A Mixed Integer Linear Programming Model for
Optimal Production Planning in Tangerine Supply Chain

Chaimongkol Limpianchob[1,2,*]

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ABSTRACT

Tangerine is a variety of mandarin orange and the major export fruit of Thailand, with increased exports each year. There are tangerine production plants across the country, especially in the northern and central regions. For marketing reasons, there is a strong need for a reliable decision tool to manage the whole business. To address this problem, a harvesting and production planning model was developed as a realistic planning model of a production plant for the tangerine supply chain in the northern region. The supply chain problem was formulated as a mixed-integer linear programming model. Analysis of the optimization results when compared with traditional planning showed that the proposed model can save up to 10.16% of the operational cost. In addition, the model can be applied to estimate the tangerine processing capacity of the facility in order to establish future sales policies.

Keywords: Tangerine, supply chain management, production planning, mixed integer linear programming

INTRODUCTION

The tangerine is a one of the most popular varieties of citrus fruit commonly known as the orange in Thailand, where it readily found in all regions because it can be grown in tropical and subtropical areas and also it has become economically important as it is experiencing an increasing trend as an export commodity (Office of Agricultural Economics, 2015) as shown in Table 1. However, tangerine production plants in

Thailand often face problems with managing the large volume of tangerines due to an imbalance between supplies from harvested areas and the demands of customers and these can affect efficiencies in production planning.

The northern region has the highest production of tangerines where there are a large production plants involved in the complete tangerine industry supply chain (Ministry of Agriculture and Cooperatives, 2014). The harvesting fields consist of self-owned areas or

Table 1 Tangerine exports from Thailand.

	2012	2013	2014
Fresh tangerine (t)	81	161	321
Value (THB million)	1.14	2.14	5.59

Source: Office of Agricultural Economics, 2015.

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[1]   Department of Industrial Engineering, Faculty of Engineering at Kamphaeng Saen, Kasetsart University, Nakhon Pathom 73140, Thailand.
[2]   Centre of Excellence in Logistics, Kasetsart University, Nakhon Pathom 73140, Thailand
*   Corresponding author, e-mail: fengckl@ku.ac.th

third-party farms that are located close to the plant. Both harvested areas and third-party farms can be either owned by the company or available to the company under long-term contracts. Once the tangerines have been delivered to the processing plant, a decision has to be made on whether the fruit should be transported to a warehouse for later processing or sent directly to the processing line. Final destinations may be overseas, regional and local markets.

A supply chain is an integrated system of raw materials, information and organizations in which the raw materials that are acquired get converted into products and finally get delivered to customers (Chopa and Meindl, 2013). Supply chain management has attracted a large amount of interest from academics and practitioners (Christopher, 2005). Equally, food supply chains are composed of organizations that are involved with the production and the distribution of food (Zuurbier et al., 1996). The main fact that differentiates a food supply chain from other supply chains is its purpose to guarantee the provision of safe and healthy products that are fully traceable from farm to fork (Bourlakis and Weightman, 2004).

Operations research methods have been applied to the food supply chain during the last 10 years. Ahumada and Vilalobos (2009) reviewed planning models in the agri-food supply chain. However, a key concern in the agri-food supply chain is the short shelf life of perishable and seasonal products where substantial effort is required to maintain product freshness and availability at the point of sale. Additionally, Stadtler and Kilger (2000), provided more detailed descriptions of industrial cases. Some examples include a system integration of the production planning and shop floor scheduling problems by Kejia and Ping (2007), a case involving the sugar cane supply chain in Brazil by Sanjay and Marcus (2013) and a case of aquatic organism farming by Jerbi et al. (2012).

Mathematical programming planning models have been advanced to develop and apply to production planning models in different types of the food industries. For example, Doganis and Sarimveis (2007), proposed the scheduling needs in the yogurt production lines of a major dairy company located in Athens, Greece. They utilized mixed-integer linear programming to formulate the optimal production and scheduling models to address limitations in daily production time associated with 18 different products and sequence setup times. Arnaout and Maatouk (2010) formulated mixed-integer linear programming to schedule grape harvesting operations for wine production; the models applied two heuristics and compared the reduction in computational time. Zhang and Wilhelm (2011) revised production planning in the specialty crops industry covering fruits, vegetable, grapes and wine. Amorim et al. (2012) reported on the production and distribution of perishable foods with integration to optimize the freshness of fruits based on minimizing the stocks of stored raw material. The models compared two cases considering whether the products were fixed or variable.

This study considered an optimization model for the tangerine supply chain to provide system integration of the harvesting scheduling and production planning problem. The proposed model explicitly considered capacity constraints and operation sequences using mixed-integer linear programming in the minimum cost mode. The output of the model can be used both as an operational planning tool and as a strategic tool to analyze current planning under various scenarios.

