trips for truck type l, from producer p, with fruit type q
X_{pqt}	Binary variable with the value 1 if fruit is purchased from producer p, of type q and storage time t, and otherwise the value is 0
C_p	Binary variable with the value 1 if the fruit is purchased from producer p, and 0 if not.

$$Min\ Z_1 = Min \sum_{p\,\epsilon\,P}\sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T} CC_{pqt}X_{pqt}O_{pqt} \ +\ \sum_{p\,\epsilon\,P}\sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T} CT_pX_{pqt}O_{pqt} \ +\ \sum_{p\,\epsilon\,P} CA_pC_p + \sum_{\mathrm{l}\,\epsilon\,\mathrm{L}}\sum_{\mathrm{p}\,\epsilon\,\mathrm{P}}\sum_{\mathrm{q}\,\epsilon\,\mathrm{Q}} CFT_l\, Y_{lpq} \tag{3.1}$$

s.t.

$$\sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T} X_{pqt} \ \leq\ M\ C_p \qquad \forall\, p\,\epsilon\, P \tag{3.2}$$

$$\sum_{p\,\epsilon\,P}\sum_{t\,\epsilon\,T}\sum_{l\,\epsilon\,L} W_{pqtl} \geq \sum_{t\,\epsilon\,T} D_{qt} \quad \forall q\,\epsilon\, Q \tag{3.3}$$

$$\sum_{l\,\epsilon\,L} W_{pqtl} \ \leq\ X_{pqt}\ O_{pqt} \qquad \forall\, q\,\epsilon\, Q, p\,\epsilon\, P, t\,\epsilon\, T \tag{3.4}$$

$$\sum_{t\,\epsilon\,T} W_{pqtl} \leq QM_l\, Y_{lpq} \qquad \forall\, q\,\epsilon\, Q, l\,\epsilon\, L, p\,\epsilon\, P \tag{3.5}$$

$$X_{pqt}, C_p\ \epsilon\ \{0,1\} \qquad \forall\ p\,\epsilon\, P, q\,\epsilon\, Q, t\,\epsilon\, T \tag{3.6}$$

$$Y_{lpqt}\ \epsilon\ \mathrm{Z}^{+} \qquad \forall\, l\,\epsilon\, L, p\,\epsilon\, P, q\,\epsilon\, Q, t\,\epsilon\, T \tag{3.7}$$

$$W_{pqtl} \geq 0 \qquad \forall\, p\,\epsilon\, P, q\,\epsilon\, Q, t\,\epsilon\, T, l\,\epsilon\, L \tag{3.8}$$

Constraint (3.2) establishes that if a fruit variety is bought from a producer, all the production of this fruit variety must be bought from him/her. This particular decision is associated with a derived fixed administration cost calculated in the objective function. As mentioned, this cost is related to both technical visits by the plant professionals to the orchards and the processing of purchase documents. Constraint (3.3) indicates that the quantity of fruit to buy of a specific type and specific storage time must meet the processing plant's demand. Constraint (3.4) shows that the quantity of fruit to buy will be less than the supply that is available from the producers. Constraint (3.5) allows determining the number of total trips to be made per truck during the purchase season. Constraints (3.6), (3.7) and (3.8) correspond to the integrality and non-negativity constraints on the decision variables, respectively.

3.3.2 Model for storing fresh produce

Once the apples have been purchased, they are removed from the orchard and transported to the plant for selection and assignment to a cold storage chamber. The ripening characteristics must be preserved in the fresh produce for good processing, which makes it essential to choose a cold chamber that maintains the quality of the fruit until it is processed. Hence, segregation of the fruit by the type of refrigeration to choose should assure meeting the demand of the plant without interruption.

The objective function of the proposed model (3.9) seeks to minimize the costs associated with transport from the processing plant to warehouses, costs for keeping the fruit in the cold chambers, fixed costs for storage and the cold chamber, and fixed costs for transport. Table 3.2 presents the indices, parameters and decision variables used in the formulation of the models.

Table 3.2 Model indices, parameters and decision variables of the model for storing fresh produce.

Indices	
c	Available warehouse index
n	Available cold chamber index
q	Fruit type index
t	Fruit storage time index (3 = short term, 2 = medium term, 1 =long term)
l	Index for the truck type available for transport
Parameters	
CT_{qtc}	Cost of transport from the plant for fruit type q with storage time t destined for warehouse c (US$ /tonnes)
CE_{cn}	Cost of keeping the fruit in warehouse c, in cold chamber n (US$ /tonnes)
CA_c	Fixed cost for warehouse c
CF_{cn}	Fixed cost of chamber n in warehouse c
CFT_l	Fixed cost of transport using truck type l
$qtyc$	Number of warehouses available
W_{cn}	Storage capacity of cold chamber n in warehouse c (tonnes)
QM_l	Maximum load of truck type l (tonnes)
TE_{cn}	Type of refrigeration technology in cold chamber n in warehouse c (3 = short term, 2 = medium term, 1 =long term)
D_{qt}	Quantity of fruit to store of type q with storage time t (tonnes)
Decision Variables	
X_{qtcnl}	Tonnes of fruit type q with storage time t in warehouse c in cold chamber n transported in truck type l.
Y_{lcn}	Number of trips by truck type l to warehouse c to cold chamber n.
A_c	Binary variable with value 1 if warehouse c is used, and 0 if not.
ME_{cnqt}	Binary variable with value 1 if fruit type q with storage time t is kept in warehouse c in chamber n.

$$Min\ Z_2 = Min \sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T}\sum_{c\,\epsilon\,C}\sum_{n\,\epsilon\,N}\sum_{l\,\epsilon\,L}(CT_{qtc} + CE_{cn})\,X_{qtcnl} + \sum_{c\,\epsilon\,C} CA_c\,A_c + \sum_{c\,\epsilon\,C}\sum_{n\,\epsilon\,N}\sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T} CF_{cn}\,ME_{cnqt} + \sum_{l\,\epsilon\,L}\sum_{c\,\epsilon\,C}\sum_{n\,\epsilon\,N} CFT_l\,Y_{lcn} \tag{3.9}$$

s.t.

$$\sum_{t\,\epsilon\,T}\sum_{q\in Q} ME_{cnqt} \leq 1 \qquad \forall\, c\,\epsilon\,C, n\,\epsilon\,N \tag{3.10}$$

$$\sum_{l\,\epsilon\,L} X_{qtcnl} \leq W_{cn}ME_{cnqt} \qquad \forall c\,\epsilon\,C, n\,\epsilon N, t\,\epsilon\,T \tag{3.11}$$

$$\sum_{c\,\epsilon\,C}\sum_{n\,\epsilon\,N}\sum_{l\,\epsilon\,L} X_{qtcnl} \geq D_{qt} \qquad \forall q\,\epsilon\,Q, t\,\epsilon\,T \tag{3.12}$$

$$\sum_{n\,\epsilon\,N}\sum_{q\in Q}\sum_{t\in T} ME_{cnqt} \leq qtyc\ A_c \qquad \forall c\,\epsilon\,C \tag{3.13}$$

$$ME_{cnqt} = 0 \qquad \forall c\,\epsilon\,C, n\,\epsilon\,N, q\,\epsilon\,Q, t\,\epsilon\,T : t < TE_{cn} \tag{3.14}$$

$$\sum_{q\,\epsilon\,Q}\sum_{t\,\epsilon\,T} X_{qtcnl} \leq QM_l\ Y_{lcn} \qquad \forall l\,\epsilon\,L, c\,\epsilon\,C, n\,\epsilon\,N \tag{3.15}$$

$$Y_{lcn} \in \mathbb{Z}^{+} \qquad \forall l \in L, c \in C, n \in N \tag{3.16}$$

$$A_c, ME_{cnqt} \in \{0,1\} \qquad \forall c \in C, n \in N, q \in Q, t \in T \tag{3.17}$$

$$X_{qtcnl} \geq 0 \qquad \forall q \in Q, t \in T, c \in C, n \in N, l \in L \tag{3.18}$$

Constraint (3.10) establishes that only one type of fruit can be stored in each cold chamber. Constraint (3.11) makes the amount of fruit to be stored in each of the cold chambers in the warehouses subject to the choice of chamber and its storage capacity. Constraint (3.12) shows that the quantity of fruit to be stored must be equal to the fruit required and that was purchased in the purchase model. Constraint (13.3) shows the activation of a cold chamber within a warehouse in order to store fruit only if the warehouse is active. Constraint (3.14) ensures that fruit is not stored in a cold chamber if it has a length of storage time lower than the chamber's refrigeration technology allows it to stock. Constraint (3.15) limits the maximum number of trips per truck at full capacity according to truck type and the amount of fruit to buy from the producers. Constraints (3.16), (3.17) and (3.18) correspond to the integrality and non-negativity constraints on the decision variables, respectively.

3.3.3 Integrated model for purchasing and storing fresh produce for a processing plant.

In this model, the indices, parameters and decision variables are the same as those presented previously in Tables 3.1 and 3.2. Next, the formulation of the model proposed to integrate the purchase and storage of fresh produce to be used in the dehydration process is presented.

$$Min\, Z = Min(Z_1 + Z_2) \tag{3.19}$$

s.t.

$$\sum_{c \in C} \sum_{n \in N} \sum_{l \in L} X_{qtcnl} = \sum_{p \in P} \sum_{l \in L} W_{pqtl} \qquad \forall\, q \in Q, t \in T \tag{3.20}$$

Eq. (2), Eq. (3), Eq. (4), Eq. (5), Eq. (6), Eq. (7), Eq. (8), Eq. (10), Eq. (11), Eq. (13), Eq. (14), Eq. (15), Eq. (16), Eq. (17) and Eq. (18).

The objective function minimizes all the costs associated with purchasing and storing fresh produce, that is, it aggregates the costs of objective functions Z_1 = (3.1) and Z_2 = (3.9).

Constraint (3.20) permits joining the purchase and storage together given that the fresh produce purchased is equal to the fresh produce to be stored in the cold chambers. The other constraints for this model correspond to the constraints given in the purchasing and storing models.

The mathematical models presented in this section allow supporting processing plant decisions about purchase and storage, separately, and also when these decisions must be made jointly. Using one of these models will depend on the supply chain configuration of the horticulture produce and on the information available in the supply chain stages. For example, in Chile, according to information from processing plant managers sometimes during the fresh fruit purchasing period there is no certainty about the number of available cold chambers for storing fruit. However, since the harvest period has already begun, it is necessary to make the supplier selection for fruit purchase as fast as possible. Information of available cold chambers generally does not exist since at the beginning of the harvest season plants are negotiating their rent price. This situation means that at the beginning of the harvest season only the purchase model could be useful. The storage model could support decisions once the lease contracts are ready. Additionally, using one of these models would also depend on the kind of fruit to be processed and the time that it is expected to be processed. For example, sweet cherry, because of its high perishability, is not stored but still it is necessary to support decisions about fresh fruit purchase and supplier selection.

Given that the integrated model includes two types of costs (purchasing and storing) and, generally, minimizing these costs at the same time is not possible since they are conflicting objectives; that is, the improvement of one of them causes the deterioration of the other, it is of interest to analyze and compare an approximation as a bi-objective model that permits handling both problems independently. To this end the ε – constraint method proposed by Haimes *et al.* (1971) is used. The technique consists of converting a multi-objective model into a mono-objective one. Various versions of the *ε* – constraint method have been proposed in the literature each attempting to improve the original method or adapting it to a specific type of problem, as for example, the work done by Ehrgott and Ryan (2002), Laumanns *et al.* (2006) and Hamacher *et al.* (2007).

3.4. Case Study

3.4.1. Company Description

The company where the case study was carried out is an agro industry that has been producing dehydrated fruit, vegetables and preserves in the Maule Region, Chile for more than 50 years. The company processes more than 36,000 tonnes of raw material annually, which undergoes selecting, washing, cutting and/or heating processes depending on the desired product. Mainly, the company processes apple (18,250 t/year), cherries (400 t/year), peaches (150 t/year), tomatoes (1,750 t/year), peppers (8,000 t/year), and celery (3,120 t/year). Therefore, the largest amount of processed fresh produce is apple representing 60% of the raw material for processing followed by peppers at 25%.

The plant for dehydrating apple has about 236 producers of different varieties of apples; an annual demand for fruit of about 28,000 t; an availability of 12 warehouses with a maximum of 70 cold chambers with different types of refrigeration technology permitting different storage times for the fruit; and a fleet of about 30 rented trucks, types 1, 2, and 3 with different load capacities: 9.9 t, 12.2 t, and 25.1 t, respectively. It should be noted that all the fruit is purchased by the company which sends it to outsourced warehouses because it has no cold storage chambers of its own.

In order to store the fresh produce for a longer time a classification system is applied which takes into consideration harvest conditions, orchard and ripening of the fruit in receiving. This system classifies each batch of fresh produce and the type of cold chamber where it will be stored is determined accordingly. This classification, called segregation, indicates the how long the fresh produce can be stored maintaining its condition for processing. Table 3.3 presents the type of storage required according to the segregation established for each variety. This segregation was done by the quality control professional in the receiving area of the plant considering the physiological index of the fruit as explained in Section 2.

Table 3.3 Type of storage according to variety and segregation of the fresh apples

Variable	Variety	Segregation	Cold Chamber Required
D_1	Royal Gala	Long	Controlled Atmosphere
D_2	Royal Gala	Medium	*Smart Fresh*
D_3	Royal Gala	Short	Conventional Refrigeration
D_4	Granny Smith	Long	Controlled Atmosphere
D_5	Granny Smith	Medium	Smart Fresh
D_6	Granny Smith	Short	Conventional Refrigeration
D_7	Fuji	Long	Controlled Atmosphere
D_8	Fuji	Medium	Smart Fresh
D_9	Fuji	Short	Conventional Refrigeration
D_{10}	Braeburn	Long	Controlled Atmosphere
D_{11}	Pink Lady	Long	Controlled Atmosphere
D_{12}	Red	Long	Controlled Atmosphere

Currently, in spite of having done the fruit segregation, none of the previously described factors were included in the purchasing process (quantity and storage time of the fruit, types of storage). The company buys all the fruit that its storage capacity will allow in order to achieve the production programmed for the year.

When the processing plant can not satisfy the demand for a fruit variety with a required quality, it is possible to buy fruit with equal or higher quality to meet the unsatisfied demand. As mentioned before, the conversion rate from fresh fruit to dehydrated product is better for long-term fruit than for short-term fruit. For this reason under this criterion, it would seem preferable to always buy long-term fruit to allow having good quality fruit throughout the processing season. Nevertheless, since the purchase price and the storage cost in controlled atmosphere chambers are more expensive, it is not always profitable to choose this alternative.

3.4.2. Application of the proposed models to the case study

The models were applied taking into consideration the data for one processing season at the plant (Table 3.4). For this season there is a demand of 28,120 t, a supply of 58,821 t from 279 producers and an available storage capacity of 129,850 bins. A bin is a container with capacity of approximately 0.380 tonnes of fruit that allows efficiently storing, handling and transporting it.

Table 3.4 Characteristics of the demand and supply for the season (in # of t)

	Long	*Medium*	*Short*	Total
Demand	12,160	8,360	7,600	**28,120**
Supply	38,378	10,532	9,910	**58,821**

Of the 57 total cold chambers available, 21 have conventional refrigeration, 11 have Smart Fresh technology and 25 have controlled atmosphere technology, making a total cold storage capacity of 129,850 bins. Table 3.4 presents the total demand and the total supply of different apple varieties segregated by long, medium and short term. The processing plant uses the demand values proposed in the sales plan for the season as elaborated by professionals of the Commercial Department of the company. The sales plan is estimated according to the historical behavior of the demanded dehydrated product. On the other hand, the supply values are estimated by the processing plant according to historical data obtained from past seasons. In Table 5 the demand and supply values for each variety and segregation time are shown.

The optimization software used for applying the proposed models to the case study is ILOG-OPL, version 6.1, with CPLEX-12.6, installed in a computer with an Intel(R) Core (TM) i5-5300U CPU 2.30 GHz processor, 8 GB of RAM and a 600 GB hard drive.

3.4.2.1. Applying the purchasing model to the season under study

From the computed results when the purchasing model was applied to the data provided by the processing season under study 25,390 decision variables and 10,329 constraints were generated in a computational period of 100.17 s after 274,250 iterations.

On applying the fresh produce purchasing model to the season under study, the model selected 143 of the 279 available producers with a proposed storage of 17,842 t, 5,726 t and 4,551 t for long, medium and short terms, respectively. The total demand for fresh produce was met for the season but as there is the condition of meeting the demand for fruit with long term storage (long segregation) above the rest, only if the supply exists and complies with the resulting costs being the minimum, are there variations with respect to the fruit purchased for each of the segregations. Table 3.5 gives the fresh produce purchasing proposal for the season.

Table 3.5 Fresh produce purchasing proposal for the season applying the purchasing model

Variety	*Cost (per kg)*	*Segregation*	*Supply (t)*	*Demand (t)*	*Actual Purchase (t)*	*Proposed Purchase (t)*	*Actual N° Producers*	*Proposed N° Producers*
Royal Gala	US$0.051	Long	8,699	1,520	772	2,909	29	27
		Medium	2,953	1,520	1,986	1,154	30	8
		Short	1,456	1,520	3,476	496	34	9
Granny Smith	US$0.059	Long	15,465	5,320	1,040	8,116	58	45
		Medium	5,898	4,180	4,592	2,902	76	19
		Short	6,081	3,420	6,141	1,902	79	20
Fuji	US$0.045	Long	4,585	3,040	432	4,537	8	43
		Medium	1,680	2,660	729	1,670	27	21
		Short	2,373	2,660	4,117	2,153	67	34
Braeburn	US$0.036	Long	3,618	1,140	2,022	1,140	41	13
Pink Lady	US$0.038	Long	2,740	760	2,451	760	38	10
Red	US$0.024	Long	3,272	380	516	380	37	6
Total t			***58,825***	***28,120***	***28,120***	***28,120***		

The processing season began with an initial supply of 58,825 t supplied by 279 producers, whereas the processing plant demand was 28,120 t. This demand was completely met, not only in reality but also in the results given by the purchasing model. The difference is found in the segregation for each apple variety. For example, for the Royal Gala variety with long, medium and short storage time the demand is 1,520 t for each storage time, however, the purchase is 2,909 t, 1,154 t and 496 t, respectively. This purchase results from seeking to buy the majority of the fresh produce with a long storage time over fruit with shorter storage times which is why the model found the purchase proposed (Table 5) to meet plant requirements but taking into consideration the cost of purchasing fresh produce, transport and administration for each of the producers. As can be observed in Table 3.9, there are purchase prices that are differentiated by fruit variety rather than segregation.

Other differences are observed in the number of producers needed to meet the demand in each of the segregations present for each apple variety. For example, the Royal Gala variety with long term storage moves from buying from 29 producers to 27 producers, whereas the Red variety moves the purchasing from 37 producers to only 6. This improved purchase planning is due to a better vision of the purchasing transport and administration costs at the time of choosing a producer.

Regarding transport from the producers to the processing plant, Table 3.6 presents the number of trips to be made by each type of truck that the plant had available for the season under study.

