

Chapter 7

Optimal Transport Planning for the Supply to a Fruit Logistic Centre

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7.1 Introduction

Supply chain planning has been studied intensively in recent years (Catalá et al. 2013) in particular for production and transport planning (Mula et al. 2006; 2010), but less in the agri-food industry (Ahumada and Rene Villalobos 2009). Ahumada and Rene Villalobos (2009) distinguish two main types of agricultural supply chains: fresh and non-perishable agri-food chains. They review fresh products paying attention to their logistical complexity, their limited shelf life and the interest of the public on the safety of these products. On the other hand, according to Verdouw et al. (2010) fruit supply chains exhibit some food-specific characteristics such as long lead times, seasonable production, quality variations between producers and plots, fast handling, short delivery time to preserve freshness and special storage conditions and packing demands (Trienekens et al. 2012). Hence, fruit supply chain planning is a complex system involving the interaction of different agents in charge of production, processing, storing and distribution (Fig. 7.1).

The fruit industry is very important in Europe being the EU a major fruit producer. The majority of fruit production in the EU takes place in southern countries like Spain, expecting a significant increase in following years as response to fruit demand (Verdouw et al. 2010). According to the FAOStat in 2011, the rank of Spain in the world for selected fruits was: third one for peaches and nectarines, fifth one for cherries, sixth one for pears and eighth one for plums (FaoStat 2013). Within the EU-27 the role of Spanish fruits is also important being the first producer

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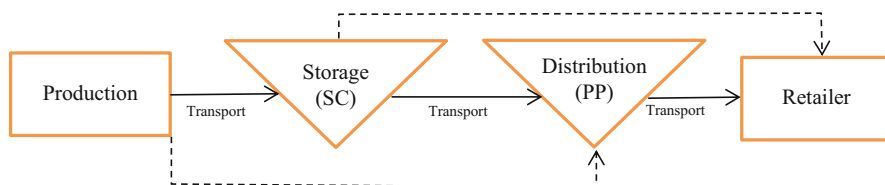


Fig. 7.1 General fruit supply chain structure

of nectarines, the second producer of pears, cherries and peaches, the third producer of plums and the sixth producer of apples (Eurostat 2013). Such a position has stimulated the Spanish fruit industry to evolve, becoming very competitive and looking for a more efficient management of supply chains.

Logistics of fresh fruits is a problem related with the balance between the price achievable in the market and the quality of the product. Quality is related with parameters like sweetness, crunchiness and strengthens, connected in some way with the optimal ripeness of the fruit. The fresh fruit sector is affected by seasonality, understood here as the production of fresh fruits during a limited period of time (Hester and Cacho 2003). This time period is variable depending on the decay of the fruit variety and the admissible means of preservation. There are fresh fruit varieties that have to be consumed rather quickly after harvesting like apricots, cherries and berries in general. Other fruits can complete more slowly the maturation process after harvesting and then enlarge their marketing time window. Even though, there are environmental conditions during storage and transportation that can be used to regulate fruit quality in some extension like cooling, temperature control or controlled atmosphere.

The motivation of this chapter is the PP operating with limited storage capacity, so fruits to be processed have to be transported from intermediate storage centres. This chapter aims to formulate a mixed integer linear programming model to optimise the transport planning of fruit varieties from storage centres (SCs) to a packaging plant (PP) for being processed upon demand to cover daily orders. The main interest of the decision maker is to avoid idle times at the PP and the stock breaking of fruits to be processed. Then, the PP has to maintain a rolling stock to cover committed orders without stopping the processing line. An additional interest concerns the distribution of workload among trucks and drivers available. Depending on the demand, the model may suggest the opening of a controlled atmosphere SC. Then, the model organise the transports from the cooperatives supplying convenient fruit varieties to the PP, maintaining a stock capable of satisfying the daily demand from the customers.

As a case study, the model is applied to a fruit logistic centre (FLC) located in one of the most important production areas of fresh fruit of Spain, in Lleida. However the FLC has special features, the model has been developed in general terms for being applied on most fruit supply chains worldwide.