PROBLEM DESCRIPTION

The following activities take place in a typical tangerine production plant in the northern region of Thailand. There are several sources, processing lines, demand nodes and time periods. The supply chain problem of the company contains decisions concerning the design of the production

flow and the timing of shipping and storage in the warehouse. Main decisions are associated with whether harvested fruit should be received from third-party farms. Furthermore, a consideration of the flow of the tangerines in each process must be applied to satisfy demands. In addition, it is necessary to consider restrictions on the capacities of the harvested areas, the production lines and the shipping and the storage in the warehouse. The general flow diagram for a single processing line is provided in Figure 1 and the steps in the process are described below.

(i) Tangerine from self-owned and from third-party farm (X_1) are delivered to the warehouse at the production plant. In general, non-processed tangerine storage is undesirable for economic reasons. However, it may be necessary if the delivery of tangerines exceeds the processing capacity of the line. In some cases, tangerines from the self-owned farm are purchased directly by retail customers (X_2) so the company must allocate tangerines to these customers.

Figure 1 Schematic diagram of a production plant (SP = Pre classification; WAP = Waxing module).

(ii) The tangerines enter the processing line (X_3), floating in a water stream treated with fungicides. Then, they enter the pre-classification (SP) stage depending on the degree of defect or damage where any non-tradable tangerines are separated for juice production (W_1).

(iii) If required, washed tangerines (X_4) enter the waxing module (WAP) where they are sprayed with wax and further dried with hot air. To process tangerines without wax (X_5), the WAP is simply by-passed.

(iv) All tangerines (X_4 and X_5) undergo quality classification into several sizes or weights at the packaging stage. Some waste is also produced at this stage (W2). Then, they are packaged according to the container specified by the client.

(v) Finally, the processed tangerines are kept in warehouses (X_6 and X_7) until further delivery (X_8 and X_9) or they may be delivered directly to the customers.

The following brief description of several important issues illustrates the complete scenarios of activities.

Supply of tangerines

The supplying company obtains tangerines from two sources—harvested areas and third-party farms.

The harvested areas are owned by the company and the tangerines must be removed during the planning period. In each harvested area, the volume of the tangerines can be estimated because the supply is based on the harvest of the tangerines from the previous year; it is relatively easy to get an almost exact estimate. Tangerine production is normally carried out during the whole year and the supply is consistent.

For third-party farms, the tangerines become available after entering into a contract which enhances the availability of the tangerines for the whole planning period. For each third-party farm, there is an estimated volume of tangerines that is harvested in each period.
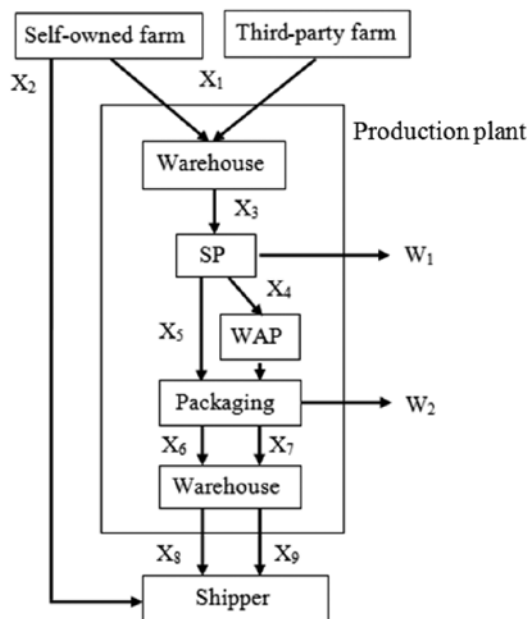
Warehouse

The warehouse is used to balance seasonal variation between supply and demand; it also offers more shipping possibilities. Throughout the season, the tangerine products are sourced from fresh tangerines that were previously in excess of the processing capacity of the line and had been stored in either the warehouse for later processing or the containers of tangerines from the packaging section. Moreover, there is a separate capacity warehouse for fresh tangerines from the harvested areas and the tangerine products that must be kept in the warehouse.

Waste

A fraction of non-tradable tangerines due to esthetic issues (damage, imperfections and extremes in size, among others) is eliminated from the processing line in the different classification modules and this waste is sold for tangerine juice production.

Labor policy

The company has a permanent labor force, with a single 8-hour working shift throughout the whole season. However, temporary staff may be required to cover two 8-hour working shifts during certain periods in order to satisfy commercial commitments.

MATHEMATICAL MODEL

The model was formulated as a mixed-integer linear programming problem, which is explained below. The model was defined in terms of sets of variables, the constraints that must be satisfied and the objective function

Let I be the set of harvested areas, C the set of customer areas and T the set of time periods. The set of harvested areas contains subsets for self-owned (I_P) and third-party farms with potential to be contracted (I_{PS}). An index i is used for harvested areas, c for customer areas and t for time periods.