Table 3.6 Number of trips made by trucks and transportation costs from producers to the processing plant - comparison between the real case and the model proposal

	Types of truck according to load capacity			
	Type 1	Type 2	Type 3	Total trips
Total trips real (n°)	1,425	1,182	75	2,682
Total trips proposed (n°)	1,355	1,145	42	2,542
Difference Total trips (n°)	***70***	***37***	***33***	***140***
Total Cost Real (US$*)	68,040	76,806	8,689	153,536
Total Cost Proposed (US$*)	64,698	74,402	4,866	143,966
Difference Total Cost (US$*)	***3,342***	***2,404***	***3,823***	***9,570***

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

The model proposes having a greater quantity of type 1 trucks to meet the transport demand. This result serves as the basis for planning plant operations because from the beginning of the season the number of trips needed during the fresh produce purchasing process is known and also what type of truck is best to use. When comparing the number of actual trips with the number of trips proposed by the model a decrease of 140 trips can be seen, which means savings of around US $ 9,570. This happens because a better supplier purchase plan is obtained, optimizing at the same time the required transport.

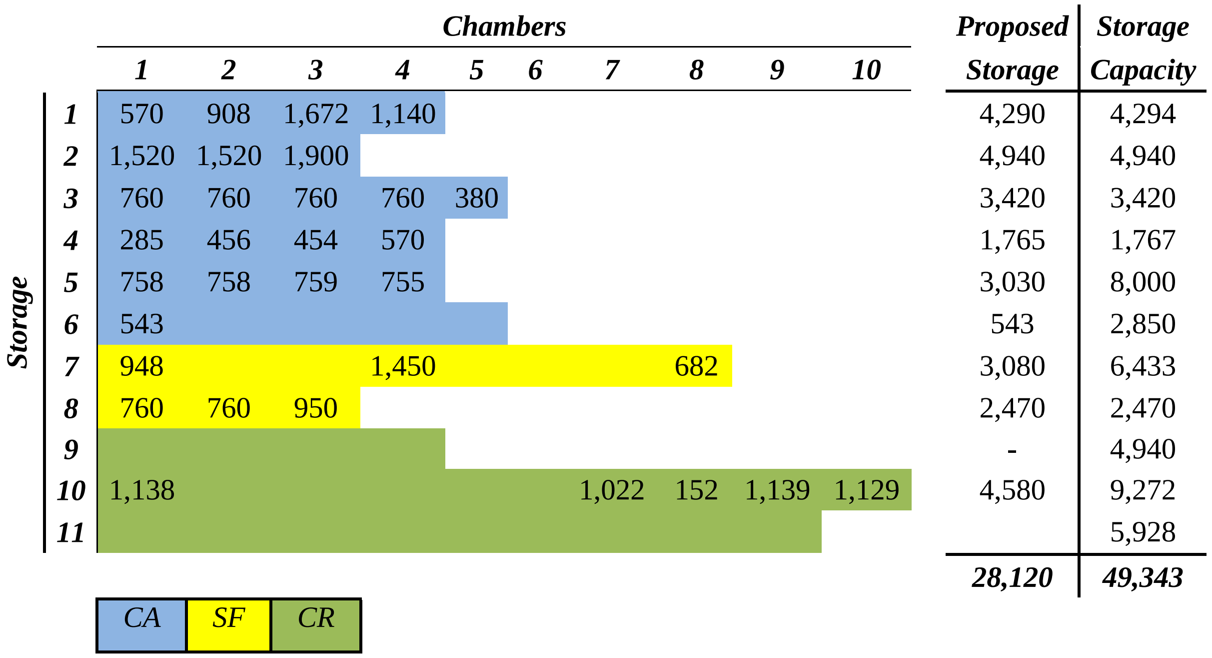
On comparing the results obtained for the purchase of fresh produce, the actual purchase cost is US$ 1,710,392 versus the results given by the proposed purchasing model at US$ 1,580,659 which gives an 8% saving equal to US$ 129,733 for the season under study. The reductions are due to purchasing the fresh produce from those producers who permit minimizing the costs of purchasing, producer administration and transport of the fresh produce, optimizing the best combination of storage time / purchase cost / producer-to-plant distance.

The participation in the total costs for each term of the objective function of the purchasing model is the following: the cost of purchasing raw material contributes 90.8%, followed by the transport costs at 9.1% and finally, the producer administration costs at 0.1% participation.

3.4.2.2. Applying the storage model to the season under study

When applying the fresh produce storage model based on the amount of fresh produce that the purchasing model proposes (Table 3.5), the storage plan that is shown in Table 3.7 is obtained. The model with its 8,262 decision variables and 2,767 constraints was resolved in 629.65s after 21,224,455 iterations.

Table 3.7 Fresh produce storage proposal for the season applying the storage model.



Storage	*Chambers 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Proposed Storage*	*Storage Capacity*
1	570	908	1,672	1,140							4,290	4,294
2	1,520	1,520	1,900								4,940	4,940
3	760	760	760	760	380						3,420	3,420
4	285	456	454	570							1,765	1,767
5	758	758	759	755							3,030	8,000
6	543										543	2,850
7	948			1,450				682			3,080	6,433
8	760	760	950								2,470	2,470
9											-	4,940
10	1,138						1,022	152	1,139	1,129	4,580	9,272
11												5,928
											28,120	***49,343***

CA	*SF*	*CR*

Table 3.8 Summary of the fresh produce storage proposal for the season applying the storage model.

	Actual Storage				**Proposed Storage**			
Segregation	*CA*	*SF*	*CR*	***Total t***	*CA*	*SF*	*CR*	***Total t***
Long	6,878	354		7,232	17,843			17,843
Medium		7,215	91	7,306		5,726		5,726
Short		2,698	10,884	13,582			4,551	4,551
Total t	6,878	10,267	10,975	**28,120**	17,843	5,726	4,551	**28,120**
Storage Capacity	20,311	8,892	20,140	49,343	20,311	8,892	20,140	49,343
Total Cost (US$*)	56,149	85,073	86,792	***228,015***	146,221	47,974	18,372	***212,540***

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

For the season under study (Table 3.8) there is a demand for 17,843 t long storage to be kept in controlled atmosphere (CA) refrigeration chambers where the objective is to extend the physiological quality of the fruit for approximately 9 months, if possible; 5,726 t to be kept in Smart Fresh (SF) refrigeration chambers where the fruit can be kept for approximately 6 months; and 4,551 t for short term storage to be kept in conventionally refrigerated (CR) chambers where the physiological characteristics can be maintained for approximately 3 months.

On observing the real storage done by the company there is a disorganized plan and distribution of the purchased fresh produce into the cold chambers. For example, the segregation with long storage time has a demand for 7,232 t that should have all been kept in controlled atmosphere chambers, but there are 354 t that are put into Smart Fresh chambers which makes for inefficient organization of the purchased fruit since this type of cold storage is not the ideal one for the type of fruit purchased. Similar behavior can be seen for medium and short term storage segregations (Table 3.8) in that there are 91 t placed in conventional refrigeration chambers and 2,698 t kept in a Smart Fresh chamber. It must be remembered that the number of bins to store in the different cold chambers is the purchasing model output that will be the input for the storage model.

Table 3.9 Number of trips by truck and transportation costs from the processing plant to the warehouses - comparison between the real case and the model proposal

	Types of truck according to load capacity			
	Type 1	Type 2	Type 3	Total trips
Total trips real (n°)	1,237	1,365	40	2,642
Total trips proposed (n°)	1,129	1,344	25	2,498
Difference Total trips (n°)	***108***	***21***	***15***	***144***
Total Cost Real (US$*)	28,272	39,043	2,546	69,861
Total Cost Proposed (US$*)	25,804	38,442	1,591	65,837
Difference Total Cost (US$*)	***2,468***	***601***	***955***	***4,024***

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

Regarding transport from orchards to the processing plant Table 3.9 shows how the model proposes having a greater number of types 1 and 2 trucks and leaving aside type 3 trucks in order to meet the transport needs, thus obtaining a total transport cost of US$ 65,837. Knowing the number of trips necessary for the purchase serves as base for planning plant operations so that at the beginning of the season the number of trucks and trips assigned to each one will be known. When comparing the number of actual trips with the number of trips proposed by the model, a decrease of 144 trips is observed which means savings of around US $ 4,024. This reduction is obtained because of a better storage plan reducing the number of trips to the warehouses.

Comparing the actual results for storing the fresh produce, US$ 297,914, with those provided by the model, US$ 278,477, it can be seen that there is a saving of 7%, that is, US$ 19,437. The reduced costs are due to having optimally assigned the fruit to the different chambers in order to better maintain the individual physiological characteristics of the fruit for each type of segregation. When analyzing the optimum cost it is observed that fresh produce storage accounts for 76.3% of the cost and the rest is for transport.

3.4.2.3. Applying the integrated model for purchasing and storing decisions

When doing the joint optimization of the purchase and storage of the fresh produce, the proposal is for

13,826 t of long segregation, 5,067 t of medium segregation and 9,226 t of short segregation with there being an initial demand for 12,160 t, 8,360 t and 7,600 t in each of the segregations, respectively. The real model with 33,651 decision variables and 13,096 constraints was resolved in 1749.16 s after 54,889,038 iterations.

Table 3.10 Fresh produce purchasing proposal for the season under study applying the integrated model.

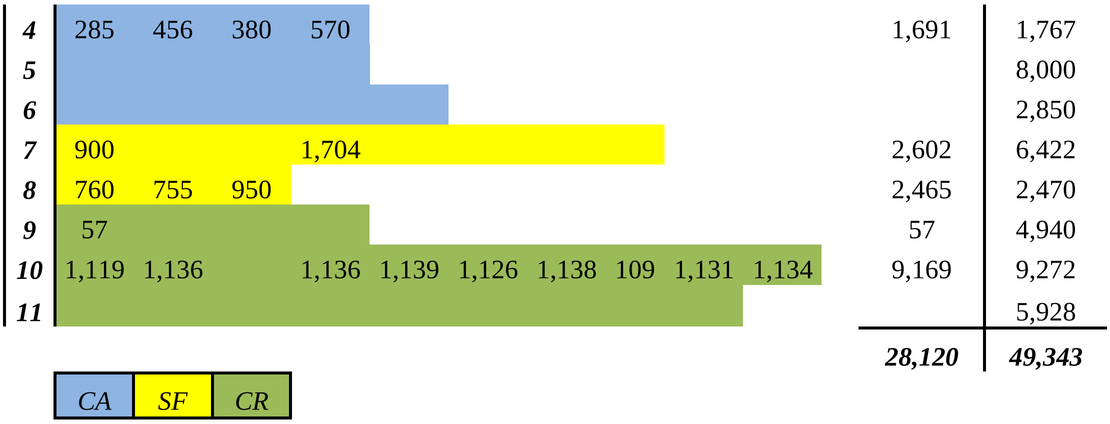
Variety	*Cost (per kg)*	*Segregation*	*Supply (t)*	*Demand (t)*	*Actual Purchase (t)*	*Proposed Purchase (t)*	*N° Actual Producers*	*N° Proposed Producers*
Royal Gala	US$0.051	Long	8,699	1,520	772	2,611	29	35
		Medium	2,953	1,520	1,986	755	30	8
		Short	1,456	1,520	3,476	1,193	34	27
Granny Smith	US$0.059	Long	15,465	5,320	1,040	4,604	58	31
		Medium	5,898	4,180	4,592	2,652	76	17
		Short	6,081	3,420	6,141	5,663	79	56
Fuji	US$0.045	Long	4,585	3,040	432	4,330	8	40
		Medium	1,680	2,660	729	1,659	27	23
		Short	2,373	2,660	4,117	2,369	67	38
Braeburn	US$0.036	Long	3,618	1,140	2,022	1,140	41	10
Pink Lady	US$0.038	Long	2,740	760	2,451	760	38	13
Red	US$0.024	Long	3,272	380	516	380	37	6
Total t			***58,825***	***28,120***	***28,120***	***28,120***		

Table 3.10 gives the fresh produce purchasing proposal for the season under study. The initial supply and demand are the same as for the purchasing model. The total demand was met both in reality as well as in the results that the integrated model provided. The difference is observed in the actual and the recommended purchase for the different segregations required for each variety of fruit. For example, for the Royal Gala variety the long, medium short term segregations have a demand of 1,520 t each whereas 2,611 t, 755 t, and 1,193 t, respectively, were purchased. This purchase is due to the fact that the demand for short and medium storage time can be met with fruit with longer storage time.

Moreover, it is noteworthy that for the Royal Gala variety with long storage time, the purchase was made from 35 producers rather than from 29 and, on the contrary, for the Red variety the purchase was made from only 6 producers rather than 37. On comparing the results given by the purchasing model and the integrated model (Table 3.5 and Table 3.10 respectively), differences can be seen in the quantity of fruit by segregation. These differences occur now because the integrated model for purchasing takes into consideration the costs associated with storage which means that the model has a better vision of the complete process for purchasing, transport and storage of the fresh apples.

Table 3.11 Proposal for fresh produce storage applying the integrated model.

		Chambers										***Proposed***	***Storage***
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***Storage***	***Capacity***
Storage	***1***	570	912	1,672	1,139							4,293	4,294
	2	1,520	1,520	1,900								4,940	4,940
	3	711	684	747	760							2,902	3,420



4	285	456	380	570							1,691	1,767
5												8,000
6												2,850
7	900			1,704							2,602	6,422
8	760	755	950								2,465	2,470
9	57										57	4,940
10	1,119	1,136		1,136	1,139	1,126	1,138	109	1,131	1,134	9,169	9,272
11												5,928
											28,120	***49,343***

CA *SF* *CR*

Table 3.12 Summary of the fresh produce storage proposal for the season applying the integrated model.

	Real Storage				***Proposed Storage***			
Segregation	*CA*	*SF*	*CR*	***Total t***	*CA*	*SF*	*CR*	***Total t***
Long	6,878	354		7,232	13,826			13,826
Medium		7,215	91	7,306		5,067		5,067
Short		2,698	10,884	13,582			9,226	9,226
Total t	6,878	10,267	10,975	**28,120**	13,826	5,067	9,226	**28,120**
Storage Capacity	20,311	8,892	20,140	49,343	20,311	8,892	20,140	49,343
Total Cost (US$*)	56,149	85,073	86,792	***228,015***	110,884	41,666	37,375	***189,925***

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015 from www.bcentral.cl

The results given by the proposed model for storage presented in Table 3.11 are clearly different from those obtained with the individual model (Table 3.7). For storage for the season under study (Table 3.12) there is a demand for 13,826 t in long term storage to be kept in controlled atmosphere (CA) cold chambers, 5,067 t to be kept in Smart Fresh (SF) cold chambers and 9,226 t to be kept in cold chambers with conventional refrigeration (CR) which is contrary to the disorganized distribution of the fruit as it was really stored by the company. Regarding the costs of the process, the integrated model gives a cost of US$ 189,925, 16% less than the real cost obtained in the studied season.

Table 3.13 Number of truck trips and transportation costs for the integrated model - comparison between the real case and the model proposal

	Types of truck according to load capacity			
	Type 1	Type 2	Type 3	Total trips
Total trips real (n°)	2,662	2,547	115	5,324
Total trips proposed (n°)	2,532	2,436	80	5,048
Difference Total trips (n°)	***130***	***111***	***35***	***269***
Total Cost Real (US$*)	106,202	110,227	11,880	228,309
Total Cost Proposed (US$*)	101,016	105,423	8,264	214,703
Difference Total Cost (US$*)	***5,186***	***4,804***	***3,616***	***13,606***

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

Regarding transport from the producers to the processing plant, Table 3.13 shows the proposed number of trips to be carried out by each of the types of truck that the plant has available. As is observed, the type of truck most used is the one that can transport up to 9.9 t with 2,532 trips per season followed by the type of truck with a load capacity of up to 12.2 t with 2,436 trips and finally, with type 3 truck with 80 trips and a maximum load of 25.1 t. As well, it is mentioned that the total cost for transport is US$ 214,703. This result serves as a base for planning plant operations since at the beginning of the season the number of trips to be made during the fresh produce storing process is known along with what type of truck is the best to use. When comparing the number of actual trips with the number proposed by the model, there is a decrease of 269 trips which represents savings of around US $ 13,606 for transportation costs. So, improving fruit purchase and storage planning optimizes the number of truck trips and, accordingly, diminishes transportation costs.

In brief, for the season the plant demand was met with 74,000 bins of fresh produce from 178 producers at a total purchase cost of US$ 1,593,341. The produce was stored in 8 warehouses using 30 cold chambers (table 11) at a cost of US$ 248,774 for storage which brings the total cost to US$ 1,842,115.

On comparing the results obtained for the purchase of fresh produce US$ 1,593,341 with the observed actual value of US$1,710,392, there was a 9% saving equaling US$ 117,051. The result is higher than the US$ 1,580,659 given by the individual model.

On comparing the results obtained for the integrated storage model, US$ 248,774, with the actual value observed, US$ 297,914, there was a 16% saving which equals US$ 49,140. Similarly, the result is lower than the US$ 278,477 given by the individual model since its solution stems from the individual purchasing model.

Altogether, the costs involved in purchasing and storing fresh produce (US$ 1,842,115) compared to the actual value observed in the season (US$ 2,008,306) indicated an 8% saving (i.e. US$ 166,191). A comparison of the total aggregated cost from the individual models (US$ 1,859,136) and the result from the integrated model turns out to be equally advantageous. There is a small difference of 0.92% (i.e. US$ 17,021) in savings between using one model or the other. This difference is due to the integrated model in planning the purchase of fresh produce now also takes into consideration the costs associated with fruit storage.

Computing time ranges from an average of 197.56 s for each of the individual purchasing and storage models to a time of 1,749.16 s for the integrated model which is still reasonable for its use in reality.

3.4.3. Analysis of the integrated model using the ε – constraint method

The integrated model seeks to minimize the cost of important activities within the agro industry, these being the purchase and storage of fresh fruit to be processed. Generally, it is not possible to minimize these costs at the same time since their objectives enter into conflict, that is, the improvement of one of them causes the other to deteriorate. For this reason in order to find the trade-off curve between these two objective functions the ε-constraint method proposed by Haimes et al. (1971) was applied. To construct this curve it is necessary to estimate the worst value (F_c^p) and the best value (F_c^m) of the costs for buying fresh fruit, and the worst value (F_a^p) and the best value (F_a^m) of the costs for storing fresh fruit.

On one hand, F_c^m is calculated replacing the objective function (19) of the integrated model by (1), where the terms associated with fresh fruit storage are removed but constraint (20) is preserved. Consequently, only the costs associated with the fresh fruit purchase are minimized (purchasing model). On the other hand, F_a^m is obtained replacing (19) by (9) minimizing the costs associated with storage regardless the cost of purchase (storage model).

To obtain F_a^p, we consider the storage model and we introduce a new constraint ($Z_1 \leq F_c^m$). This new constraint limits the fresh fruit purchase costs to being less than or equal to the best purchase cost value, that is, F_c^m. Similarly, to calculate F_c^p, a new constraint is added to the purchasing model ($Z_2 \leq F_a^m$). This constraint establishes that the fresh fruit storage costs must be less than the best storage cost value, that is, F_a^m.

The rest of the points in the trade-off curve are obtained running the purchasing model, where the right hand side value of the constraint that limits the fresh fruit purchase costs is modified. This value varies between F_a^m and F_a^p.