7.2 Problem Description

Supply chain structure may vary from country to country having different configurations, but sharing characteristics inherent to the fruit industry (Verdouw et al. 2010). A generic fruit supply chain is shown in Fig. 7.1, adapted from the modelling approach presented by Rong et al. (2011). During the harvesting season, the different fruit varieties are usually picked and collected in pallets by farmers who deliver them to the SC or PP, either to be stored or processed (Broekmeulen 1998). Sometimes, SCs are close or part of a PP, depending if the PP is operated by the same company or cooperative or if fruits are distributed quickly or not. Some fruits like apples and pears can be stored for long, others not so, like peaches and some very little like cherries or apricots. However, in all cases, cooling systems is an element to consider for controlling the maturation process and the decay of fruits. This way, apples and pears are available during all year if they are stored in controlled atmosphere while the rest of fruits produced in Europe have a limited marketing time window.

Producers transport harvested fruits to the SC. Regular SC send fruits to the PP in few days or weeks. However, SCs with controlled atmosphere have to be filled with fruits and closed for a longer period. Facilities with controlled atmosphere allow fruits to be stored up to 12 months, but they have to be only opened when all the content is going to be retrieved for processing in the PP. The PP is in charge of washing, sorting and grading of fruits; packaging and labelling in the end of packaging lines. Afterwards, fruits are distributed to retailers to fulfil the day-to-day orders. Operation at PP has to be planned beforehand because ordered fruits have to be processed on time. Transports have to be also planned according to the availability of trucks and drivers even when these activities are outsourced (Hsiao et al. 2010).

A usual fruit supply chain may involve different producers that supplies fruits during the harvesting season to a PP, where they are processed and delivered to the consumer by different retailing channels. The number of PPs may depend on the size of the company and the number of producers, but it is agreed that a PP is the core of the fruit supply chain from a tactical point of view (Blanco et al. 2005). Two main functions are assigned to a typical PP: warehousing and distribution. However, the problem studied here relies on a structure of the supply chain keeping warehousing and distribution apart. Let's consider fruit producers grouped in cooperatives. Individual cooperatives only have storage capacity and thus, the warehouse function is deployed by them. The distribution function, including processing activities, is centralised in the so-called FLC where all orders are concentrated and served. Orders are fulfilled by the fruits stocked in the cooperatives. The FLC manages the logistics of the chain, that is, the planning, implementing and controlling the efficient cost-effective flow and storage of fruits, in-process inventory, distributed fruits and related information from

producers and retailers for the purpose of conforming the customer requirements (Van Goor et al. 2003). Thus, according to Manzini and Accorsi (2013) the FLC, as crucial node in the chain, can contain the main source of inefficiency, waste and uncontrollable costs throughout the fruit supply chain.

The long-term storage can be of two types: cooling storage or controlled atmosphere storage. Once a storage is open the preservation chain of fruits is broken and the maturity process progress again making necessary to empty the storage before opening a new one. An issue is the continuous supply of fruits to the centre for a non-stop operation of the packing lines. Fruits have to be sorted out the storages few days before shipping to recover natural properties related to follow-up a good maturity process. Fruits sent by cooperatives to the logistic centre are shipped the same day, but the FLC is who select the suppliers and determines which storage facilities to open. Only a secure inventory is maintained permitting to start up the following day. Then, the logistic centre acts as a PP but without storage capacity which relies on the cooperatives.

The flow of fruits managed from the logistic centre varies along the year. More transport capacity is needed during the harvesting season. There is an increment of transports from fields to cooperatives, among cooperatives and from cooperatives to the FLC (Fig. 7.2). Transports from fields are done by farmers while those to the FLC are planned and controlled by the logistic centre. Out of the harvesting season transports from fields and among cooperatives disappear and only remain the flow from cooperatives towards the FLC. The reason is because not all fruit are available all-round the year. There are perishable fruits with a limited marketing window. No technical means of decay control are feasible for them. However, apples and pears can be preserved in controlled atmosphere and marketed out of the harvesting season.