Variables

The optimal values of variables are provided by the solution of the optimization problem and can be grouped into continuous variables and binary variables. For each week in the time horizon, the optimal values of the following variables are defined:

X_{1i}^t The harvested quantity of tangerine from area i in time period t, $i \in I_P \cup I_{PS}$

X_{2i}^t The quantity of tangerine that is purchased by retail customers at area i in time period t, $i \in I_P \cup I_{PS}$

X_3^t The total quantity of tangerines from the warehouse to the processing line in time period t

X_4^t The quantity of tangerines to the waxing stage in time period t

X_5^t The quantity of non-waxed tangerines passed to the packaging stage in time period t

X_6^t The quantity of non-waxed tangerines to the packaging stage and sent to warehouse in time period t

X_7^t The quantity of tangerines waxed to packaging stage and send to warehouse in time period t

X_8^t The total quantity of non-waxed tangerines that is transported to customers at the end of time period t

X_9^t The total quantity of waxed tangerines that is transported to customers at the end of time period t

$LabI_i^t$ The total number of laborers working in the harvested area

$LabII^t$ The total number of laborers working in the packaging sector.

The optimal quantities of tangerine variables stored in the warehouse for $t = 0$ is defined under the initial conditions

InI^t Total volume of tangerines stored in the warehouse at the end of time period t

$InII^t$ Total volume of non-waxed tangerines stored in the warehouse

$InIII^t$ Total volume of waxed tangerines stored in the warehouse.

Next, the set of binary variables needed in the model formulation can be defined as:

$$Pta_i^t = \begin{cases} 1, \text{ if the area } i \text{ is the harvested area in} \\ \quad \text{period } t, i \in I_P \cup I_{PS}, \\ 0, \text{ otherwise.} \end{cases}$$

Parameters

Cap_i The maximum capacity at source i, $i \in I_P \cup I_{PS}$

$CaPL^t$ The maximum processing capacity in time period t

$CaWI$ The draft capacity of the warehouse for tangerine storage

$CaWII$ The draft capacity of the warehouse for tangerine product storage

$CaWT$ The draft capacity of waxed processing

$DemI_k^t$ The demand of retail customer k in time period t

DmI_{km}^t The demand of customer k for ordered product m in time period t

$RoLB$ The maximum proportion of the number of laborers working in the harvested area

$RoLP$ The maximum proportion of the number of laborers working in the packaging sector

RoD The maximum proportion of the waste in the pre-classification sector

$RoNI$ The maximum proportion of the waste of non-waxed tangerines in the packaging sector

$RoNW$ The maximum proportion of non-waxed tangerines

RoW The maximum proportion of waxed tangerines

$RoWI$ The maximum proportion of waste of waxed tangerines in the packaging sector.

Constraints

The constraints needed for the harvesting in different areas can be calculated using the constraint Equations 1 and 2 as follows:

$$\sum_{t \in T} Plt_i^t = 1, \forall i \in I_P \tag{1}$$

and

$$\sum_{t \in T} Plt_i^t \leq 1, \forall i \in I_{PS} \tag{2}$$

Constraint Equation 1 specifies that each self-owned area has to be harvested exactly once (in exactly one time period) during the planning period and constraint Equation 2 specifies that each potential harvested area to be contracted has to be harvested at most once during the planning period. If the constraints in (2) are satisfied strictly with inequality, then no harvesting takes place in any of the time periods in that harvested area, which is interpreted as no contract has been taken in that harvest area. Thus, there is no supply from the harvest area in this case.

Constraint Equation 3 ensure that the total harvested volume of tangerines in a period never exceeds the supply source capacity:

$$X_{1i}^t + X_{2i}^t \leq Cap_i Plt_i^t, \forall i \in I_P \cup I_{PS}, \forall t \in T \tag{3}$$

where Cap_i is the volume of tangerines available from area i.

Since the tangerines may be purchased directly by retail customers, constraint Equations 4 and 5 ensure that all retail customer demand is satisfied:

$$\sum_{i \in I_P} X_{2i}^t \geq \sum_{k \in Cus} DemI_k^t, \forall t \in HP \tag{4}$$

and

$$\sum_{i \in I_P} \sum_{t \in T} X_{2i}^t \geq \sum_{k \in Cus} \sum_{t \in T} DemI_k^t \tag{5}$$

where the demand of retail customer k in time period t is denoted by $DemI_k^t$. The total demand at the end of time period t will be satisfied using constraint Equations 4 and 5.

Constraint Equation 6 ensures the availability of laborers in the harvested area:

$$X_{1i}^t + X_{2i}^t = RoLB(LabI_i^t), \forall i \in I_P \cup I_{PS}, \forall t \in T \tag{6}$$

where $RoLB$ represents the maximum proportion

of the number of laborers working in the harvested area.