The instances performed in the bi-objective analysis, in particular the trade-off curve showed in Figure 4, help the decision maker to realize the total cost behavior according to purchase and storage decisions. For instance, if a lower storage cost is considered, a greater cost for purchasing the fresh fruit is required and vice versa. Moreover, purchasing costs have a greater effect on the total costs than the storage costs as $(F_a^m - F_a^p)$ = US$ 14,612 represents a decrease of approximately a 6% in the total storage costs, while $(F_c^m - F_c^p)$ = US$ 98,780 is approximately a 9.5% of reduction in the total purchase costs. Hence, it becomes necessary to find suitable solutions taking both objectives into account.

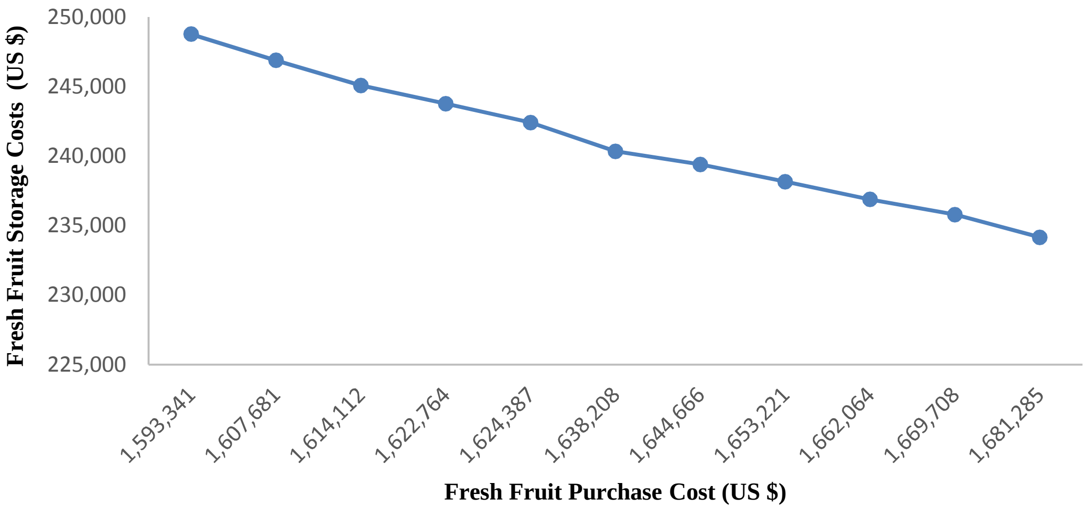


Figure 3.4. Trade-off between storage cost versus purchase cost

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

Analyzing the Pareto curve (Figure 3.4), when comparing tactical decisions about purchasing and storing fresh fruit, it can be observed that purchase decisions have greater impact than storage decisions. This happens because the fruit purchase represents about 80% of total costs in the Chilean dehydrated fruit industry. However, good cold storage management is relevant for guaranteeing fruit of the best quality throughout the season and maintaining the storage costs as low as possible.

Table 3.14 Results summary for each instance considered in the trade-off curve

	Purchase (Tonnes)			*N° Suppliers*	*N° Cold Chamber*			*N° Warehouses*	*Costs (US$)**		
Instance	Short	Medium	Large		CR	SF	CA		*Purchase*	*Storage*	*Total Cost*
1	9,226	5,067	13,826	179	10	5	15	8	1,593,341	248,774	1,842,115
2	9,227	5,114	13,778	182	11	5	14	8	1,607,681	246,894	1,854,575
3	9,230	5,200	13,689	182	10	5	14	8	1,614,112	245,091	1,859,203
4	9,145	5,240	13,734	184	12	5	13	8	1,622,764	243,777	1,866,541
5	9,211	5,328	13,580	185	12	4	14	8	1,624,387	242,415	1,866,802
6	9,284	5,430	13,405	185	11	6	13	8	1,638,208	240,353	1,878,561
7	9,299	5,450	13,370	185	10	6	12	7	1,644,666	239,405	1,884,071
8	9,398	5,468	13,253	187	12	6	12	7	1,653,221	238,160	1,891,381
9	9,432	5,473	13,214	190	13	6	11	7	1,662,064	236,886	1,898,950
10	9,348	5,530	13,241	192	13	7	10	6	1,669,708	235,797	1,905,505
11	9,334	5,649	13,136	194	12	8	10	6	1,681,285	234,162	1,915,447

(*) Dollar: US$665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

As can be observed in Table 3.14, as the fresh fruit purchasing cost increases, the number of selected producers increases from 179 to 194. This occurs because increasing purchasing costs causes the necessity to select cheaper suppliers. Further, when the storage cost increases, the number of selected cold storage units (warehouses) increases from 6 to 8. Consequently, improving the purchase cost has greater impact on total costs than improving the storage cost does.

Table 3.14 is useful for the dehydration company as they can make decisions about the number of different cold chambers to lease once the fresh fruit purchase plan is defined. Furthermore, analyzing jointly Figure 4 and Table 14, it can be observed that minimizing the purchase costs does not imply purchasing fresh fruit of poor quality, but rather purchasing fruit of the best quality in order to obtain good conversion rates of fresh fruit into dehydrated fruit along the entire processing season. Because it is difficult to find producers with high quality fresh fruit, the number of selected producers is smaller than the case when the storage costs are minimized. For this reason, the fresh fruit purchase should be carried out quickly at the beginning of the season, considering the high competitiveness among agro industry companies for obtaining high quality fresh produce.

In this analysis, it is possible to realize that storage decisions are influenced mainly by the quality of the purchased fruit and by storage availability rather than the minimization of storage costs. In this sense, assuming no limitations for obtaining all the required cold chambers, the dehydration company should put effort into purchasing more long term fruit and storing it in long term cold chambers (CA). Thus, short and medium term fruit should be purchased mainly to satisfy the demand at the beginning of the season. On the other hand, in case there are few cold chambers available, the dehydration company should purchase more medium term fruit, because short term (CR) and medium term (SF) cold chambers are more numerous than long term chambers. Therefore, short and long term fruit should be purchased only for satisfying the demand at the beginning and at the end of the season, respectively. According to this, when comparing instance 11 with instance 1, instance 11 presents a smaller quantity of long term cold chambers (CA), but a larger quantity of medium (SF) and short term (CR) cold chambers. Therefore, the purchased fruit is stored in a larger number of cheaper cold chambers, saving approximately $ 14,612 in storage costs. Because of the limited availability of long-term cold chambers, the company should buy a larger quantity of short and medium term fruit over a long term fruit which implies an increase of purchase costs around US$ 98,780. This increase is mainly due to augmenting the number of selected fresh fruit producers with whom to negotiate (administration costs).

It is important to notice that in Chile the demand for cold chambers is high during the fruit season. The dehydrated apple industry must compete for the cold storage supply with other agro industries such as fresh fruit export companies. Therefore, a good estimation of the required number of cold chambers is of interest to the company and it helps to rent them quickly. This way, the processing plant assures and maintains the quality of the fruit and the operation during all the season.

3.5. Feedback from the agro industry business in Chile

The optimization models proposed in this study are directed to agro industrial plant administrators to facilitate decision making on the purchase of raw material and its placement in cold storages. Currently, the purchase of raw material in processing plants is done arbitrarily, taking into consideration only the amount available from the suppliers, i.e. producers, without considering the required storage time for the raw material purchased (segregation). This happens even though this information is available at the beginning of the season from studies and visits done by personnel in charge of purchasing at the plant. Not using the information about the storage time of the raw material causes selecting the available cold technologies to also be done arbitrarily. Consequently, making decisions at the processing plant on purchase and storage of the required raw material becomes complicated.

In order to validate the proposed models they were applied to real data of a processing season with the purpose of evaluating later the behavior of the models and discuss the coherence of the results with the agro industrial plant. The plant contributing to the case study processes about 28,120 tonnes of fresh apple during a season to obtain around 1,800 tonnes of dehydrated product. When the purchase and storage models are used, improvements in the conversion rate of fresh fruit to dehydrated product can be obtained. For example, during the analyzed processing season the plant obtained a conversion rate of 1/11.83, which means that 1 kilogram of dehydrated product was obtained from 11.83 kg of fresh fruit. If the proposed model solution were applied (purchase and storage solution), a conversion rate of 1/10.99 could be obtained which means that 1 kilogram of dehydrated product could be obtained by processing 10.99 kilograms of fresh fruit. This proposal would allow the plant to buy a smaller amount of fresh fruit in order to satisfy the demand for dehydrated product. As can be observed in Table 10, 28,120 tonnes of fresh fruit were purchased in reality divided into 13,850 tonnes of short-term apple, 7,307 t of medium-term apple and 7,233 t of long-term apple. On the other hand, the optimization model proposes buying 9,229 t of short-term apple, 5,066 t of medium-term apple and 13,825 t of long-term apple. As mentioned before, purchasing fruit of better quality (long-term apple) allows improving the conversion rate performance. In this case study the model solution permits saving around 2,000 tonnes of fresh fruit, which represents purchase, storage and transportation cost savings of about US $ 156,333. That means 26,120 tonnes of fresh fruit instead of 28,120 tonnes would be required to produce 1,800 tonnes of dehydrated fruit. This smaller amount of required fruit represents savings of approximately 9 percent of total costs (purchase, storage and transportation costs).

In addition, the results were presented for validation to three heads of operations and purchasing belonging to different agro industrial businesses in the Maule Region in Chile who face similar situations to the case study. These professionals in the area observed a correlation between the results provided by the models and the reality that exists in their companies. In current practice, the purchase plan is done manually by personnel with years of experience making their purchases based on the availability of individual fruit and not on the total fruit available from producers and its different segregations. This brings about the storage assignment also being done manually, only taking the capacity of the cold storage into consideration but not the amount of fruit to be kept, nor the time a particular fruit can be stored, nor the type of refrigeration available and its capacity.

Given the previous, the professionals consider the proposed models useful tools, appropriate for use in practice with a good software interface where these models were integrated and fed with real data (DSS or Decision Support System). The implementation of such a DSS using these models in the agricultural processing industry would require companies to contract employees with knowledge of mathematical modeling and information management since, today, very few of them have personnel with the necessary qualifications. Moreover, an investment in information technology is necessary to implement and develop the decision tools that correspond to a DSS, both in terms of computer equipment and the optimization programs.

For using the integrated model, it is necessary to have all the parameter information before the beginning of the harvesting and processing season. As mentioned previously, sometimes it is not possible to obtain all this information at the beginning due to things like uncertain weather conditions which affect the fruit quality in the orchards, delays in leasing cold storage chambers, uncertainty about the available truck fleet for transporting the fruit, among others. Although the trucks fleet is negotiated by companies at the beginning of the season, during this period the trucks can suffer damage or can transport other horticultural loads because of their need to meet the high demand.

3.6. Conclusions and future research

In Chile the complexity of purchasing, transporting and storing fresh apples for dehydration is very relevant since 52% of the fruit and vegetable production goes to agro industrial processing plants, of which approximately 33% is dehydrated (Oliva, 2011).

The proposed models can be applied to different types of agro industries that use fresh produce in their processing, being able to apply them either individually or in the integrated form to support tactical decisions on purchase, transport and storage. This allows approaching different situations in the agricultural supply chains. Models that support the decisions involved in this study have not been found in the literature on this topic.

The first model permits determining the fresh produce purchase, seeking to minimize the purchase price, the producer administration costs, and the costs for transport of the produce to the processing plant taking into consideration the existing fruit supply and the producers. The model allows for selecting producers that provide the best combination of purchase price/storage time/distance to the producer. The second model allows establishing the fresh produce storage so that storage costs and transport costs are minimized. Integrating the first and second models permits a joint consideration of the purchase, transport and storage of fresh apples for dehydration with the purpose of optimizing the supply chain in cases where the decisions involved are done by the processing plant.

The solution provided by the purchasing model permits generating a plan for supplying fresh produce to an agro industrial plant. This supply plan must be carried out quickly and efficiently at the beginning of the season because there is a lot of competition among processing plants for obtaining fresh fruit with the required quality and the supply of fresh fruit is limited. This situation causes the development of a supply plan for a processing plant to be a complex task. The solution provided by the storage model permits contracting at the beginning of the season the refrigeration chambers necessary to preserve the quality of the fruit purchased and to meet all the forthcoming production needs. As happens in the supply plan it is necessary to make decisions about cold storage selection quickly, almost at the beginning of the harvest season, because of the high competitiveness for this resource among the processing plants. Since fresh fruit must be processed throughout the season, it is necessary to select the type of refrigeration technology required and timely carry out lease agreements with the warehouses. In this way, it will be possible to have fresh fruit with the required quantity and quality throughout the season. During the processing season in Chile a shortage of cold chambers has been observed and, sometimes, despite the availability of cold chambers their locations are so far from the processing plants (more than 200 kilometers) that their leasing is not economically feasible for the plants. In the harvest season, Chilean processing plants compete to rent cold chambers for storing apples, kiwis, pears, peaches, plums, blueberries, raspberries and blackberries at the same time.

The proposed models were applied during a processing season in a fruit dehydration plant in the Maule Region of Chile. When applying the models data was used from one processing season. On applying the purchasing model the results given would allow an 8% saving, implying a decrease in the purchase, transport and producer administration costs. Furthermore, on applying the storage model, the results given would permit a 7% saving, implying a decrease in the storage and transport costs. Finally, the results provided by the integrated model would allow an 8% reduction in total costs for both the purchasing and the storage decisions. The computational complexity of the proposed models is low with an average resolution time of approximately 1,800 s which makes its use feasible in actual practice.

In the Chilean agro industrial plants, the planning for the purchase, transport and later storage of fresh produce is done by means of the experience and knowledge of each section head, resulting in purchasing and storage errors that cause an increase in costs for these activities. For this reason the optimization models proposed in this study serve as decision making tools that make a contribution to the area of agro industrial supply chains.

Future research could be done on incorporating into the model the uncertainty of the supply from each of the producers. Moreover, as is mentioned in this study, the proposed models have as an objective to optimize 85% of the costs implicated in dehydrated fruit processing made up of the purchase, storage and transport of the fruit. Thus, a possible extension could be to integrate the remaining 15% of the total costs implied in the process, that is, take into consideration the model for the dehydration process. The costs associated with this process are energy, labor and the necessary supplies. Moreover, following this same line of research, it would be interesting to have a model that permits opening the refrigeration chambers that already have fresh fruit stored in them and planning its transport from the warehouses to the processing plant seeking to minimize the costs involved not only in the transport but also in the refrigerated inventories in order to meet the demand for fruit during a processing season in the plant.

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Chapter 4:

Supporting Decision Making in Opening Cold Storage Centers and Transporting Fresh Fruit to Processing Plants

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Abstract

Processing plants in the fruit industry play a key role in supply chain management for both, fresh and processed fruit. They are in charge of the development of procurement plans closely connected with warehouse planning operations which involve the opening of cold storage units depending on the cooling technology as well as the planning and scheduling of fruit transport to the plant to avoid idle processing periods. Hence, a multi-period mixed integer linear programming model of the fruit supply chain is proposed, which takes into account the variety of fruit, the inventory preserved in different cold storages, the processing capacity, the quantity and capacity of transport means and the daily demand. A real case study of a fruit processing plant located in Chile was considered. A planning horizon of fifteen days was considered resulting in savings in transportation and management of cold storage costs.

Keywords. Fruit Industry. Optimization. Operational Planning. Transportation. Procurement Plan.

4.1. Introduction

In recent years the industrial sector has seen an increment in the development of optimization models for decision support in supply chain management as Catalá et al. (2013) stated. However, this increment is not reflected in the agribusiness sector (Plà *et al*., 2014). This is also confirmed in the literature reviews conducted by Lucas and Chajed (2004), Weintraub and Romero (2006), Gu *et al*. (2007), Ahumada and Villalobos (2009), Audsley and Sandars (2009), Akkerman et al. (2010), and Bjorndal *et al*. (2012). These authors do report the scarce research done in operations research applied to agribusiness. More recently, the survey of Soto-Silva *et al*. (2016) focused on the fruit industry. They reported only 28 papers dealing with decision problems in the fresh fruit supply chain (FSC).

Quality aspects are relevant to perishable products (Guerzoni *et al*. 1996, Brecht *et al.* 2003, Rico *et al*. 2007). Pahl and Voss (2014) revised optimization models that integrate the deterioration and shelflife of a product in the production planning and supply chain. They found that little research was based on empirical data and, as a consequence, feedback from the industry or practitioners was lacking. Quality deterioration of perishable products is related to the refrigeration temperature as several authors have already pointed out (Chung and Norback 1991; Ambrosino and Sciomachen 2007; Hsu *et al.* 2007; Hu *et al.* 2009; Nakandala *et al.* 2016). The same authors had developed models focusing on the last stage of the supply chain, i.e. the distribution of perishable products from plants or logistics centers to end customers. More recently, Song and Ko (2016) presented an optimization model to compare the transport of perishable food and traditional refrigerated trucks, which optimizes the end-customer satisfaction through the quality of the food. A different approach was presented by Van der Vorst *et al.* (2009) who presented a simulation model that integrated changes in product quality depending on the storing time and cooling temperature emphasizing design aspects of the supply chain. Similarly, Rong *et al.* (2011) proposed an optimization model to plan production, distribution, and transport of perishable foods considering the change in product quality due to different cooling methods. The outcome of the model indicated the route and the temperature at which a product had to be distributed to the customer.

However, there are special conditions in the fresh fruit supply chain management compared to other supply chains to maintain quality and freshness as presented by Verdouw *et al.* (2010). Even though, none of previous studies has addressed the coordination of activities related to the procurement of raw material from cold storage or warehouse operation planning. Regarding this, Nadal-Roig and Plà (2015) in a preliminary study proposed a procurement plan based on mixed integer linear programming to schedule daily assignments of trucks for transporting fresh fruit from different storage facilities to a fruit logistics center to meet the demand at minimum operation cost. Later, Soto-Silva *et al.* (2016) proposed a different mixed integer linear programming model taking into consideration storage with different cooling technologies to supply a processing plant. The model planned a daily schedule for obtaining fruit from different types of cold storage and its transport to a processing plant according to the arrival of orders. The authors pointed out the difficulties encountered in tactical coordination and planning among different chain actors within the FSC with most of the problems being related to warehouse planning. Several years before, Gu *et al*. (2007) had already stated the lack of research applied to real warehouse operation planning problems: receiving, storage, picking up orders and shipping. The coordination of the FSC has to handle customer orders; consider the daily processing plant capacity depending on the number of production lines associated with the final product (e.g. juice, concentrate, dehydrated or fresh fruit); the inventory of fruit in cold storage and the number of trucks available for transportation. However, there are no studies to support multi-period decisions of picking up fruit from cold storage to supply processing plants according to the authors' knowledge. These decisions involve opening cold storage unit, which once opened cannot be closed again, and the raw material stored there having to be marketed quickly. This situation is rather common to all perishable product supply chains. Moreover, Diaz–Madroñero *et al.* (2015) noted the lack of proposals for tactical optimization models integrating production, transport and route planning decisions applied to real cases.

In this context, a multi-period mixed integer linear programming model of the fruit supply chain is proposed in this collaborative research article. The model aims to minimize the transportation cost and the holding cost related to cold storage. This paper is concerned with warehouse planning in view of coordinating the flow of fresh fruit required by the plant to operate and satisfying costumer's demand at the same time. This model is applied to a real case in a plant processing peaches previously stored in cold storage units with different cold technologies, located in the O'Higgins region (Chile).

This paper is structured as follows. Section 2 describes the cold storage and fruit supply chain in general and in Chile in particular. In Section 3 the formulation of the mathematical model is presented. Decision variables provide the scheduling to open cold storage chambers, the retrieval and transportation of fruit to the agro-industrial plant without down time. Real data from an agro-industrial plant located in Chile was used to test the model and a discussion of the results is described in Section 4. Finally, in Section 5 conclusions and future research are presented.