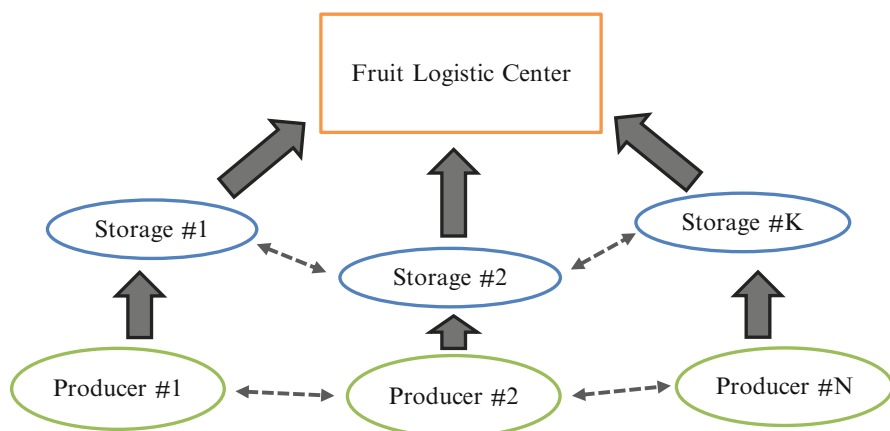


Fig. 7.2 Possible paths followed by fruits from producers till the fruit logistic centre

7.3 Modelling of the Transport Planning Problem of a Fruit Logistic Centre

Transport planning in an FLC is a task with a variable workload depending on the daily demand of fruits, the arrival of new orders and the number of trucks available. The problem modelled here represents the operational planning for a day. The demand of fruits is defined for the next day and the manager makes the planning with which the activity in the FLC will start the following day. However, new orders may arrive or changes in priorities can be introduced. These unforeseen changes may force to refine or redo the original planning again changing the schedules for truck drivers and suppliers. It is in this context that the following model is formulated.

7.3.1 Decision Variables

There are two sets of decision variables according to the quantity of goods to be delivered and the number of trucks needed to perform these operations. The first one, X_{ifcv} , represents the quantity of fruit to be transported in kilograms from the cooperatives of producers to the logistic centre, where the subscripts: i represents the cooperative of producers to procure the fruit ($i = 1, 2, \dots, |I|$); f represents the variety of the fruit ($f = 1, 2, \dots, |F|$); c represents the category of the f -fruit ($c = 1, 2, \dots, |C|$) and v represents the truck to be used ($v = 1, 2, \dots, |V|$). The second one, the binary variables $Y_{iv} \in [0, 1]$ are defined to represent the expected numbers of trips for the truck v from the cooperative i to the logistic centre.

The total number of decision variables varies from season to season and depending on the number of storages used to preserve and deliver fruits in winter. These fruits are also apples and pears of different varieties and categories.

7.3.2 Objective Function

The primary objective is the minimization of the daily cost of transport. This results in a minimum number of trips that allows the FLC to satisfy the demand. Depending on the unitary cost coefficients, they can be easily adapted to represent distances, load in kilograms or cost in euros.

$$\min C = \min \sum_i \sum_v c_i Y_{i,v}$$

This is in other words, the minimisation of the sum of the transport cost from the cooperative i to the FLC, given the number of trips to perform, $Y_{i,v}$, are covered by the truck v . A secondary result interesting for practical purpose is the schedule of transports derived from the optimal solution.

7.3.3 Constraints

7.3.3.1 Nature of Daily Demand of Fruits

The daily demand is given by the sum of all customer orders confirmed for the day and that must be delivered. Moreover, a threshold corresponding to a security stock of fruits has to be considered to allow the smooth operation of the FLC during the day and the start-up of the following one. Based on the arriving orders and the experience of the FLC manager, this threshold is stated. If the total demand is represented by D_{fc} , the total quantity for each fruit and category X_{ifcv} transported from all cooperatives must be higher than it:

$$D_{fc} \leq \sum_{i,v} X_{ifcv} \quad f = 1, 2, \dots, |F|; \quad c = 1, 2, \dots, |C|$$

7.3.3.2 Number of Loads and Total Load

The various trucks' capacities require constraints on the total load carried by available trucks due to the orders with high volume. Given the capacity of trucks is known, C_v , and the maximum number of trips a truck can do from a specific cooperative of producers, Y_{iv} , a constraint verifying the total amount of fruits transported is taken into consideration:

$$\sum_{fc} X_{ifcv} \leq C_v Y_{iv} \quad i = 1, 2, \dots, |I|; \quad v = 1, 2, \dots, |V|$$

This constraint allows the decision maker to detect paths with more demanded trips and then, assigning trucks of more capacity to satisfy the demand given when necessary. Note that different fruits and categories can be transported by the same truck visiting a cooperative.