4.2. Fruit storage and transport to processing plants

4.2.1. General fruit supply chain

Planning and coordination of harvesting, processing, storage and distribution within the fruit supply chain need the different chain agents to be well coordinated (Oliva 2011; Soto-Silva *et al*. 2016b). Coordination is important firstly in the delivery of fruit to cold storages where it is received and secondly, in the transfer from cold storages to processing plants. The procurement of fruit to the plant has to assure a continuous flow of raw material and the fulfillment of incoming demand (Oliva 2011). The FSC is generally segmented, as shown in Figure 4.1, into four major areas: fruit-production, storage, processing and distribution (Nadal-Roig and Plà, 2015). Verdouw *et al.* (2010) has noted that the structure of the fruit supply chain can have different configurations, but the agents remain the same.

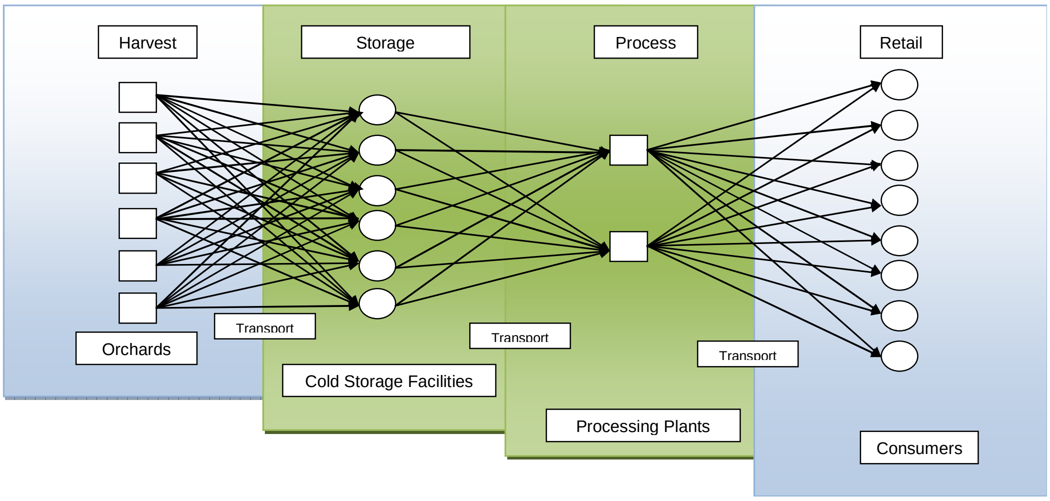

Figure 4.1 General structure of the network fruit supply chain (adapted from Jang *et al.* 2002)

Different degrees of process complexity are associated with the final products such as fresh fruit, juice, dried or canned fruit. For example, minimal processing is applied to fresh fruit involving three steps: washing, sorting and packaging of the product. The operation period in the plant can be all year long depending on raw material in stock and product demand. During each season, a plant can process different fruits from different varieties held in different types of cold storage.

In the end, customers establish the characteristics of the product demand like the amount, type of fruit, type of packaging or processing. Principal costumers are wholesalers. Bulk product sales are minimal and mainly addressed to the domestic market or to secondary industries with minimum added value.

4.2.2. Cold storage facilities

Cold storage facilities are needed in the fruit industry and help to preserve the freshness of the product. In general, storage units can be owned by the plant or rented. The storing time depends on the fruit and variety. For example, apples and pears, depending on the variety, can be stored up to 9 months. On the contrary, cherries have minimal storing time and are commonly shipped the same day that they are harvested. A cooling system to control the ripening process is required at all times for any fruit since it also mitigates deterioration resulting in longer shelf life (Nadal-Roig and Plà 2015). As an opened chamber (i.e. cold storage) quickly loses cold conditions, it is important to plan prior to opening and withdrawing the fruit to meet the demand without wasting any of the product. The opening of a chamber causes the fruit to start deteriorating slowly, so that the fruit has to be processed in the short term and the chamber emptied as quickly as possible. In addition, it is necessary to coordinate chamber opening in order to open the ones with cheaper cold technology (preserving fruit less time) earlier than those with more expensive technology (storing fruit for a longer period).

There are currently the following types of technology: Conventional Cold (CC) based on the temperature control by a thermostat, thereby maintaining the fruit stored for approximately three months; Smart Fresh (SF) has a built-in phytoregulator diffusion system protecting the fruit against the effects of ethylene during storage (ethylene is related to the ripening of fruits), allowing fruit to be kept for a period of approximately six months; and Controlled Atmosphere (CA), where concentrations of oxygen, carbon dioxide and nitrogen, as well as temperature and humidity, are regulated to preserve fruit for approximately nine months.

4.3. Modelling the opening of cold storage and fruit transportation to a processing plant

As stated, production planning in a fruit processing plant is performed according to incoming orders. It is expected to have the uninterrupted operation of the plan with the convenient procurement of raw material from storage. Thus, the mathematical model proposed to integrate the opening of cold storage units and the fresh fruit transport to a processing plant is formulated as follows. Prior to that, indices, parameters and decision variables of the model are presented in Tables 4.1, 4.2 and 4.3 respectively.

Table 4.1 Indices of the model

i	Index for the fruit type
k	Index for the cold storage units
t	Index for the processing period in days
p	Index for the cold storage technology
r	Index for the number of available trucks

Table 4.2 Parameters of the model

ST_{ik}	Initial stock of fresh fruit for each variety i stored in cold storage k
D_{ti}	Demand at period t of fruit type i
N_k	Cold type technology present in each cold storage unit k
CF_{kr}	Fixed cost per truck r and trip to the cold storage unit k
CV_k	Transportation cost from cold storage k to the processing plant per kg of fruit
$CARR_k$	Cost of leasing chamber k, per kg of fruit
M	Big M (very large scalar)
$NMVC_r$	Minimum number of trips for truck r
CMC_r	Maximum load for truck type r
TTV_{kr}	Truck travel time for truck r to cold storage k
$NMHV_r$	Maximum number of driving hours for truck r
HPC_{rt}	Average number of travelling hours by truck r, over period t
α_k	Cost for opening the cold storage unit, depending on technology.
β	Penalty for deviation from the average travel time by truck.

Table 4.3 Decision variables of the model

X_{iktr}	kg of fruit to withdraw from cold storage k at period t with truck r
$\mathrm{VC}_{\mathrm{ktr}}$	Number of trips from cold storage k to the processing plant at period t and truck r
INV_{ikt}	Inventory of fruit type i in cold storage k at period t in kg
Ta_{rt}	Number of hours greater than the average number of hours for truck r, at period t
Ea_{rt}	Number of hours lesser than the average number of hours for truck r, at period t
HV_{rt}	Number of travelling hours for truck r, at period t
$\mathrm{W}_{\mathrm{ikt}}$	Binary variable with value 1 if there is fruit in storage k, at period t and 0 otherwise
Y_{kt}	Binary variable with value 1 if storage k is opened at period t and 0 otherwise
$\mathrm{Z}_{\mathrm{ikt}}$	Binary variable with value 1 if fruit type i was withdrawn from the storage k at period t

	and 0 otherwise.
WP_{ikt}	Binary variable with value 0 if storage k with fruit type i is not yet open at period t and 1 otherwise
WPP_{it}	Binary variable with value 1 if fruit type i was withdrawn at period t from two chambers, and 0 otherwise.

$$\begin{aligned}\text{Min Z} = & \sum_{r\in R}\sum_{k\in K}\sum_{t\in T} CF_{kr} * VC_{ktr} + \sum_{i\in I}\sum_{r\in R}\sum_{k\in K}\sum_{t\in T} X_{iktr} * CV_k + \sum_{k\in K}\sum_{t\in T} Y_{kt} * \alpha_k \\ & + \sum_{i\in I}\sum_{k\in K}\sum_{t\in T} INV_{ikt} * CARR_k + \beta \sum_{r\in R}\sum_{t\in T} Ta_{rt} + Ea_{rt}\end{aligned} \tag{4.1}$$

Subject to:

$$W_{ikt} + Y_{kt} = 1 + Z_{ikt} \qquad \forall i \in I, k \in K, t \in T \tag{4.2}$$

$$INV_{ikt} \leq M * W_{ikt} \qquad \forall\, i \in I, k \in K, t \in T \tag{4.3}$$

$$Y_{k(t-1)} \leq Y_{kt} \qquad \forall\, k \in K, t \in T: t \geq 2 \tag{4.4}$$

$$\sum_{r\in R} X_{iktr} \geq Z_{ikt} \qquad \forall\, k \in K, t \in T, i \in I \tag{4.5}$$

$$\sum_{r\in R} X_{iktr} \leq M * Z_{ikt} \qquad \forall\, k \in K, t \in T, i \in I \tag{4.6}$$

$$\sum_{r\in R}\sum_{k\in K} X_{irkt} \geq D_{ti} \qquad \forall\; t \in T, i \in I \tag{4.7}$$

$$INV_{ik1} = ST_{ik} \qquad \forall\, k \in K, i \in I \tag{4.8}$$

$$INV_{ikt} = INV_{ik(t-1)} - \sum_{r\in R} X_{ik(t-1)r} \qquad \forall\, i \in I, k \in K, t \in T: t \geq 2 \tag{4.9}$$

$$ST_{ik} - INV_{ikt} \leq ST_{ik} * WP_{ikt} \qquad \forall\, t \in T, i \in I, k \in K \tag{4.10}$$

$$ST_{ik} - INV_{ikt} \geq WP_{ikt} \qquad \forall\, t \in T, i \in I, k \in K \tag{4.11}$$

$$\sum_{k\in K}(Z_{ikt}) - 1 \leq M * WPP_{it} \qquad \forall\, t \in T, i \in I \tag{4.12}$$

$$\sum_{k\in K}(Z_{ikt}) - 1 \geq WPP_{it} \qquad \forall\, t \in T, i \in I \tag{4.13}$$

$$(1 - W_{ik(t+1)}) \geq WP_{ikt} + WPP_{it} - 1 \qquad \forall\, i \in I, k \in K, t \in T: t < T \tag{4.14}$$

$$\sum_{i\in I} X_{iktr} \leq CMC_r * VC_{ktr} \qquad \forall\, t \in T, r \in R, k \in K \tag{4.15}$$

$$\sum_{k\in K} TTV_{kr} * VC_{ktr} \leq NMHV_r \qquad \forall\, t \in T, r \in R \tag{4.16}$$

$$\sum_{k \in \mathrm{K}} TTV_{\mathrm{kr}} * \mathrm{VC}_{\mathrm{ktr}} = \mathrm{HV}_{\mathrm{rt}} \qquad \forall\, \mathrm{t} \in \mathrm{T}, \mathrm{r} \in \mathrm{R} \tag{4.17}$$

$$\sum_{k \in \mathrm{K}} \mathrm{VC}_{\mathrm{ktr}} \geq \mathrm{NMVC}_{\mathrm{r}} \qquad \forall\, \mathrm{t} \in \mathrm{T}, \mathrm{r} \in \mathrm{R} \tag{4.18}$$

$$Ta_{\mathrm{rt}} \geq \mathrm{HV}_{\mathrm{rt}} - \mathrm{HPC}_{\mathrm{rt}} \qquad \forall\ \mathrm{r} \in \mathrm{R}, \mathrm{t} \in \mathrm{T} \tag{4.19}$$

$$Ea_{\mathrm{rt}} \geq \mathrm{HPC}_{\mathrm{rt}} - \mathrm{HV}_{\mathrm{rt}} \qquad \forall\ \mathrm{r} \in \mathrm{R}, \mathrm{t} \in \mathrm{T} \tag{4.20}$$

$$\mathrm{VC}_{\mathrm{ktr}} \in \mathrm{Z}^{+} \qquad \forall\ \mathrm{k} \in \mathrm{K}, \mathrm{r} \in \mathrm{R}, \mathrm{t} \in \mathrm{T} \tag{4.21}$$

$$X_{\mathrm{iktr}}, INV_{\mathrm{ikt}}, Ta_{\mathrm{rt}}, Ea_{\mathrm{rt}}, HV_{\mathrm{rt}} \geq 0 \qquad \forall\ \mathrm{i} \in \mathrm{I}, \mathrm{k} \in \mathrm{K}, \mathrm{r} \in \mathrm{R}, \mathrm{t} \in \mathrm{T} \tag{4.22}$$

$$\mathrm{W}_{\mathrm{ikt}}, \mathrm{Y}_{\mathrm{kt}}, \mathrm{Z}_{\mathrm{ikt}}, \mathrm{WP}_{\mathrm{ikt}}, \mathrm{WPP}_{\mathrm{it}} \in \{0,1\} \qquad \forall\ \mathrm{i} \in \mathrm{I}, \mathrm{k} \in \mathrm{K}, \mathrm{t} \in \mathrm{T} \tag{4.23}$$

The objective function (4.1) minimizes the costs associated with the transport of fruit from cold storage to the processing plant, the maintenance cost of the fruit in cold storage and opening of the cold storage unit. An additional term is appended associated with the balance of trip hours for each of the trucks during the planning horizon considered. This term minimizes the truck deviation from average travel time.

Constraint (4.2) states that fruit from a cold storage unit can only be withdrawn in the case that the unit is opened. Constraint (4.3) indicates that fruit can be withdrawn from a cold storage unit if there is fruit in it. Constraint (4.4) indicates whether or not to open a cold storage unit which will be opened at a later time. Constraint (4.5) indicates that the fruit withdrawn from a cold storage unit must to be greater than 1 kg. Constraint (4.6) works in conjunction with restriction (4.5), stating that fruit withdrawn from a cold storage unit cannot be higher than M, which is the total amount of fruit in the cold storage at the beginning of the season. Constraint (4.7) ensures that the amount of fruit withdrawn from a cold storage unit must meet the demand of the processing plant. Restriction (4.8) indicates that the initial inventory of fruit stored in cold storage needs to be equal to the initial stock of fruit. Constraint (4.9) updates the inventory at the time of storing the fruit stored in cold storage units. Constraint (4.10) allows knowing if fruit has been withdrawn from a cold storage unit at any time. Constraint (4.11) works in conjunction with restriction (4.10) and indicates that if there is a difference in kilograms stored, it is because fruit was withdrawn at some time from a cold storage unit. Constraint (4.12) shows whether fruit in more than two cold storage units was withdrawn at a given time. Constraint (4.13) works in conjunction with restriction (4.12) and states if fruit was removed from more than one cold storage unit. Constraint (4.14) allows deciding if fruit can be withdrawn or not at a future time, if fruit is taken from a chamber and if it is taken from more than one chamber at that time. The purpose of this restriction is that cold storage chambers containing a particular type of fruit be opened one at a time, which would allow opening single chambers simultaneously as long as the demand for that type of fruit warrants it. Constraint (4.15) limits the maximum number of trips by truck capacity depending on the type of truck and the amount of fruit to be withdrawn from cold storage. Constraint (4.16) limits the number of trips per truck to a maximum number of driving hours for each truck driver. Constraint (4.17) indicates the number of hours per truck. Constraint (4.18) ensures a minimum number of daily trips to assign each truck available for transporting fruit from cold storage to the processing plant. Constraints (4.19) and (4.20) allow the model to balance the hours of driving per truck per day, minimizing the hours that are above or below the average daily trip hours made by each truck. Constraints (4.21), (422) and (4.23) correspond to non-negativity and integrality constraints of the decision variables, respectively.

4.4. Case study of a Chilean company

Chile expects to become a leader in the food industry in the next few years. Therefore, the industry’s technical progress in reducing quality losses and lead times is of great interest. In this context, research to support transport planning and storage in agribusiness, and in particular for fruit export, contributes to achieving this goal and catch the interest of Chilean companies.

In Chile, each cold storage facility can store only 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. The transport of fruit from cold storage to the plant is coordinated by the receiving plant. The fleet of trucks used in transportation can be owned or leased. The latter is the more common in Chile, guaranteeing by contract a minimum number of trips. Hence, payment is arranged according to the agreed number of trips by truck. This way, daily variations in the demand can be handled more easily (Oliva 2011) even though the frequent re-planning decisions required due to unforeseen arrival of orders or changes in production planning at the processing plant (Crainic and Laporte 1997).

4.1. Company description and data used for the case study

The company collaborating in this research and where the mathematical model was deployed is currently one of the Chilean leading fruit exporters of high quality fruits. Their orchards are located in the Metropolitan Region and the O'Higgins Region. The company had planted 2,600 hectares in 2013 and accounted mainly for two business units, (1) trading fresh fruit: kiwi fruit, grapes, stone fruit, avocados, citrus, peaches and apples; and (2) dried fruit: prunes, walnuts and almonds. Our study is focused on different varieties of canning peaches (10,825 t in 2013) the only fruit the company keep in cold storage facilities.

The inventory in each storage facility at the beginning of the 2013 season and the number of storage units in each are presented in Table A.1. In total, the company has 62 cold storage units or facilities, of which 23 have a capacity of 400 bins, 30 have a capacity of 600 bins, and nine have a capacity of 1,000 bins (one bin contain about 380 kg of fruit). Regarding cold technology, 21 units have conventional cold storage facilities, 27 smart fresh and 14 controlled atmosphere. The assignment of fruit variety to cold storage warehouses is done based on the experience of the employee in charge of this task. This employee took into account the distance from fields to the warehouse, plus the capacity of each cold storage facility. However, these expert decisions resulted quite often in coordination errors when opening later storage units to procure the processing plant (Oliva 2011). Table A.2 shows the stocked fruit and varieties in the warehouses at the beginning of the 2013 season and Table A.3 corresponding demand.

For transportation, the company had 4 trucks available with a capacity of 9.8 t, 12.2 t, 12.2 t and 25.1 t respectively. Decisions for assigning these trucks to different warehouses were based on the experience of the plant manager and production manager of the company. For modelling purposes, the workload of each truck should be balanced, both in the number of trips and in the number of working hours. Hence, we propose the following equation to estimate the average time (in hours) per trip for the truck *r*, in the period *t* (HPC_{rt}):

$$HPC_{rt} = \left(\frac{D_{ti}}{\overline{CMC}} \times \frac{T}{R}\right) \times \overline{TTV} \qquad (24)$$

where D_{ti} is the demand at period *t* of fruit type *i* (c.f. Table 2). *T* represents the days of the planning horizon (15 days for this case study) and R represents the number of available trucks during the period (4 trucks for this case study). The parameter $\overline{CMC}$ represents the total load average of the truck fleet, and it is obtained by taking the sum of the truck loads and dividing by the number of available trucks. In this case study, $\overline{CMC} = 15{,}706.67$ kg. The parameter $\overline{TTV}$, defined as the average travel time from cold storage to the processing plant, is calculated summing up all truck travel times and dividing by the number of cold storage units and the number of trucks. For this case study, $\overline{TTV} = 0.66$ hours.

4.4.2. Application of the proposed model

The software used for solving the model proposed in the case study was IBM ILOG-OPL v6.3 and CPLEX v12.6, installed in a computer with Intel® Core ™ i5-5300U CPU 2.30 GHz processor, 8 Gb of RAM and 600 Gb of hard disk. The time horizon considered was for 15 days as agreed by the company collaborating in this research. A longer planning horizon was not considered advisable given the lack of reliable estimates of daily demand and the derived re-planning tasks. Using the data presented in Appendix A the model was solved.

For this instance, the model has 69.252 constraints and 105.808 decision variables of which 3,968 are integer, 74,593 are continue and 27,247 are binary. The solving time was 184.5 seconds, after 306,434 iterations reported. Thus, as a first consequence of these figures was that re-planning would be affordable in field conditions. Table 4.4 shows the results for the fruit withdrawn from the corresponding cold storage and daily demand of the plant satisfied. Storage units not reported remained closed with the initial inventory still available. As shown, to cover daily demand over the time horizon no controlled atmosphere storage was opened. Most of the demand was covered with conventional cold storage (seven units) while only three were Smart Fresh. This result reflects one of the objectives of the study, which was to prioritize the opening of chambers with short term preservation over chambers with long term preservation.

Table 4.4. Fruit to withdraw from each cold storage during the time horizon (in tonnes)

Ware house	Storage Unit	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
A1	*2*	-	-	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	123.5
	3	-	-	-	-	-	-	11.4	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	75.2
	4	-	-	-	-	-	-	7.6	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	80.6
	5	7.6	19.0	19.0	19.0	19.0	19.0	19.0	19.0	9.5	-	-	-	-	-	-	150.1
A4	*3*	-	-	-	-	-	-	15.2	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	106.4
A6	*8*	-	-	-	-	-	-	7.6	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	129.2
	9	-	33.1	33.1	33.1	33.1	33.1	7.6	-	-	-	-	-	-	-	-	172.9
	10	15.2	13.3	13.3	13.3	13.3	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	220.4
	12	15.2	30.4	19.0	19.0	19.0	19.0	19.0	-	-	-	-	-	-	-	-	140.6
	13	-	-	-	-	-	-	-	-	9.5	19.0	19.0	19.0	19.0	19.0	19.0	123.5
Withdraw (t)		38.0	95.8	93.9	93.9	93.9	95.8	112.1	87.4	87.4	87.4	87.4	87.4	87.4	87.4	87.4	1322.4
Demand (t)		38.0	95.8	93.9	93.9	93.9	95.8	112.1	87.4	87.4	87.4	87.4	87.4	87.4	87.4	87.4	1322.4

CA	*SF*	*CC*

In addition, the quality of the proposed solution respected the practical condition that only one cold storage unit of a given variety of fruit can be opened at a time, in an ordered way, not allowing two units of a given variety opened at the same time and avoiding overlaps (see Table 4.5). For example, for fruit variety V2 with a demand of 273.6 t, the first cold storage chamber to be opened is #5 (Warehouse A1 with Conventional Cold); once it was emptied (i.e. at day 9), chamber #13 (Warehouse A6 with Smart Fresh) was opened to withdraw the remaining fruit to complete the demand in the time horizon studied. A similar situation is observed for the variety V_4 (Table 5).

Table 4.5. Fruit to be withdrawn per variety and cold storage from day 1 to day 15 (in tonnes)

<table>
<tr><th></th><th colspan="15"><i>Day</i></th><th></th></tr>
<tr><th><i>Variety</i></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>SFCs (t)</th></tr>
<tr><td>1</td><td colspan="7">from W6 (#12) 140.6 t</td><td colspan="8"></td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="9">from W1 (#5) 150.1 t</td><td colspan="6"></td><td>0</td></tr>
<tr><td colspan="8"></td><td colspan="7">from W6 (#13) 123.5 t</td><td>114.8</td></tr>
<tr><td>3</td><td colspan="2"></td><td colspan="13">from W01 (#2) 123.5 t</td><td>118.6</td></tr>
<tr><td rowspan="2">4</td><td></td><td colspan="6">from W6 (#9) 172.9 t</td><td colspan="8"></td><td>0</td></tr>
<tr><td colspan="6"></td><td colspan="9">from W6 (#8) 129.2 t</td><td>98.8</td></tr>
<tr><td>5</td><td colspan="15">from W6 (#10) 220.4 t</td><td>7.6</td></tr>
<tr><td>6</td><td colspan="6"></td><td colspan="9">from W4 (#3) 106.4 t</td><td>45.6</td></tr>
<tr><td>7</td><td colspan="6"></td><td colspan="9">from W1 (#4) 80.6 t</td><td>109.4</td></tr>
<tr><td>8</td><td colspan="6"></td><td colspan="9">from W1 (#3) 75.2 t</td><td>162.3</td></tr>
</table>

The actual fruit withdrawn from cold storage during the period under study was compared with the fruit withdrawal proposed by the model (Table 4.6). In both cases the demand of 1,322.4 t was satisfied. While the model proposed withdrawing 951.9 t and 370.5 t from CC and SF storage units respectively, the company actually withdrew 662.4 and 609.5 t respectively, plus 40.5 t from CA storage. This difference indicated that the model tended to open and completely empty a storage unit before opening any others. At the same time, the model gave priority to opening storage units holding fruit for a shorter time, such as with CC and SF technology.

Table 4.6. Comparison between observed and proposed removal of fruit.

		Observed		***Proposal***	
Cold technology	Initial Stock (t)	Final Stock (t)	Fruit Withdrawn (t)	Final Stock (t)	Fruit Withdrawn (t)
CC	2,714	2,051.6	662.4	1,762.1	951.9
SF	4,704	4,094.5	609.5	4,333.5	370.5
AC	3,407	3,366.6	40,500	3,407.1	-
Total (kg)	10,825	9,502.67	1,322.4	9,502.7	1,322.4
Leasing Cost (US$*)		34,900.18		35,030.08	
Opening Cost(US$*)		2,497.5		1,397.45	
Total Storing Cost (US$*)		37,398.63		36,427.53	

(*) Dollar: $665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

If a variety did not have enough stock in CC or SF storage to meet the demand, then the model would open the cold storage units with CA. This was not the case in reality, since 40.5 t of a variety were removed from CA storage. The company argued that planners had made the decision to open the storage units closest to the processing plant regardless of the cooling technology. Moreover, they did not consider inventory costs and the cost of opening storage units neither have concern about the quick emptying of a storage once opened. Therefore, the company confirmed and accepted the goodness of the model proposal to this point in which leasing and opening costs were balanced through the objective function. When comparing the total costs of storage, the actual situation at a total cost of US $ 37,397.63, while the total cost obtained with the model solution was US $ 36,427.53. This shows a reduction of US $ 970.10, which corresponds to about 5%.

A total of 117 trips were proposed from storage to the processing plant, in order to meet the demand over the study period. The number of trips during the period was balanced for each driver (i.e. truck). Trucks #1, #2, #3 and #4 were assigned 28, 29, 29 and 31 trips respectively. The fruit load in tones to be carried and the scheduling per truck (number of trips per truck) over the time horizon is presented in Table 4.7.

Table 4.7. Tonnes transported and number of trips made by each truck in the study period

		Days during the period															
Truck		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total (t)**
Truck 1	t	3.0	13.3	18.6	16.7	11.0	12.9	9.5	15.2	19.0	19.0	15.2	15.2	19.0	15.2	15.2	218.2
	trips	***1***	***2***	***2***	***2***	***2***	***2***	***1***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***28***
Truck 2	t	7.6	18.2	24.3	13.3	21.7	24.3	19.0	20.9	19.4	19.4	20.5	18.6	18.6	19.4	17.1	282.3
	trips	***1***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***29***
Truck 3	t	12.2	24.3	18.6	21.7	19.0	20.5	15.2	17.1	18.6	18.6	17.5	19.4	19.4	18.6	20.9	281.6
	trips	***1***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***29***
Truck 4	t	15.2	39.9	32.3	42.2	42.2	38.0	68.4	34.2	30.4	30.4	34.2	34.2	30.4	34.2	34.2	540.3
	trips	***1***	***2***	***2***	***2***	***2***	***2***	***4***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***2***	***31***
Total t		38.0	95.8	93.9	93.9	93.9	95.8	112.1	87.4	87.4	87.4	87.4	87.4	87.4	87.4	87.4	**1,322.4**
Total trips		4	8	8	8	8	8	9	8	8	8	8	8	8	8	8	**117**

The average trips per day was 8 for the entire fleet, with a daily average of 2 trips per truck and a standard deviation of 0.1 trips. In addition, the total trip average to be performed by each truck was 29.3, with a standard deviation of 1.3 trips over the time period. Day seven was the day with the maximum number of trips, which corresponds to the maximum daily demand (see Table 9). It was Truck #4 that performed more trips than the rest. This truck was chosen to transport the fruit as it is the one with the greatest capacity. Trucks #1, #2, #3 and #4 transported 218.2 t 282.3 t 530.3 t 281.6 t of fruit, respectively (Table 7). Clearly, Truck #4 was assigned more loads to carry as it had the biggest capacity (25.01 t), while Trucks #1, #2 and #3 had 9.9 t, 12.2 t, 12.2 t, respectively.

The first day of the season was different from the rest as the activity in the plant started so, there was less demand. To transport the fruit necessary for that day, Truck #4 could have been assigned two trips. However, to count each day for the entire fleet of trucks, to prevent unbalanced workloads for drivers and the risk of leaving drivers out, at least one trip per day per truck had been agreed on with the company. For this reason, on Day 1 every truck made a trip (see Table 7). Maintaining a fleet of trucks available ensures the transportation of all fruit during the days when the plant demand increases.

Just as balanced trips are important, so are working hours. The daily average working hours for all trucks was 4.9 hours. Total trip hours for all trucks for the entire period was 72.8 hours, which corresponds to the sum of hours occupied by each truck during the whole period. Moreover, the model balanced the daily number of hours of each truck trip, i.e. 1.2 hours per day per trip, with a standard deviation of 0.2 hours. This was also corroborated by the analysis of the average number of trips per truck presented in Table 4.7.

Table 4.8. Number of trips by truck from cold storage to the processing plant and associated transportation costs during the period.

	Truck				
	Truck 1	Truck 2	Truck 3	Truck 4	Total
Proposed trips (#)	28	29	29	31	117
Total trip time(h)	21.0	18.2	18.0	15.6	72.8
Total Cost (US$*)	**635.60**	**887.20**	**846.50**	**1,704.80**	**4,073.10**
Observed trips (#)	33	33	36	35	137
Real Total Cost (US$*)	**749.10**	**1,009.60**	**1,050.90**	**1,924.80**	**4,734.20**

(*) Dollar: $665.52 Chilean pesos, taken on Wednesday, July 29, 2015, from www.bcentral.cl

Real and modeled number of trips required to procure the fruit for the processing plant were also compared. Table 4.8 shows the total number of trips during the period was 117, with a total cost of US $ 4,073.10, while in reality the company reported 137 trips and a total cost of US $ 4,734.20. Therefore, the model solution reduces transportation costs by US $ 661.20, representing a significant saving of 15%. A detailed analysis truck by truck revealed the highest cost was US $ 1,704.80 for Truck #4 with 31 trips. This higher cost compared to the rest of the trucks is because of the higher capacity and the rent being more expensive. On the other hand, although the number of trips obtained by the model for Trucks #1, #2 and #3 was similar, the costs associated with the transportation were different. This was because Truck #1 had a lower capacity, so their rent was lower, with a total cost of US $ 635.58. Trucks #2 and #3 with the same capacity had a total transportation cost of $ 887.20 and US $ 846.50, respectively. The cost of transportation and the number of trips obtained with the model for each truck were lower than the values observed in the actual situation. The company acknowledged there could be room for some overestimation in the proposed transportation cost since unforeseen items like maintenance tasks or substituting drivers may cause extra expense. However, the margin of 15% was enough to be convinced that real improvements could be obtained by implementing the model solution.

When considering the cost of storage and transportation, the total cost obtained with the model was US $ 40,500.60 while in the real situation the cost was US $ 42,132.89. Thus, the model as proposed led to savings of US $ 1,632.23 representing approximately 6% of the total cost. In relation to the cost structure, the cost of storing fruit represented 81.6% of the total costs obtained with the model, while the transportation cost was smaller and equivalent to approximately 18.4% of total costs. This cost structure was similar to the one observed in the real situation by the company, where storage costs accounted for 80.4% of total costs and transportation costs, 19.6%. It is worth mentioning that the storage cost is also affected by decisions made during the harvesting season when raw material is bought and cold storage rented to be filled with the harvest. These decisions are out of the scope of the present study but are envisioned as future extensions of the present research.

4.5. Conclusions

This study proposed a multi-period optimization model to plan the opening of the cold storage units with different cold technologies in a finite planning horizon in order to meet the demand for fresh fruit by a processing plant. Along with this warehouse planning, the fleet of trucks available at the processing plant was allocated for transporting the fruit balancing working hours and the number of trips for each truck driver. The model minimizes the leasing and opening costs for the cold storage and the cost for transporting the fruit to the plant. In this sense, the model developed contributed to improving the efficient transport and inventory management.

The model was applied to a real case with the support of a company in the assessment of the solution reported by the model. A planning horizon of 15 days was adopted. Real cases improve the link between business and researchers to solve problems in the area, either at the operational, tactical or strategic level. Hence, the outcomes of the model were compared with actual ones. As a result, the model showed a reduction of approximately 15% in transportation costs and 5% in cold storage costs. The solution provided by the model met practical requirements for opening the cold storage, ie, chambers with cheaper cooling technology were opened before those with more expensive technology. Regarding the use of trucks, the model balanced workload and working hours of truck drivers. This condition was very important in practice because the transportation was outsourced to a third party and they may have stopped delivering the service if a minimum number of trips were not guaranteed. This would be harmful for the procurement of fruit by the plant in the peak season. The resulting solution was accepted by the decision makers involved in this collaborative research.

Finally, it would be interesting to extend the model to include decisions in the earlier stages of the supply chain. For instance, planning the production and purchase of fresh fruit from the orchards taking into consideration the available cold storage and reduce storage costs. The development of such a model would improve the strategic and tactical planning of operations production-storage-procurement of fresh fruit for a processing plant.

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Appendix A. Data related to the Chilean Company during 2013 used to feed the parameters of the model.

Table A.1 Stored fruit at the beginning of the 2013 season.

	Stored fruit	**Capacity of cold storage facilities**			**Total**
Warehouse	Canning peaches (t)	400 bins	600 bins	1,000 bins	**Units**
#1	819	1	4	-	5
#2	1,444	5	5	-	10
#3	304	4	-	-	4
#4	2,497	5	10	-	15
#5	1,300	1	3	2	6
#6	4,460	7	8	7	22
Total (t)	**10,825**	23	30	9	**62**

Table A.2 Stored varieties of canning peaches in the warehouses.

		Warehouse					
Variety	**Variety**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**
V_1	Andross		X		X	X	X
V_2	Ross Peach	X	X		X		X
V_3	Loadell	X					X
V_4	Bowen				X		X
V_5	Carson		X		X	X	X
V_6	Klampt				X		
V_7	Everst	X					X
V_8	Hesse	X	X				
V_9	Kakama		X	X		X	
V_{10}	Tirrenia						X
V_{11}	Rizzi						X

Table A.3. Daily demand of the processing plant according to the variety of fruit (in tonnes)

	Day															
Variety	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total**
V_1	15.2	30.4	19.0	19.0	19.0	19.0	19.0	-	-	-	-	-	-	-	-	***140.6***
V_2	7.6	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	***273.6***
V_3	-	-	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	***123.5***
V_4	-	33.1	33.1	33.1	33.1	33.1	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	***302.1***
V_5	15.2	13.3	13.3	13.3	13.3	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	***220.4***
V_6	-	-	-	-	-	-	15.2	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	***106.4***
V_7	-	-	-	-	-	-	7.6	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	***80.6***
V_8	-	-	-	-	-	-	11.4	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	***75.2***
Total	**38,0**	**95.8**	**93.9**	**93.9**	**93.9**	**95.8**	**112.1**	**87.4**	**87.4**	**87.4**	**87.4**	**87.4**	**87.4**	**87.4**	**87.4**	**1,322.4**

Chapter 5:

A Decisions Support System for Purchasing and Storing Fresh Fruit for Processing

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To be submitted to: **Decision Support Systems**

Abstract

This work proposes a decision-support system to optimize purchasing operations, cold storage and fresh fruit freight. Due to the fact that within the supply chain of fresh fruit there are still problems that have not been addressed, optimization tools are required to support decisions in the agro-industrial area so that these processes are carried out in an efficient way. At present, in the Chilean reality, there is no software to support the decisions of fresh fruit supply in a process plant, which can allow planning efficiently the involved processes. Currently, these processes are carried out independently and manually. This requires a DSS which can offer the particularity of solving at least a couple of problems within the fresh fruit supply chain to allow an optimum tactical planning for the rest of the season of the process plant. Therefore, this study provides the DSS to select growers, their subsequent purchase of fresh fruit, and the allocation of the fruit to the best cold chamber available. To show the practical implementation of this DSS, a real case study has been carried out in a company of dehydrated apples. The implementation of the model shows that it is possible to achieve improvements of approximately 10% in costs, equivalent to save about US$50,000 per season.

Keywords. **Decisions Support System in Agriculture, Tactical Planning, Agricultural Planning**

5.1. Introduction

The Chilean exports of dehydrated products have shown a rapid growth in the last decades. This is reflected in the total of agro-industrial products exported, where 36% corresponds to dehydrated products, and dried apple in particular has a 7% participation. At the beginning of the 1980s around US$20 million were exported with a total of 13 thousand tons shipped. In 2010 sales were more than US $ 251 million and 122 thousand tons were exported (Chilealimentos, 2010). The growth of dehydrated product industry is also reflected in the participation within the 201 agro-industries registered in Chile in 2005, where 33% is dehydration plants, 29% is frozen product plants, 28% canning plants, and 9% juice plants (CIREN, 2005). Currently, Chile is the first world exporter of dried apples, representing 33.3 % of global exports (Bravo, 2010).

In the dried fruit industry, the purchase of a good fresh product and storage are critical issues within the supply chain, since both activities are related to obtaining a good yield in the transformation of fresh fruit into dried fruit (Oliva, 2011, Soto-Silva *et al.*, 2017). This yield in the dehydration industry is known as the conversion factor (cf) and it is defined as the necessary kilograms of fresh fruit to obtain a kilogram of dried fruit (Soto-Silva *et al.*, 2017).

In the Chilean industry of dried apple, the harvest takes place between February and May, when the purchase prices are lower and there is a wide range of fresh fruit in quantity and quality. There is also the possibility of purchasing fruit off harvest season, but there is a lower supply, lower quality and higher prices. Currently in Chile, when purchasing fresh products, the agro-industrial processing plants only consider the amount of fruit offered by growers, without taking into account the quality. This situation makes it difficult to store fresh products, since there is no clear information about the varieties and the quality of the product. This information is necessary to assign the fresh product to the different types of existing storage, which may be of short, medium and long-term (Oliva, 2011).

The choice of the type of storage is relevant, because it is necessary that the fruit quality at the time of being purchased remains unchanged in the time. This is because the fruit is processed between the months of March and November where, as mentioned above, to obtain a good final product, good raw material is needed. Currently, these decisions are made by reviewing the historical data from the past purchases and based on the experience of the decision-making process, which often leads to the selection of growers of fresh products with features not required by the plant and a storage allocation not suitable for the purchased fruit (Oliva, 2011).

An important fact in the process of dehydration is that the purchase, storage and transportation of fresh raw material represents 85% of the total costs involved in the process, followed by the energy with 5%, labor with a 5% and production supplies with the remaining 5% (Oliva, 2011). Within the total cost of fresh fruit supply and storage, purchase implies 70%, storage 25% and freights the remaining 5% (Soto-Silva *et al.*, 2017).