7.3.3.3 Timetable of Trucks

Trucks are normally used for several trips per day. It is considered that all trips start and finish at the FLC. It is assumed that a truck is driven by the same driver. The number of trucks available may vary. However, the availability of drivers who cannot drive more than a legal number of hours $J(v)$ is more stringent.

On the other hand, depending on the cooperative of producers, the loading and unloading time may vary depending on resources available for such tasks. Regarding the trip time covering the distance from the fruit logistic centre to the cooperative is affected by the type of lorry, the load and the speed to cover the path.

Thus, the total transport time for each truck $\sum_i TT_i Y_{iv}$ must not exceed the available number of working hours of corresponding truck driver:

$$\sum_i TT_{iv} Y_{iv} \leq J(v) \quad v = 1, 2, \dots, |V|$$

where

$TT_{iv} = \frac{D_i \cdot (\frac{1}{V_{ccv}} + \frac{1}{V_{scv}}) + W_i}{C_v}$ represents the trip time for truck v to cover the path

FLC—cooperative i —FLC, being:

D_i : Distances from cooperative i to the FLC.

V_{ccv} : Speed of the given carriage means v , with load.

V_{scv} : Speed of the given carriage means v , without load.

W_i : Waiting time at the i -cooperative.

C_v : Loading capacity of truck v .

However, previous constraint can be reinforced taking into account the availability of trucks and the maximum time drivers can be working per day (T_v):

$$\sum_i \sum_v TT_{iv} \cdot Y_{iv} \leq \sum_v T_v$$

7.3.3.4 Multiple Transports Per Truck

Aside the time, the trucks are allowed to make per day a certain number of transportations. These transports are independent of the cooperative to visit. This means, a truck can transport fruit from the same cooperative or not until it reaches its maximum number of daily trips. Therefore,

$$\sum_i Y_{iv} \leq NT_v \quad v = 1, 2, \dots, |V|$$

This constraint tends to balance the number of trips per truck and hence, the workload of drivers. It can be also specified in terms of total distance covered by day or in total fruit carried per day or simply as stated just in total number of trips per day.

7.3.3.5 Fruit Inventory at the Cooperatives of Producers

The quantity of the fruit to be transported from each cooperative i for fruit f and category c must not exceed the cooperative inventory for this fruit type and category:

$$S_{ifc} \geq \sum_{fcv} X_{ifcv} \quad i = 1, 2, \dots, |I|; \quad f = 1, 2, \dots, |F|; \quad c = 1, 2, \dots, |C|$$

7.3.4 Size of the Problem

In order to give a view about the problem in terms of size, this section details the total amount of decision variables and restrictions, irrespective of the input data used for the execution of the model:

Total number of constraints:

| | |
|-------------------------------------|-----------------------|
| Nature of daily demand of fruits | $F \times C$ |
| Number of loads and total load | $I \times V$ |
| Timetable of trucks | $V + 1$ |
| Multiple transports per truck | V |
| Fruit inventory at the cooperatives | $I \times F \times C$ |

Total #constraints: $FC + IV + V + I + V + IFC = FC(1 + I) + V(I + 2) + 1$.

Total number of variables:

Continuous variables procuring fruits to the FLC:

$$X_{ifcv} : I \times F \times C \times V$$

Integer variables representing trips:

$$Y_{iv} : I \times V$$

Total #variables: $IFCV + IV = IV(FC + 1)$.

7.4 Application of the Model: A Case Study

To illustrate the use of the model, a real case is considered from a Spanish company specialised in pome fruit with a similar supply chain structure than that described previously. The main actors of this supply chain are three: the individual farmers, the producer cooperatives where farmers send their production to be stored and a cooperative owning the FLC. Main fruit types are grouped in pome (apples and pears) and stone (nectarines, peaches, cherries and plums).

ACTEL is a Spanish fruit cooperative of second order (i.e. a cooperative of cooperatives, the so-called cooperatives of first order) with one LFC. Different cooperatives of fruit producers (29 in total) are the stakeholders of ACTEL. Individual producers, members of a cooperative, are in charge of the growing, harvesting of fruits. Fruits are sent to the corresponding cooperative for storage while ACTEL, as logistic centre, is in charge of packaging, labelling and distribution to international retailers, exporters and local retailers, wholesalers and food service providers. The FLC is ruled by ACTEL and manage the fruit supply chain. Few of the fruits are sold directly without any processing by producer cooperatives, although most of them are stored only very short.

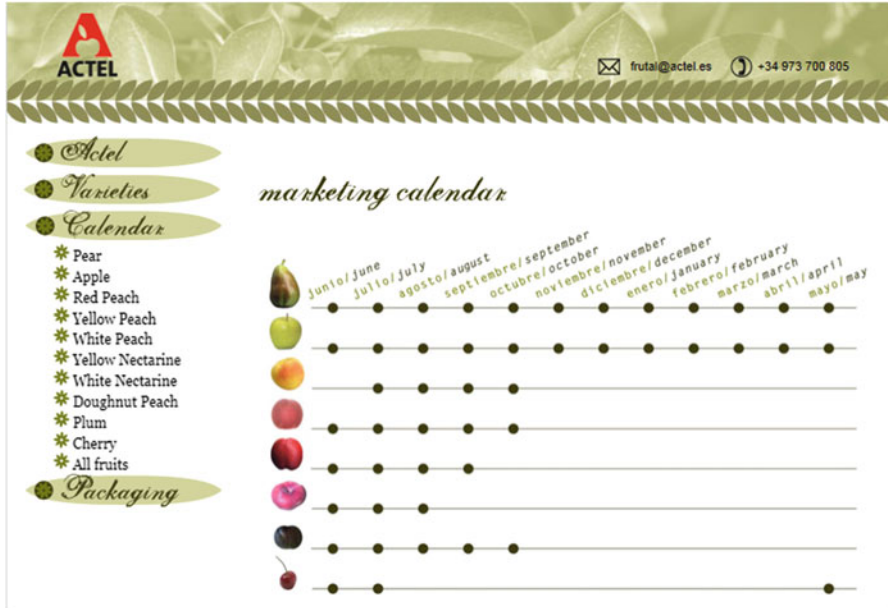


Fig. 7.3 Fruits processed by ACTEL and regular marketing calendar (http://www.actel.org/fruits_catalog/eng/calendario.html)

In Fig. 7.3, the fruits processed in ACTEL are displayed, as well as the marketing calendar. As shown, July is the most complicated month given all fruits are being harvesting and marketing. On the other side, from November to April only apples and pears are available, thanks to the use of storage facilities under controlled atmosphere. The type of coordination with costumers differs a lot, including spot market, informal long-term relations, formalised contracts and partnerships. Especially, big retailers have specific requirements regarding variety, size, ripeness, certificates, labels and packaging. Fruits can be ready for distribution 24 h after harvesting. However, they are trying new products that include processing like peeled apples for vending machines.

As fruit types have different temperature control protocols and because packaging rates are typically fruit dependent, the different fruit types should be considered as separated commodities. The FLC takes decisions regarding cool storage of fruits and storage under controlled atmosphere for pome fruits. For example, when and how storage facilities has to be filled and closed for fruits being processed later. The FLC organises the transports of fruits to the logistic centre for processing and distribution to fulfil the orders received from customers.

7.4.1 Formulation of the Model

The FLC has an averaged capacity for processing of around 150 ton per day although the maximum stocking capacity is between 4 and 5 ton only. The continuous supply of fruits is necessary during the day to allow the non-stop operation of the FLC. There are 29 cooperatives available to provide fruit to the FLC. Figure 7.4 shows the relative location of cooperatives and their distance regarding the FLC (coordinates 0.0). The exact distance can be found at Appendix 1 as well as the total time per trip (loading, unloading and trip time) from the cooperatives to the FLC.