Currently, in Chile there is no a supporting tool to take an optimal decision for the purchasing process, storage and transport of fresh fruit for the dehydration process (Soto-Silva *et al.*, 2017). In addition, relevant parameters are not being considered in the supply and storage planning of fresh fruit, such as cold chambers availability, the number of growers, the quality of each grower's fruit and the availability of trucks for transport. All the planning in the supply and storage process, whose ultimate goal is to achieve the preservation of the fruit quality as long as possible so that the conversion of fresh fruit into dehydrated fruit is optimal during the preparation season, is based on the experience of those who are responsible for different processes (Soto-Silva *et al.,* 2017).

One of the tools that help a good decision-making is the Decision Support System (DSS). As defined by Alyoubi (2015), a DSS is an information system tool that supports the decision-making process. It is an interactive and adaptable information system, computer-based, which allows decision-makers to find solutions to different problems (Turban and Aronson, 2000)

The DSS is applied in different types of decisions, such as: Strategic Planning, Management Control and Operational Control, implemented in different areas such as wine, agriculture, livestock, production of perishable and non-perishable items (Turban and Aronson, 2000). In these areas, the DSS provides a wide range of applications, including agriculture, water resources, environment, organizational management, health and business (Fountas *et al.,* 2015). Within these sectors, DSS is used to improve personal efficiency, speed problem resolution, facilitate interpersonal communication, promote lifelong learning and training, and increase the organizational control (Mir and Quadri, 2009). For example, in the agricultural field, DSS can be designed to be used by agronomists, soil scientists, agricultural engineers, entomologists, climate experts, farmers, students and extension workers, who must make important decisions within the supply chain they are working on (Mir and Quadri, 2009).

Within the research of agro-industrial area, which proposes a DSS, we can find Pla *et al.* (2004), who propose a DSS that integrates a Markovian model for supporting the decisions of reproduction on a pig farm. Mir and Quadri (2009) present a review of DSS applied to agriculture, noting that within the areas that have had a major study in the agro-industry is the integrated crop management, fertilizer management, weed management, water management, plant protection, soil erosion, pollution management and control. Bochtis *et al.* (2012) present a DSS that aims to show the optimal routes within a field used by different vehicles that cross it. The goal is to minimize the soil area used for transport, and also minimize CO2 emissions. Elsheikh *et al.* (2013) present a decision-support system that allows planning the crop to be planted in an area, considering the geography, the water and the soil quality. An important point is that the system considers not only the quantitative data, but also the experience of experts to categorize each zone and their possible crops. Lopez and Pla (2014) present a support system to make decisions of the supply chain of sugar cane. This system allows planning the harvest and the transport of sugar cane from the orchards to the processing plants. Kerselaers *et al.* (2015) presents a DSS that allows managing the use of agricultural land in a given province. Sánchez-Cohen *et al.* (2015) present a DSS to support crop decisions in lands where there is a water shortage. This allows farmers to make decision to plant a certain crop based on the analysis that the DSS offers. Among the reviews, the one presented by Fountas *et al.* (2015) show that from the 141 articles reviewed, 75% shows PC applications, and the majority deals with field operation management, with a coverage rate of 89%, followed by 81% of operating reports, and financing with 64%. Tanuja *et al.* (2016)

show the development of a DSS to improve agricultural yields of crops, through precision agriculture. The DSS supports with the information from the growers to make a decision about the crop in their fields. The DSS is based on a web and mobile application, which allows growers make decisions about farming and crop fields in real time. Navarro-Hellin *et al.* (2016) present a DSS for smart irrigation of agricultural crops, which plans the needed water according to sensors in the field to collect weather and soil information, and it allows the DSS forecast and give an optimal irrigation plan for the field. This work is applied and validated in a field in Spain that has grown citrus fruits.

To support the complex decision-making in the purchase, storage and transport of fresh fruit, the Chilean agro-industry does not have tools to support this type of decisions (Soto-Silva *et al.*, 2017). The objective is to select the growers and assign the fresh product to the most suitable cold storages to obtain the industrial standard conversion factor throughout the process period. Currently, these processes are carried out by the operations, supply, and processing and storage staff based on the experience gained through time. To do this, records are taken in Excel spreadsheets and text files. These are the only tools used for decision-making.

Therefore, in this research it is proposed a tactical decision support system (DSS) for the purchase, transport and storage of fresh products, in order to minimize the costs of these activities and maintain the quality of the product as long as possible. To do this, the DSS uses the mathematical model, which is proposed by Soto-Silva *et al.* (2017). They present a mixed integer linear programming that allows optimal planning of supply, storage and transport of fresh fruit. As mentioned by Mir and Quadri (2009), Fountas *et al*. (2015) and Jain and Raju (2015) in their literature reviews, there are still areas in agriculture, such as irrigation, cultivation, harvesting, processes and refrigerated transport, where it is possible to develop tools to support the decision (DSS), having as a final objective to improve the efficiency in different processes within the agricultural supply chain (Sanchez-Cohen *et al.,* 2015).

The DSS is applied to a real case study corresponding to a processing plant of dried apples located in Maule Region, Chile. This plant has approximately 236 fresh fruit growers of different qualities, an annual fruit demand of about 28 million kilograms, 12 cold storage centers, with a total of 70 cold chambers, which have different cooling technologies. It also has a leased fleet of approximately 30 trucks, segmented into 3 types of trucks according to the load capacities of each one.

The following section describes the activities of purchase and storage of fresh products in Chile, whose final destination is process plants. In section 3, we present the development of the decision support system. Section 4 shows the implementation of DSS to a dehydrator in the Maule Region, Chile. Finally, section 5 shows the company feedback, and Section 6 presents the conclusions of this research and future research is mentioned.

5.2. Supply chain for apples destined for the dehydration process in the Chilean agro industry.

Figure 1 below shows a diagram of the supply chain involving the purchase, transport and storage of fresh apples destined to process of dehydration plants in Chile. This chain is similar to other fruit and vegetables chains that are raw material for the agro-industry. The diagram shows all the actors involved, and the flows between them, although the last part of the chain, which deals with fresh fruit dispatch from the cold storage to the processing plants, is not included in the objective of this research.

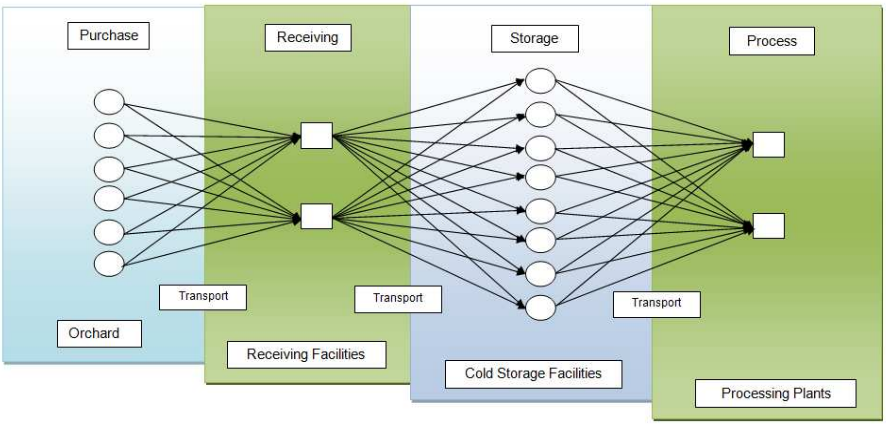


Figure 1. General structure of the supply chain for apples destined for processing in Chile (Soto-Silva *et al.*, 2017)

Next, the interaction between the elements of the supply chain is described (Figure 1).

The harvest is carried out by the growers who are, in general, the owners of the orchards. This crop is collected in containers called bins whose load capacity is about 380 kg. The processing plant is responsible for picking up the containers from the orchard and receives them in the plant where the payment, accounting and control of apple conditions are made (González-Araya *et al.*, 2014). Then, the fruit is placed in a cold storage, either in refrigerated cells within the plant or rented. It should be noted that the decision to store the fruit or send it directly to process is made by the process plant when receiving the fruit. If it is going to be stored, it fruit quality should be considered and thus select the cold chambers that contain cold conditions as long as possible to maintain the fruit quality. In Chile, a process plant tends to have a demand of approximately 30,000 t of fresh products, available for purchase from about 250 growers who offer six varieties of fruit with three different duration time (short, medium and long term).

The storage time depends on the type of cold chamber that is used. In addition, for all the fruits stored, the ripening process must be controlled by the cooling system (Nadal-Roig and Pla, 2015). A storage facility can have different types of cold stores, such as chambers with conventional cooling technology (CR), where the temperature is controlled by a conventional thermostat which allows keeping the fruit over a period of about 3 months (short-term). Chambers with Smart Fresh technology (SF) that incorporate the dissemination system of phytosanitary-regulator Smart Fresh, which minimizes the synthesis of ethylene in fruit respiration during storage, allow the fruit to be kept for about 6 months (mid-term). And finally, chambers with controlled atmosphere (CA) where oxygen concentrations, carbon dioxide and nitrogen are regulated along with the temperature and humidity, that is to say, the chamber has a controlled climate allowing the fruit to be maintained over a period of about 9 months (long-term). Generally, the plants have more than one cold storage in order to have fruit available to be processed throughout the year. In Chile, it is possible to have only one type of fruit stored in a cold chamber at the same time (Olive Oil, 2011).

The transport within the entire supply chain is usually outsourced because it is too expensive to maintain a truck fleet, thereby avoiding the cost of drivers and truck maintenance (González-Araya *et al.*, 2014). The payment policies are varied, but the most common are the payment per kilogram or bins transported per kilometer, or a price is negotiated for the entire season.

In Soto-Silva *et al.* (2017) it is explained in detail the purchase, storage and transportation process of fresh fruit that is intended an apple dehydration plant.

The management of information in each of the stages of the supply chain (purchase, storage and transportation) is at most in Excel worksheets, and may sometimes not be able to have a record of the necessary information for good decision-making. Sometimes this information is duplicated and there is no certainty of truth.

5.3. Decision Support System Design

To help make purchasing, storage and transport decisions of fresh fruit for the dehydration process, the following section presents the development of a DSS. The main objective of the DSS is that the user, in particular the one responsible for the supply and storage of a process industry, can generate supplying plans and lease contracts with cold storages. This can be done through a computer tool that implies easy communication with the user and the given solution will be supported by a mathematical model that delivers the optimal solution to the problem.

Currently, agriculture is in constant change due to, for example, the market conditions, weather, exchange rates, supplies shortage, among others. That is why it is necessary to optimize the processes to ensure that the decisions taken are the most efficient, thereby reducing the costs and time in the implementation of solutions (Mir and Quadri, 2009).

5.3.1. Mathematical Model

The mathematical model included in the DSS is a model of mixed integer linear programming which looks for and integrates all the requirements of the fresh fruit supply problem for a dehydration plant, focusing on the purchase, storage and transport. The model used corresponds to the integrated model proposed by Soto-Silva *et al.* (2017), which seeks to respond to the problem.

The objective of the mathematical model is to minimize the total costs involved in the process. These costs are generated by the purchase, storage and transportation of fresh fruit. To select the fresh fruit suppliers, it is important to select those that enable them to comply with the requirement of the same type and segregation of fruit requested by the commercial area of the company, at a minimal cost. For the cold storage, it is important to minimize the number of cold chambers that are used to maintain the fruit quality as long as possible. This is due to the fact that the process in plant takes about 9 months, because of the capacities of daily process in plants. It must be considered that the purchase and storage must be guided by the final objective of finding good yields in the conversion of fresh fruit into dried fruit, therefore questioning what is purchased, how much is purchased and where it is stored play a critical role in the supply chain of dried apples (Oliva, 2011, Soto-Silva *et al.*, 2017).

The indexes, parameters, decision variables and the model of mixed integer linear programming are defined in Appendix A.

The most important decision variables for the purchasing process of fresh fruit are represented by W_{pqtl}, that shows the amount of fresh fruit purchased from each of the suppliers. The most relevant decision variables for the storing process of fresh fruit are represented by X_{qtcnl} that shows the amount of fresh fruit stored in cold storage chamber that are available. The mathematical model is presented in Appendix B.

The objective function seeks to minimize the associated costs with the fruit purchase, transportation cost from the growers to the processing plant and the administrative costs of the growers who the fruit is purchased from. It also minimizes the fixed and variable costs associated with transport from the process plant to the storage centers, costs of maintaining the fruit in cold chambers and fixed costs for storage and chamber.

The mathematical model presented and explained in detail in Appendixes A and B is incorporated into the decision support system (DSS), which allows to find in an optimal way the supply, storage and fresh fruit transport program. The details of the DSS construction are presented below.

5.3.1 DSS Structure

Next, Figure 2 shows the DSS structure, which begins with a mathematical model connected to a database. Both elements are nested in the DSS whose main component is the interface with the user.

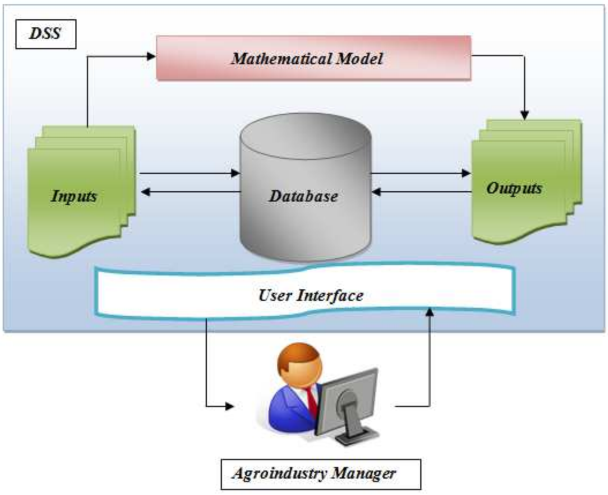


Figure 2. Structure of the DSS (based on Lopez and Pla, 2014)

As shown in Figure 2, the mathematical model is the starting point to begin developing a DSS, which gives the empirical validation of the problem that is been represented. To represent and find solutions, it is necessary to handle input data for the mathematical model, which are the parameters required for modeling the problem, whose storage is performed in a database. In the same way, the outputs of the model called decision variables are managed through a database.

The communication with the user is done through an interface, which is responsible for the decision-maker. For the DSS developed, work is carried out with the storage and production area of a process plant, in order to analyze the best alternatives in the management of the input/output of data from DSS.

5.3.2. Graphic interface

Once the mathematical model is defined, which is described in section 5.3.1 and in Appendixes A and B in detail, a DSS in the programming platform of NetBeans IDE (version 8.0) is created. This tool aims at lifting relevant information to generate various input parameters to the model, developing the respective programming of the problem, based on the programming language of optimization software ILOG OPL Development Studio IDE (version 6.0.1) using the Cplex software (version 12.6) as an engine of solution.

For the user's graphical interface, it was considered suggestions from staff who work in supply management of raw material in plants of the southern central zone of Chile. In Figure 3 below, the DSS structure is presented.

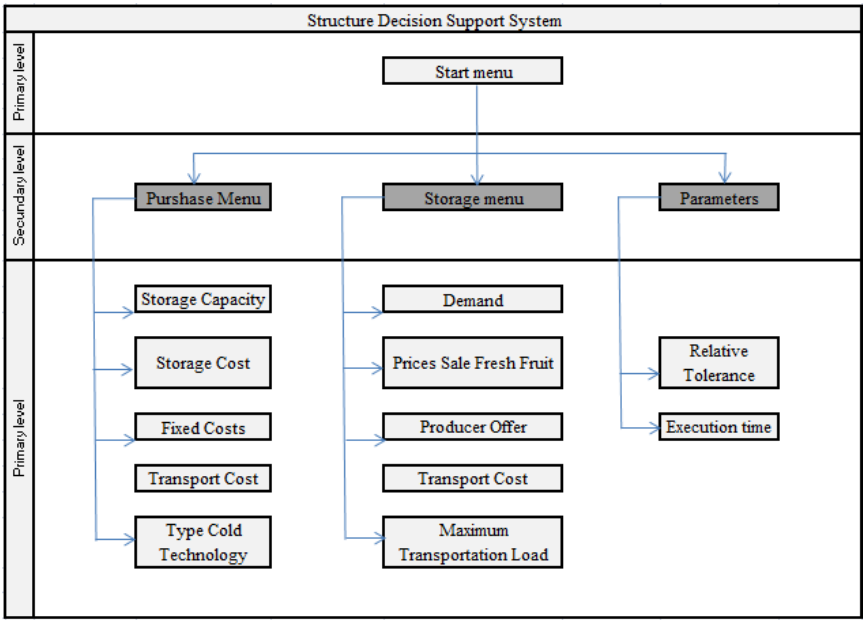


Figure 3. DSS Structure.

As shown in Figure 3, these are three major areas that were considered important: first, optimization of fresh fruit purchase, then, cold storage and finally relevant information to the running parameters and type of solution being sought with the optimization model that is in DSS.

The first two menus represent the problems intended to address with an integrated model for fresh fruit supply and storage. This division is made since each process to be optimized has different requirements and parameters. In addition, this separation allows a better order for both planning and reviewing the stored information. Within the information needed, it is found the grower's data, available cold storage and the demand of processing plant.

Regarding the menu associated with parameters, it has relevant information to each of the runs that are intended to be made to the mathematical model. Two parameters can be calibrated, such as running time and relative tolerance of the solution found. In practice, it may happen that the decision-makers need an almost optimal solution, therefore calibrating some of these parameters, such planning, can be found quickly.

The system allows changing and adding new parameters in each area and, at the same time, it allows to modify information already stored. This feature is important because all the information is variable, since there may be changes in the growers' data, for example prices and varieties of offered fruits, the cold chambers available, among others.

Figure 4 shows the diagram of the planning process of purchase, storage and transportation of fresh fruit, which describes the various stages and actions that are performed in order to obtain the supply planning of a processing plant.

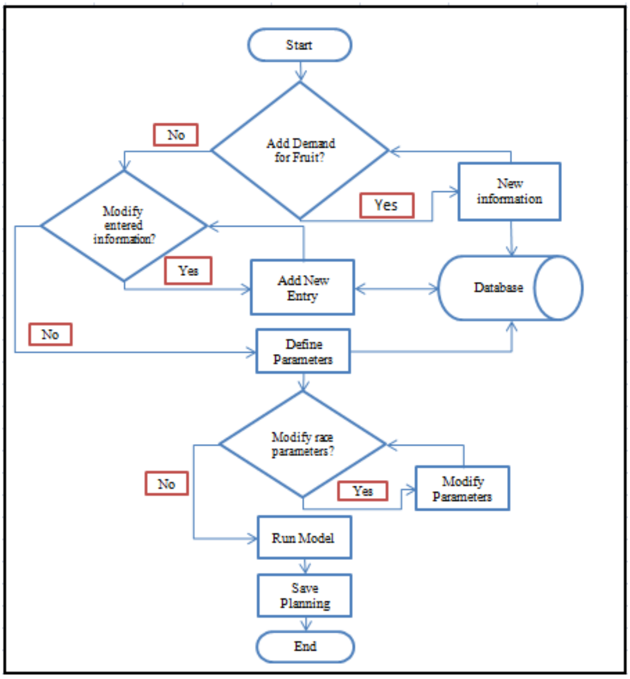


Figure 4. The process diagram of purchase, storage and transport of fresh fruit.