All the cooperatives have in their stock three varieties of pears (Blanquilla, Conference and Alexandrine) and two of apples (Golden and Red Delicious) representing five different fruits ($f=5$). Each variety can have until eight different categories ($c=8$) according to the fruit's size (101, 104, 108, 201, 202, 215, 218 and 220). In Appendix 2, the detailed stock per cooperative, variety and category is shown. Note that this stock corresponds to the winter season.

Daily, the FLC manager sets up the expected demand of fruit per variety and category to deliver to the customers as well as a threshold needed in the FLC to ensure the delivery of fruits. Out of the harvesting season, and in a certain days, it is possible to not have demand or threshold for some categories. Appendix 3 shows the demand and the threshold data used in the model for each variety.

The FLC has outsourced the transport from cooperatives, but the work plan and the schedule of trips are provided by the FLC. The number of trucks available is variable and can be adapted from the needs of FLC from one day to the following day. During the low season (non harvesting months), the FLC uses regularly two different types of trucks with different load capacities and a total of four trucks named T1, T2, T3 and T4. The first type can transport 24 ton each truck (trucks T1 and T3 in the results) and the other one (trucks T2 and T4 as referred in the text) is smaller, that is, of 14 ton. The truck's cost is a daily price, without taking into

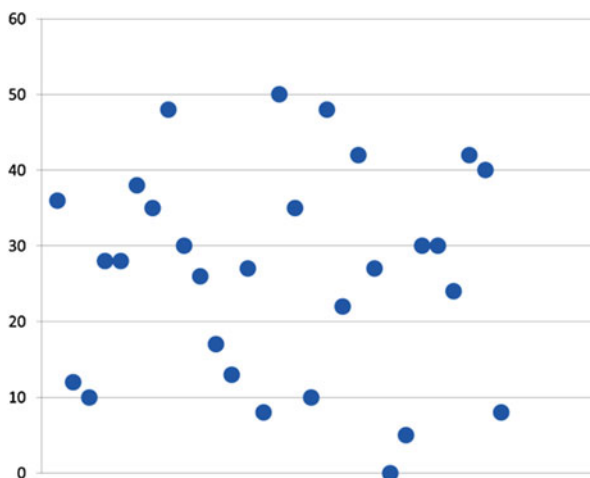


Fig. 7.4 Cooperatives location from the logistics centre

account the kilometres done or the load transported by trucks. At this time, two trucks of each type are used regularly. However, the FLC can have additional trucks available from the transport company if they request them in advance. During peak days at the harvesting season, the FLC can contract more than ten trucks for daily tasks.

7.4.2 Results and Discussion

To develop the preliminary version of the model and its execution, the modelling language ILOG OPL and the solver CPLEX v12.2 has been used. The hardware used in the development and test of the model was a laptop computer (Pentium Dual-Core CPU at 2.1 GHz and 4 Gb RAM). Microsoft Excel has been used for storage data, both inputs and outputs of the model due to the easy analytical use.

With the case data provided by the cooperative, the model has 4,756 variables in total (4,650 as continuous and 4,640 as integer). The model finishes in 7:14 s. This allows the FLC manager to get results in a short time and therefore to execute again the model in case the demand changes during the day, to make additional corrections if needed or to explore different alternatives. For instance, the manager can use the model to explore the impact of additional trucks or different number of trips permitted to the same supplier cooperative.

The model shows the optimal transport planning according to the remaining daily demand. As the sum of stock in cooperatives is much higher than the demand in the FLC, all demand is satisfied. Figure 7.5 shows the optimal quantity of fruit to be transported from each cooperative as well as the trucks to be used and the total quantity. Only variables for which the value is different of zero are shown.

On the other hand, the number of trips for each truck and cooperative is shown in Table 7.1. That table shows how only seven cooperatives are visited to load fruits to satisfy the FLC demand.

Furthermore, the smallest trucks T2 and T4 are not used and the biggest ones are preferred reducing in this way the total number of trips required to procure the fruits

| Coop Code | Blanquilla | | | | Conference | | | | Golden | | | |
|-----------|------------|----|----|----|------------|----|----|----|--------|----|----|----|
| | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| 2 | | | | | | | 24 | | | | | |
| 3 | | | | 24 | | | | | | | | |
| 6 | | | | | | | 2 | | | | 22 | |
| 14 | 2 | | | | | | | | 22 | | | |
| 17 | | | | | | | | | | | 24 | |
| 23 | 24 | | | | | | | | | | | |
| 29 | 24 | | | | | | | | | | | |

Fig. 7.5 Transport and quantity map for cooperatives procuring to the FLC

Table 7.1 Number of trips per truck and cooperative

| Coop code | T1 | T2 | T3 | T4 | Trips |
|-----------|----|----|----|----|-------|
| 2 | | | 1 | | 1 |
| 3 | 1 | | | | 1 |
| 6 | | | 1 | | 1 |
| 14 | 1 | | | | 1 |
| 17 | | | 1 | | 1 |
| 23 | 1 | | | | 1 |
| 29 | 1 | | | | 1 |
| Total | 4 | 0 | 3 | 0 | |

to the FLC. Therefore, trucks T1 and T3 are not necessary for that day. This table is useful to explore the increasing or decreasing in the number of trucks available. As the trucks are outsourced, the FLC can act proactively according to the demand expected in future and booking the trucks needed beforehand.

The total number of trips per truck was of four and three. A balanced result as the manager wished. This interaction between the end-user and the system is the main appreciated characteristic of the model because it allows the FLC to save time and money to plan the procurement of fruits for daily operation of the FLC. Furthermore, parameters of the model and results are recorded into an Excel spreadsheet that can be updated automatically by the ERP of the FLC. Even reports and results can be customised according to the intended use by the FLC manager. Although this model was developed to deal with an FLC, the same company owns other plants for which they find also suitable this kind of models like the procurement of a drying forage plant.

7.5 Conclusions

We have presented a mixed integer linear programming developed to support operational decision making in the transport planning for an FLC. We have illustrated the use of the model in a real case satisfying the end-user requirements. FLC manager appreciates the flexibility of the model and saving performed compared to past operation in planning the procurement of the logistic centre.

Although the results from the implementation of the model have been successful, the final adoption of the model is pending of internal adjustments allowing the complete automatism of the process.

Future work involves the running of the model for the harvesting season, where the number of fruits and categories is bigger, as well as the number of trucks involved in the transportation. Furthermore, from academic point of view the reformulation of the model as a capacitated vehicle routing problem is also in our agenda.

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Appendix 1: Distance Between Cooperatives and the FLC

| Coop code | FLC distance | Transportation time (h) |
|-----------|--------------|-------------------------|
| 1 | 36 | 4.20 |
| 2 | 12 | 1.40 |
| 3 | 10 | 1.33 |
| 4 | 28 | 2.93 |
| 5 | 28 | 3.93 |
| 6 | 38 | 3.27 |
| 7 | 35 | 4.17 |
| 8 | 48 | 3.60 |
| 9 | 30 | 3.00 |
| 10 | 26 | 1.87 |
| 11 | 17 | 2.57 |
| 12 | 13 | 2.43 |
| 13 | 27 | 3.90 |
| 14 | 8 | 2.27 |
| 15 | 50 | 2.67 |
| 16 | 35 | 2.17 |
| 17 | 10 | 1.33 |
| 18 | 48 | 4.60 |
| 19 | 22 | 3.73 |
| 20 | 42 | 3.40 |
| 21 | 27 | 3.90 |
| 22 | 0 | 0.00 |
| 23 | 5 | 2.17 |
| 24 | 30 | 4.00 |
| 25 | 30 | 3.00 |
| 26 | 24 | 2.80 |
| 27 | 42 | 4.40 |
| 28 | 40 | 3.33 |
| 29 | 8 | 2 |

Appendix 3: Demand (in ton) and Minimum Stock in the FLC (in kg)

| Variety | Minimum stock per category | | | | | | | | Demand |
|---------------|----------------------------|-----|-----|-----|-----|-----|-----|-----|--------|
| | 101 | 104 | 108 | 201 | 202 | 215 | 218 | 220 | |
| Blaquilla | 240 | 60 | | | | | | | 50 |
| Conference | 400 | 100 | | | | | | | 50 |
| Alexandrine | 80 | 20 | | | | | | | 0 |
| Red Delicious | | | | | | | | | 0 |
| Golden | 320 | 80 | | | | | | | 68 |

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