As shown in Figure 4, the process begins by entering the demand of the process plant of each of fruit varieties and qualities, which is needed to be process to meet the demand of finished product. Then, the rest of the parameters are entered, both the purchase process and the cold storage process. Once the information is entered, adjustments can be made, such as changing the cold chambers availability, fruit growers' offer, purchase prices and rental costs of cold chambers. After entering all the information, the necessary parameters required for the execution of the model must be defined. Among them, it is found the relative tolerance to find the optimal solution and the execution time.

Subsequently, the DSS is run and results are obtained. These are the purchase planning from different growers, either in quantity and variety of fruit, the allocation of purchased fruit in different cold storage centers and the kind of transport used to carry fruit from different growers to different storage centers.

5.4.3. Database

To work properly, the DSS requires a database containing all the information associated with the purchasing process, such as growers' information, quantity and quality of the fruit offered, purchasing cost and transport availability, and also information associated with the storage process, such as cold chamber availability, cold technology in each chamber, lease costs and transport availability.

All the information is stored in the database, and the process diagram is shown in Figure 5. The system allows the user to add new information and, at the same time, change the saved information before running the model. It is important to note that the data are stored in Excel files. It is decided to work in a database in Excel since this is like an ERP widely managed by workers in the Chilean business reality.

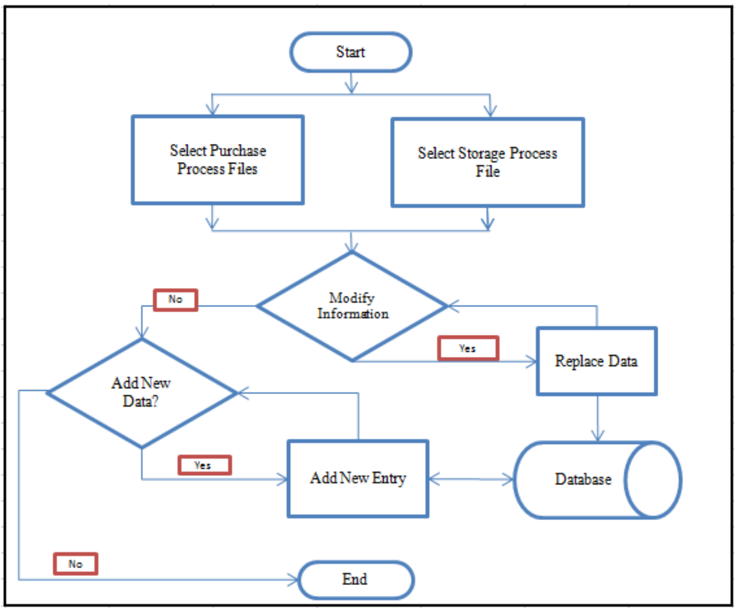


Figure 5. Process diagram for the database.

Finally NetBeans, the software where the graphical interface of the DSS is developed, creates an Excel file where the solutions for each area are transferred, either purchase and storage. Subsequently, these solutions are interpreted using dynamic and macro tables, which were programmed in the Visual Basic programming language.

An important point to be considered is that the development of the graphical interface and the design of the database are made with free software. This type of tools is chosen due to the fact that in the private enterprise, particularly in Chile, it is not common to have paid computational tools.

5.4. Application of the DSS to a case study

A real study case is carried out which shows the practical use of the tool presented and its link with the mathematical model developed by Soto-Silva *et al.* (2017).

The objective of the case study is to show the characteristics of the DSS and demonstrate the capabilities that this has to deliver an optimal planning for a good decision-making in the purchase, storage and transport of fresh fruit. In addition, to prove that based on a good integration of a mathematical model and a graphical interface it is more effective to support decision-making.

5.4.1. Description Company

The company where the case study was applied is an agroindustry producing dehydrated and preserved fruits and vegetables, developing its activities in the Maule Region, Chile. This agroindustry is the main dehydration company in the region and one of the two most important in the country, where dehydrated apple is the main export product in volume and profits.

The company processes more than 36,000 t of raw material annually, which are subject to selective, washing, cutting and / or thermal processes, depending on the required product. The company mainly processes apples (18,250 t / year), cherries (400 t / year), peaches (150 t / year), tomatoes (1.750 t/year), Paprika (8,000 t/year) and Celery (3,120 t/year). Therefore, the most processed fresh product is apple, representing 60% of the raw material to be processed, followed by peppers, with 25%.

The apple dehydrated plant has approximately 236 apple growers of different varieties, an annual fruit demand of about 28,000 t, 12 storage centers, with a maximum availability of 70 cold chambers with different refrigeration technologies, allowing different times of fruit conservation in time, and a leased fleet of approximately 30 trucks, type 1, 2 and 3, with different load capacities: 22 bins, 32 bins and 66 bins, respectively.

In order to store the fresh product longer, a classification system is applied, which considers harvest and orchard conditions, and fruit ripeness in reception. This system gives a classification to each batch of fresh product and, according to this; it determines the type of cold room where it will be stored. This classification is called segregation, which indicates the time in which the fresh product can be stored, maintaining its conditions for the process.

Currently, despite the segregation of the fruit, none of the factors described above (quantity and time of fruit storage, types of storage) are considered in the purchasing process. The company buys everything that its storage capacity allows, so as to meet the production schedule during the year.

5.4.2. Application of DSS.

To start the application, as explained above in Section 4, NetBeans must be installed, since the application was developed in Java. The first screen to display is the DSS start-up screen (Figure 6). The aim is to show the user the parameters required to load the mathematical model that is implemented in the DSS. This first screen corresponds to the secondary level presented in Figure 3.

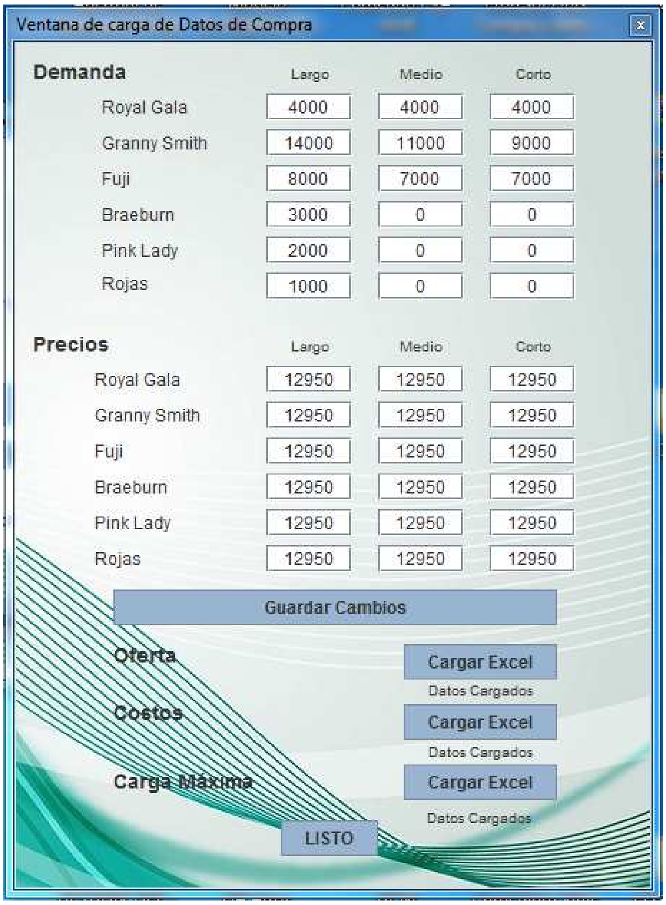
The necessary parameters for the DSS to find an optimal planning are divided into two areas: purchasing and storage. In addition, it gives the option to allow the user to find a solution to the problem by calibrating the stop of the solution search. That is to say, it is possible to stop the search by execution time or GAP.

Estado: Datos cargados: 0%

Figure 6. DSS start-up screen

The next step is to load the data from the purchasing model and the storage model, respectively.

For the purchasing data, as shown in Figure 7, first the plant demand must be registered for each one of the varieties and of each one of the segregations, respectively. Subsequently, in each variety and segregation the purchasing prices must be registered. Both the purchase prices and fruit demand were included in the DSS with a high degree of proximity to the user, since they have a higher probability of variation. Therefore, it is necessary that the relationship user / parameter be more fluent. This allows, for example concerning changes in these parameters, run the mathematical model without having to reload all the rest of parameters.



Ventana de carga de Datos de Compra

Demanda	Largo	Medio	Corto
Royal Gala	4000	4000	4000
Granny Smith	14000	11000	9000
Fuji	8000	7000	7000
Braeburn	3000	0	0
Pink Lady	2000	0	0
Rojas	1000	0	0

Precios	Largo	Medio	Corto
Royal Gala	12950	12950	12950
Granny Smith	12950	12950	12950
Fuji	12950	12950	12950
Braeburn	12950	12950	12950
Pink Lady	12950	12950	12950
Rojas	12950	12950	12950

Oferta: Datos Cargados

Costos: Datos Cargados

Carga Máxima: Datos Cargados

Figure 7. Loading of purchasing parameters

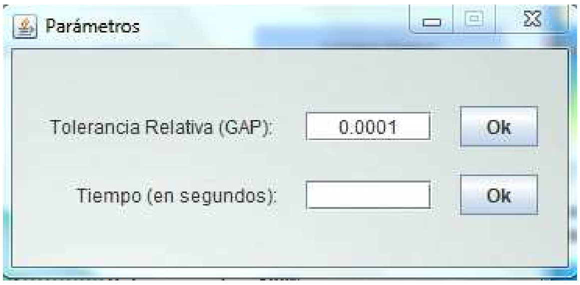
Finally, data corresponding to fruit purchasing cost from each grower, administrative costs associated with them, and transportation costs must be loaded. Particularly in this case study, there are 236 growers, so the costs of purchase and administration are loaded through an Excel file, because the management and visualization of these parameters is faster and more convenient for the user.

For the data storage, as shown in Figure 8, the parameters of capacity of each cold chamber available, maintenance costs in cold, fixed costs associated with the cold chamber, transport costs and the characterization of cold technology in each chamber must be loaded from an Excel.

Figure 8. Loading of storage parameters

When loading each one of the parameters required, a dialog box will appear which allows the user to realize that the data has been loaded properly in the DSS. It says "data loaded".

If the decision maker wants to set parameters to calibrate the implementation of the mathematical model that is in the DSS, as shown in Figure 9, it can done in the "Parameters" menu. It is possible to enter parameters to stop and rescue the solution the model has, based on two parameters. It can be stopped by Relative Tolerance (GAP) or Run Time. For the case study, the solution is rescued when the Relative tolerance is 1.0x10-4%.



Tolerancia Relativa (GAP): 0.0001

Tiempo (en segundos):

Figure 9. Execution parameters of the mathematical model in DSS

Once all the data are loaded in the DSS, the mathematical model is ready to be executed; therefore the decision-maker is ready to start searching for the solution for an optimal supply and storage planning. Figure 10 shows the status of the DSS when it is ready to be executed, particularly when the dialog "Loaded Data: 100%" appears.

Figure 10. DSS start-up screen with loaded data

When the DSS ends and the mathematical model finds a solution, the status of DSS changes to "**Finished Write**". That is to say, the optimal solution was written in an Excel file, which allows the decision maker to make a better handling and information analysis.

For the result analysis, these are taken from DSS to Excel. Currently in Chile, particularly in regional agribusiness, the most used ERP is Excel. That is why it was decided that the data analysis could be done in Excel Spreadsheets, since it is known and mastered at intermediate level user by decision-makers in the industry, whether they are responsible for fresh fruit purchasing or storage.

The results provided by the DSS concerning fresh fruit purchase are shown below in Figure 11.

Fresh Fruit Purchase	Type of quality			
Variety of fruit	Long Quality	Medium Quality	Short Quality	Total Bins
Royal Gala	5,393	3,488	3,119	12,000
Granny Smith	11,139	8,119	14,742	34,000
Fuji	11,761	3,994	6,245	22,000
Brearburn	3,000	-	-	3,000
Pink Lady	2,000	-	-	2,000
Rojas	1,000	-	-	1,000
Total Bins	34,293	15,601	24,106	74,000

Figure 11. Results delivered by DSS for fresh fruit purchase.

As shown in Figure 11, it is easy to analyze the planning of fresh fruit purchase for each variety. As it can be seen, the demand of the process plant is 74,000 bins of fresh fruit, which is fully satisfied and in addition, the demand is satisfied for each of the ordered varieties.

In Appendix B, you can find the report delivered by the DSS with the purchase plan, segmented by grower and the corresponding variety. This report is not included in this section due to lack of space, and only an excerpt of the report is presented in the appendix. In addition, it is shown the report that is delivered for the fresh fruit supply segmented by grower, variety and quality.

Concerning the fresh fruit storage in the storages available, Figure 12 shows the storage planning, segmented by fruit variety.

	ID Cold Storage											
Variety of Fruit	1	2	3	4	5	6	7	8	9	10	11	Total Bins
Royal Gala	119	5,393	-	-	988	3,000	-	2,500	-	-	-	12,000
Granny Smith	-	-	12,119	2,000	-	14,742	1,200	-	-	3,939	-	34,000
Fuji	-	5,900	-	3,165	-	6,245	2,696	3,994	-	-	-	22,000
Brearburn	-	-	-	-	-	-	-	-	-	3,000	-	3,000
Pink Lady	-	-	-	2,000	-	-	-	-	-	-	-	2,000
Rojas	-	-	-	-	-	-	750	-	-	-	250	1,000
Grand Total	119	11,293	12,119	7,165	988	23,987	4,646	6,494	-	6,939	250	74,000

Figure 12. Results delivered by DSS for cold storage of purchased fresh fruit

As shown in Figure 12, there is storage that is not used such as 9, storages that only receive one variety of fruit such as 1, 3, 5 and 11. There are storages which receive two varieties such as 2, 8 and 10, and there are storages that receive more than 3 varieties such as 4, 6 and 7. These storages can receive more than one variety of fruit because they have several cold chambers, and can store a variety of fruit in each chamber. It is necessary to remember that in each chamber only one variety can be stored due to fruit respiration, which will alter the life time in post-harvest if they are mixed. Below in Figure 13, the planning for filling with fruit the cold chambers available is presented.

Figure 13. Results delivered by the DSS for cold storage of purchased fresh fruit

	ID Cold Chambers										
ID Cold Storage	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Bins**
1	119	-	-	-	-	-	-	-	-	-	119
2	1,500	2,400	4,400	2,993	-	-	-	-	-	-	11,293
3	4,000	3,119	5,000	-	-	-	-	-	-	-	12,119
4	1,999	2,000	1,166	2,000	-	-	-	-	-	-	7,165
5	-	-	-	988	-	-	-	-	-	-	988
6	2,782	3,000	-	2,990	3,000	3,000	2,994	333	2,976	2,912	23,987
7	750	1,200	1,196	1,500	-	-	-	-	-	-	4,646
8	1,994	2,000	2,500	-	-	-	-	-	-	-	6,494
9	-	-	-	-	-	-	-	-	-	-	-
10	1,014	2,000	1,939	1,986	-	-	-	-	-	-	6,939
11	250	-	-	-	-	-	-	-	-	-	250
Total Bins	**14,408**	**15,719**	**16,201**	**12,457**	**3,000**	**3,000**	**2,994**	**333**	**2,976**	**2,912**	**74,000**

Figure 13. Results delivered by the DSS for cold storage of purchased fresh fruit

As shown in Figure 13, the DSS delivers a cold storage planning which will depend on the quality of the purchased fruit, and the availability of cold chambers with sufficient technology to preserve the fruit quality in time, according to its conditions when purchased.

5.5. Feedback from the agro industry business in Chile

The DSS proposed in this study is aimed at managers of agro-industrial plants to facilitate decision-making when purchasing raw materials and their arrangement in cold chambers. At present, the selection of growers and subsequent purchase of fresh fruit by those who are responsible for the supply of process plants is done arbitrarily, taking into account only the available amount of growers, without considering the storage time required by the fruit purchased. Although this information is available at the beginning of the harvest season, which is raised on the basis of visits made by the technical staff responsible for the purchase in the plant, it is not considered for purchase or for the correct choice of cooling technology which is present in storage chambers. As a result, it is difficult to make decisions in the process plant on the purchase and storage of raw material, due to the fact that throughout the process decisions are not supported by a system that allows them to have all the information for a correct planning in the supply chain of fresh fruit.

In order to validate what it is proposed by DSS, real data was applied to a process season, with the aim of evaluating the behavior and discussing the consistency of the results delivered by it which the agro industrial plant can count, on the basis of their planning carried out manually. The case study plant processes approximately 28,120 tons of fresh apples during a season, to obtain approximately 1,800 tons of finished products.

In addition, DSS is presented to three operation and purchase chiefs belonging to different agro-industrial enterprises from Maule Region, in Chile, which are confronted with situations similar to the study case. These professionals observed a correlation between the results provided by DSS and the reality that exists in their companies, thus validating the proper functioning of the system.

As a result, professionals consider the proposed DSS a useful tool, suitable to be used with a good software interface, and with good results that help make a good decision when planning the fresh fruit supply.

To implement the proposed DSS, which is validated in the fruit processing industry, it would require minimal skills in Excel by workers who will use the system. This is due to the fact that as explained in section 4, the DSS was developed for the user who is only responsible for both loading the parameters (data from growers and cold stores) correctly in Excel, and run the system. Users don't need to schedule or design the graphical interface, because both the results of the mathematical model that is behind the DSS and the graphical interface were validated by the process plant personnel. The interesting thing in that application is that only free software were used which enables companies not to have problems with licenses when being implemented.

In the use of DSS, the only disadvantage is that it is necessary to have all the information from the parameters before the start of the harvest season and process in the plant. As mentioned above, sometimes it is not possible to obtain all this information at the beginning due to uncertain weather conditions that can affect the fruit quality in the orchards, delays in the leasing of cold chambers, uncertainty about the truck fleet available for transporting the fruit, among others. Although the truck fleet is negotiated by the companies at the beginning of the season, during this period the trucks can be damaged or can carry other fruit loads, due to its need and high demand for transport during the fruit harvest season.

The proposed software to support decisions allows working with a mathematical programming model which plan administrators find difficult to handle and understand. Due to this, the DSS proposed is useful since it presents a user-friendly interface that simplifies the treatment with large amounts of variables and parameters, and makes the mathematical model is transparent to the user. In this way, the reformulation of the problem and its update will be easier and feasible, saving time and money for the owners and managers of the process plant who want to add or remove some function.

5.6. Conclusions and lines of future research

The proposed DSS was developed to plan tactical decisions in the supply chain of fresh fruit, particularly decisions related to selection of fresh fruit and cold storage suppliers, with the aim of maintaining the fruit quality the longest possible time before being processed. The system was tested in an agro-industrial company of dehydrated apples, in Maule Region, Chile. In general, from one company of agro-industrial process to another, the database can change size depending on the number suppliers and available storage, but not in the type of these resources that seeks to optimize. This makes the DSS presented in this research be flexible enough to be applied in other types of processing plants, whose final product is canned fruit, juice, dehydrated, fresh fruit and/or pulp.

Although all inputs are recorded in the database and are related to this case, the set of parameters can be easily adapted to represent different situations in the agro-industry, where there is a participation of transport, cold storage and selection of fresh fruit growers. Some of these variations may be the number of types of fruits needed, number and types of cold technologies available, and the amount and type of transportation needed to transport the fresh fruit.

The DSS is of great value for decision-makers such as the responsible for supply, storage, process in plant, owners and managers of process plants who used to plan only under their experience acquired by the number of years in different jobs. These reported savings of 8% in the total costs of fresh fruit purchase and it helped to select growers by comparing with the traditional programming method. In addition, there is a saving of 7% in the total costs of cold storage of fresh fruit purchased and a 9% in the total transport costs. The total savings is approximately US$50,000 in a process season of a dehydration plant.

The savings were mainly due to the fact that there is a better planning in the selection of growers, better allocation of fruit to different storage and a better use of the truck fleet available, decreasing the amount of trips to be performed by each them.

One of the upcoming investigations that could be carried out is the development of a DSS that integrates not only the purchasing decisions of fresh fruit and its subsequent storage, but also the decisions that opening and closing of the cold during the process in the plant, given the amount of fruit demand that occurs during the year.

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Appendix A. Data related to the mathematical model proposed to Soto-Silva et al. (2017), which is used in the proposed DSS.

Indices:

p :Apple producer index
q :Fruit type index
t : Fruit storage time index (3 = short term, 2 = medium term, 1 =long term)
j : Type of truck available for transport
c : Available warehouse index
n : Available cold chamber index
q : Fruit type index
t : Fruit storage time index (3 = short term, 2 = medium term, 1 =long term)
l : Index for the truck type available for transport

Parameters:

CC_{pqt}: Purchase cost for producer p of the fruit type q with storage time t (US$ /tonnes)
O_{pqt}: Fruit supply from producer p of type q with storage time t (tonnes)
CT_p: Transport cost from producer p to the plant by tonnes of fruit (US$ /tonnes)
CFT_l: Fixed cost of transport using truck type l
CA_p: Administration cost for producer p
M : Big M
D_{qt}: Demand for fruit type q with storage time t (tonnes)
QM_l : Maximum load for truck type l (tonnes)
CT_{qtc}: Cost of transport from the plant for fruit type q with storage time t destined for warehouse c (US$

/tonnes)

CE_{cn} : Cost of keeping the fruit in warehouse c, in cold chamber n (US$ /tonnes)

CA_c: Fixed cost for warehouse c

CF_{cn}: Fixed cost of chamber n in warehouse c

CFT_l : Fixed cost of transport using truck type l

$qtyc$: Number of warehouses available

W_{cn} : Storage capacity of cold chamber n in warehouse c (tonnes)

QM_l : Maximum load of truck type l (tonnes)

TE_{cn} : Type of refrigeration technology in cold chamber n in warehouse c (3 = short term, 2 = medium term, 1 =long term)

D_{qt} : Quantity of fruit to store of type q with storage time t (tonnes)

Decision Variables:

W_{pqtl}: Tonnes of fruit to buy from producer p, of type q, with storage time t transported by truck type l

Y_{lpq}: Quantity of trips for truck type l, from producer p, with fruit type q

X_{pqt}: Binary variable with the value 1 if fruit is purchased from producer p, of type q and storage time t, and otherwise the value is 0

C_p : Binary variable with the value 1 if the fruit is purchased from producer p, and 0 if not.

X_{qtcnl} : Tonnes of fruit type q with storage time t in warehouse c in cold chamber n transported in truck type l.

Y_{lcn} : Number of trips by truck type l to warehouse c to cold chamber n.

A_c : Binary variable with value 1 if warehouse c is used, and 0 if not.

ME_{cnqt} : Binary variable with value 1 if fruit type q with storage time t is kept in warehouse c in chamber n.

Appendix B. Mathematical model proposed to Soto-Silva et al. (2017), which is used in the proposed DSS.

$$\begin{aligned} Minimize & \sum_{p \epsilon P} \sum_{q \epsilon Q} \sum_{t \epsilon T} CC_{pqt} X_{pqt} O_{pqt} + \sum_{p \epsilon P} \sum_{q \epsilon Q} \sum_{t \epsilon T} CT_p X_{pqt} O_{pqt} + \sum_{p \epsilon P} CA_p C_p \\ & + \sum_{l \epsilon L} \sum_{p \epsilon P} \sum_{q \epsilon Q} CFT_l \, Y_{lpq} + \sum_{q \epsilon Q} \sum_{t \epsilon T} \sum_{c \epsilon C} \sum_{n \epsilon N} \sum_{l \epsilon L} (CT_{qtc} + CE_{cn}) \, X_{qtcnl} \\ & + \sum_{c \epsilon C} CA_c \, A_c + \sum_{c \epsilon C} \sum_{n \epsilon N} \sum_{q \epsilon Q} \sum_{t \epsilon T} CF_{cn} \, ME_{cnqt} + \sum_{l \epsilon L} \sum_{c \epsilon C} \sum_{n \epsilon N} CFT_l \, Y_{lcn} \end{aligned} \qquad (5.1)$$

Subject to:

$$\sum_{q \epsilon Q} \sum_{t \epsilon T} X_{pqt} \leq M \, C_p \qquad \forall \, p \, \epsilon \, P \qquad (5.2)$$

$$\sum_{p \epsilon P} \sum_{t \epsilon T} \sum_{l \epsilon L} W_{pqtl} \geq \sum_{t \epsilon T} D_{qt} \qquad \forall q \, \epsilon \, Q \qquad (5.3)$$

$$\sum_{l \in L} W_{pqtl} \leq X_{pqt}\, O_{pqt} \qquad \forall\, q \in Q, p \in P, t \in T \tag{5.4}$$

$$\sum_{t \in T} W_{pqtl} \leq QM_l\, Y_{lpq} \qquad \forall\, q \in Q, l \in L, p \in P \tag{5.5}$$

$$\sum_{t \in T} \sum_{q \in Q} ME_{cnqt} \leq 1 \qquad \forall\, c \in C, n \in N \tag{5.6}$$

$$\sum_{l \in L} X_{qtcnl} \leq W_{cn} ME_{cnqt} \qquad \forall c \in C, n \in N, t \in T \tag{5.7}$$

$$\sum_{c \in C} \sum_{n \in N} \sum_{l \in L} X_{qtcnl} = \sum_{p \in P} \sum_{l \in L} W_{pqtl} \qquad \forall\, q \in Q, t \in T \tag{5.8}$$

$$\sum_{n \in N} \sum_{q \in Q} \sum_{t \in T} ME_{cnqt} \leq qtyc\, A_c \qquad \forall c \in C \tag{5.9}$$

$$ME_{cnqt} = 0 \qquad \forall c \in C, n \in N, q \in Q, t \in T : t < TE_{cn} \tag{5.10}$$

$$\sum_{q \in Q} \sum_{t \in T} X_{qtcnl} \leq QM_l\, Y_{lcn} \qquad \forall l \in L, c \in C, n \in N \tag{5.11}$$

$$Y_{lcn}, Y_{lpqt} \in \mathrm{Z}^{+} \qquad \forall l \in L, c \in C, n \in N, p \in P, q \in Q, t \in T \tag{5.12}$$

$$A_c, ME_{cnqt}, X_{pqt}, C_p \in \{0,1\} \qquad \forall c \in C, n \in N, p \in P, q \in Q, t \in T \tag{5.13}$$

$$X_{qtcnl}, W_{pqtl} \geq 0 \qquad \forall p \in P, q \in Q, t \in T, c \in C, n \in N, l \in L \tag{5.14}$$

Constraint (5.2) establishes that if any fruit variety is bought from a producer, all the producer's fruit supply must be bought. Constraint (5.3) indicates that the quantity of fruit to buy of a specific type and specific storage time must meet the processing plant's demand. Constraint (5.4) shows that the quantity of fruit to buy will be less than the supply that is available from the producers. Constraint (5.5) allows determining the number of total trips to be made per truck during the purchase season. Constraint (5.6) establishes that only one type of fruit can be stored in each cold chamber. Constraint (5.7) makes the amount of fruit to be stored in each of the cold chambers in the warehouses subject to the choice of chamber and its storage capacity. Constraint (5.8) permits joining the purchase and storage together given that the fresh produce purchased is equal to the fresh produce to be stored in the cold chambers. The other constraints for this model correspond to the constraints given in the purchasing and storing models. Constraint (5.9) shows the activation of a cold chamber within a warehouse in order to store fruit only if the warehouse is active. Constraint (5.10) ensures that fruit is not stored in a cold chamber if it has a length of storage time lower than the chamber's refrigeration technology allows it to stock. Constraint (5.11) limits the maximum number of trips per truck at full capacity according to truck type and the amount of fruit to buy from the producers. Constraints (5.12), (5.13) and (5.14) correspond to the integrality and non-negativity constraints on the decision variables, respectively.

Appendix C. Purchase Planning

Purchase	Q: Variety of fruit						
ID Producer	Variety 1	Variety 2	Variety 3	Variety 4	Variety 5	Variety 6	***Grand Total***
2	-	168	144	-	-	-	312
4	88	84	121	-	-	-	293
8	-	66	-	-	-	-	66
10	298	50	282	-	-	-	630
13	-	724	-	-	-	-	724
14	-	-	408	-	-	-	408
15	64	-	-	-	-	-	64
16	-	-	72	-	-	-	72
17	162	-	342	-	-	-	504
18	-	-	112	-	-	-	112
20	68	57	-	-	-	-	125
21	-	267	-	-	-	-	267
22	72	-	-	-	-	-	72
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.	.	.	.	.	.	.	.
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276	-	-	169	-	-	-	169
277	-	37	-	-	-	-	37
279	-	85	95	-	-	-	180
Grand Total	12,000	34,000	22,000	3,000	2,000	1,000	74,000

Chapter 6:

Conclusions and Future Research

6.1. Conclusions

There are approximately 201 agro-industrial plants producing frozen and preserved fruit, pulp, juice, fresh fruit, and dehydrated products in Chile. All of these need decision support tools as the sector's competitiveness has declined in the last decade, mainly due to constant changes in the industry. Fluctuating exchange rates, increasing cost of supplies, labor shortage, and quality fruit availability for processing have had a tremendous impact on the fruit agro-industry.

The fresh fruit supply chain may rely on different tools that will allow better planning and coordination of associated activities, with the purpose of efficiently managing the scarce resources available, namely, time, labor, and money.

Chapter 1 presents the main objective of the research, which is to develop a set of tools to support decisions in the supply chain of fresh fruit. The main objective of these tools is to improve the selection of products, and the management of the purchasing, cold storage, transport and opening of the cold chambers.

In Chapter 2 a literature review is presented to support decisions within the fresh fruit supply chain; in parallel, some ´gap-bridging´ activities were done, particularly with the agro-industry private sector from the south central part of the country. As a result, some problems were found that could be addressed with optimization tools, and particularly tools that are not dealt with in the literature to date. Therefore, in Chapters 3, 4, and 5 some tools are presented that were developed to bridge the gaps found in the literature, which could solve real problems in the fresh fruit supply chain.

Thus, Chapter 3 tackles a tactical problem related to the supply of fresh fruit. Such a problem has not been examined in depth in the literature. Chapter 4 discusses a tool for decision making that could help in the management of cold chambers, in which fresh fruit is stored for up to a 9-month period. Later on, in Chapter 5, a DSS was developed in order to support decisions regarding the management of fresh fruit purchasing, storage and transport. This chapter is a continuation of Chapter 3, because the DSS uses the same mathematical model proposed in that chapter.

Thus, based on the previous chapters some conclusions can be drawn:

a) The literature review reveals a lack of research studies dealing with optimization models that support decision making on the fresh fruit supply chain. A total of 28 publications about the subject were found, from 1980 to 2015. The neglected areas include the orchard harvesting of fruit, fruit supply to processing plants, management of fresh and finished products storage, and processing plants production planning. The particularity of this review is that it focuses on work done aiming to solve problems rather than the development of the theory (cf. chapter 2). It is also important to point out that new optimization opportunities were found in order to expand the literature related to Operations Research in the fruit agro-industry. The research results presented provide some answers to the first specific objective set forth in the thesis.

b) The contribution to the literature, in the area of a fresh fruit supply chain, namely, three optimization models of mixed linear programming, can be highlighted. The first model seeks to optimize the selection of fresh fruit growers and the fruit transport to the processing plant; the second model aims to optimize the selection of cold storage and fruit transport from the processing plant to the storage facility; and finally, a model that integrated both problematics (cf. chapter 3). The models were validated in a real case study, particularly in an apple dehydrating plant; as a result of the implementation of the models proposed, a reduction of approximately 8% in the total costs involved in the process occurred. The research findings presented correspond to the second specific objective set forth in the thesis.

c) To meet the need to have an optimization model for the management of cold chambers, a mathematical model is presented that aims to optimize the use of cold chambers, so as not to damage the post-harvest life of the stored fruit, at a minimum storage and transportation cost. (cf. chapter 4). The model was validated in a real case study, specifically in a dehydrating plant where a reduction of approximately 10% in the total costs involved in the process occurred. Findings presented in this chapter address the third specific objective set forth in the thesis.

d) Using the integrated model presented in chapter 3, a Decision Support System (DSS) was developed. This includes a tool to support decisions while selecting fresh fruit suppliers, cold storage regime, and transport (cf. chapter 5). The DSS is intended for the processing plant personnel, and it is particularly directed to workers who are required to make decisions in the areas of purchasing, storage and transportation, in addition to plant owners and plat managers. An important point is that employees are reluctant to use such tools due to the answers lack of credibility, but mainly because staff has been making decisions based on on-the-job experience for years. The fourth specific objective set forth in this thesis is achieved through the research findings.

The main objective of this research study was to propose decisions support tools for the fresh fruit supply chain. This objective was achieved since a number of tools of this type are proposed, which can be divided into two areas. In the first place, tactical decisions support models, discussed in Chapters 3, 4, and 5; and secondly, state-of-the-art support tools for the fresh fruit supply chain; the discussion presented in Chapter 2 contributes in this direction.

Finally, it should be noted that the contribution of this thesis is also practical. This is because the optimization tools (cf. Chapters 3, 4, and 5) were developed and validated in conjunction with agro-industrial companies from the center-south region of the country. The models proposed were created in partnership with personnel working in agro-industrial plants, in the fresh fruit supply and storage areas. In addition, in order to validate the results that the models reveal, they were compared with actual results from each case study; differences between the two of about 10% savings in total costs were found, which translates into a cost reduction of nearly US $ 50,000 in one season.

6.2 Contribution of the thesis

This thesis contributes with different tools to decisions planning related to the fresh fruit supply chain and extends the state-of-the-art in the Operations Research area. Thus, a literature review on Operations Research applied to the fresh fruit supply chain was done, and an optimization model that supports tactical planning for the purchasing and storage of fresh fruit, an optimization model for opening cold facilities and transporting fresh fruit to the processing plants, as well as a Decision Support System (DSS) which implements the purchasing and storage optimization model were developed.

The lack of decisions support tools in the agro-industry is pointed out in various researches, such as the work done by Lucas and Chhajed (2004), Lowe and Preckel (2004), Ahumada and Villalobos (2009), Audsley and Sandars (2009), and Soto-Silva *et al.* (2016a). In this sense, this thesis contributes to the improvement of the state-of –the-art in this field.

When checking pertinent literature no reviews were found about optimization models applied to a fresh fruit supply chain. For this reason, the literature review included in this study becomes an important contribution to the Operations Research field. The objective of this research study was to focus on models applied to real cases in different kinds of fresh fruit supply chains.

The proposed models contribute to optimizing the supply chain of an agro-industrial processing plant by better selecting fruit suppliers, fresh fruit types, available cold storage facilities and transport management, through the use of a tactical optimization model. Also, they contribute to optimizing management of cold chambers in storage facilities, and the transport of fruit to the processing plants. In addition, a DSS is proposed which helps decision makers to manage the selection of growers and cold chambers utilization in a more efficient manner.

Furthermore, this thesis contributes to the acquisition of practical knowledge, namely, the work and development relationship achieved between the private sector (agro-industry) and the academia. This is was due to the fact that all the decisions support tools presented in this study were implemented and validated by Chilean agribusinesses, particularly from the O'Higgins and Maule regions. During the development of both the mathematical models and DSS, a close working relationship was established with various companies´ personnel aiming to solve their problems by using optimization tools; this was positively evaluated by decision makers.

Nowadays, especially in Chilean agro-industrial processing plants, no optimization models or DSS are available which could assist decision makers in the selection of suppliers and storage facilities, in the management of the opening process of these, as well as in the transport of fresh fruit (Oliva, 2011). This type of decision-making is carried out by reviewing historical data and considering the decision-makers expertise acquired over time (Soto-Silva *et al*., 2017).

6.3 Further Research

In addition to the conclusions listed above, future research lines can be pointed out which may complement and/or continue the research work presented above. For example, to devise a DSS integrating the models presented in Chapters 3 and 4 into a single decisions support tool. As today´s fruit agro-industry competitiveness is decimated, it is necessary to come up with decisions supporting tools to be used across the board along the supply chain.

A research study that could be done would be to expand the model presented in Chapter 3 to a stochastic model. Such an analysis would be used to examine the variability in the demand for fresh fruit when growers' supply, market prices, and conversion ratios fluctuate (from fresh fruit to dehydrated fruit).

Another research work that might be very interesting would be to integrate different issues related to fresh fruit supply chains into a single study. In the first place, integrating the purchasing and storage model proposed in this study to a fresh fruit harvest model would be very useful. This type of integration would minimize labor, harvest supplies, transportation, and cold storage costs. And although there are models that solve harvesting problems, integrated models aimed to optimize the supply across the board are non-existent in the fresh fruit supply chain in Chile.

Another example of research associated with integrated models would be to combine a production planning model with the cold storage management model proposed in Chapter 4. Devising a robust planning of the fresh fruit supply chain, adding the production management component of the plant, would help decision makers to anticipate variations that may occur, including climatic conditions, the amount of fruit harvested, the number of growers available, which may have a direct impact on the yields of the processing plants as fruit demand would be in May and total costs would increase. The objective of integrating models is to provide decision makers with tools that will allow them to mastermind mitigation plans when confronted with possible variabilities, such as those mentioned above. The thing is that the demand for finished products can actually be met on time, keeping budgeted costs.

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Appendix

Published Articles in ISI Journal

1. Soto-Silva, W.E., Nadal-Roig, E., González-Araya, M.C., Pla-Aragonés, L.M., 2016. Operational Research Models Applied to the Fresh Fruit Supply Chain. European Journal of Operational Research, 251: 345–355. DOI: 10.1016/j.ejor.2015.08.046.
2. Soto-Silva, W., González–Araya M, Oliva-Fernández, M., Pla-Aragones L., 2017. Optimizing Fresh Food Logistics for Processing: Application for a Large Chilean Apple Supply Chain. Computers and Electronics in Agriculture, 136: 42–57. DOI: 10.1016/j.compag.2017.02.020

Published Articles in Scopus Journal

1. Soto-Silva, W., Nadal-Roig, E, González-Araya, M., Pla-Aragones, L., 2016. Transport planning in processing plants for the fruit industry. In: Proceedings of 5th the International Conference on Operations Research and Enterprise Systems (ICORES 2016), pp. 71–78. DOI: 10.5220/0005646100710078.

Conference

1. Soto-Silva, W.E., González-Araya, M.C., Plà A., Ll.M., 2014, “An Optimization Model for Planning Fruit Transport from Cold Storages to Packing Plants”, Proceedings of EURO Summer Institute “OR in Agriculture and Agrifood Industry” – ESI 2014, 19 de Julio al 01 de Agosto, Lleida, España.
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