The warehouse has limited storage capacity for fresh tangerines. Let $CaWI$ denotes the storage capacity of the warehouse. The capacity constraints can then be formulated as shown in constraint Equation 7:

$$X_{1i}^t \le CaWI, \forall i \in I_P \cup I_{PS}, \forall t \in T \qquad (7)$$

The constraint defines the capacity as the volume of fresh tangerines stored at the end of the period, to ensure that the volume stored in the warehouse never exceeds the storage capacity.

The balancing constraints for the tangerines in the warehouse are expressed in constraint Equation 8:

$$inI^t = inI^{t-1} + \sum_{i \in I_P \cup I_{PS}} X_{1i}^t - X_3^t, \forall t \in T \qquad (8)$$

The maximum processing capacity of the processing line is limited by the volume of tangerines that can be handled at the entrance to the SP module. Constraint Equation 9 assures that the capacity is not exceeded:

$$X_3^t \le CaPL^t, \forall t \in T \qquad (9)$$

The tangerines enter the processing line (X_3), floating in a water stream. Then, they enter the SP stage for defect classification. The tangerines leaving the SP stage are separated and either enter waxing (X_4) or non-waxing (X_5) processesing, so the balancing constraints can be formulated according to constraint Equation 10:

$$(1 - RoD)X_3^t = RoW\left(X_4^t\right) + RoNW\left(X_5^t\right), \forall t \in T \quad (10)$$

where RoD is the fraction of wasted tangerines based on defect or damage and RoW and $RoNW$ denote the fraction of waxed tangerines and non-waxed tangerines, respectively.

The maximum processing capacity of the waxing line is determined by the number of tangerines that can be handled at the entrance to the WAP module, which is in turn dependent on the processing capacity and the number of working shifts; these factors are described by constraint Equation 11:

$$X_4^t \le CaWT, \forall t \in T \qquad (11)$$

Equation 12 defines the classification process at the packaging stage where the tangerines are packed according to the container specified by the customers:

$$X_4^t = (1 - RoWI)X_7^t, \forall t \in T \qquad (12)$$

where $RoWI$ is the maximum proportion of waste tangerines based on their size or weight. Following the packaging stage, in a similar way, the classification of non-waxed tangerines is described by Equation 13, and Equation 14 calculates the labor force working in the packaging sector:

$$X_5^t = (1 - RoNI)X_6^t, \forall t \in T \qquad (13)$$

and

$$X_6^t + X_7^t = RoLP(LabII^t), \forall t \in T \qquad (14)$$

A number of capacity restrictions regarding storage of the products at the warehouse need to be considered. Let the total storage capacity be denoted by $CaWII$. Then, the constraint is shown by constraint Equation 15:

$$X_6^t + X_7^t \le CaWII, \forall t \in T \qquad (15)$$

Equations 16 and 17 are the inventory balance equations representing the stored products remaining in the warehouse after delivery of non-waxed tangerines (X_6) and waxed tangerines (X_7) to customers:

$$InII^t = InII^{t+1} + X_6^t - X_8^t, \forall t \in T \qquad (16)$$

and

$$InIII^t = InIII^{t+1} + X_7^t - X_9^t, \forall t \in T \qquad (17)$$

Finally, constraints are required to ensure that all customer demands are satisfied. The demand of the customer k with ordered product m in time period t is denoted by. The demand constraints can now be expressed by DmI_{km}^t constraint Equations 18 and 19:

$$X_8^t \geq \sum_{k \in Cus} DmI_{km}^t, \forall m \in \Pr d : m = NW, \forall t \in T \quad (18)$$

and

$$X_9^t \geq \sum_{k \in Cus} DmI_{km}^t, \forall m \in \Pr d : m = WA, \forall t \in T \quad (19)$$

The constraints that assure the total demand at the end of period t will be satisfied are provided in constraint Equations 20 and 21:

$$\sum_{t \in T} X_8^t \geq \sum_{k \in Cus} DmI_{km}^t, \forall m \in \Pr d : m = NW \quad (20)$$

and

$$\sum_{t \in T} X_9^t \geq \sum_{k \in Cus} DmI_{km}^t, \forall m \in \Pr d : m = WA \quad (21)$$

Objective function

The objective function minimizes the sum of the harvesting cost (C^{Har}), inventory cost (C^{Inv}) and labor cost (C^{Lab}). The total cost can be expressed as:

$$z = C^{Har} + C^{Inv} + C^{Lab}$$

Let CoS_i be the fixed harvesting and purchasing cost for the supply source i, which can be either for the self-owned areas or third-party farms. The total harvesting cost can now be expressed using Equation 22:

$$C^{Har} = \sum_{i \in I_P} \sum_{t \in T} CoS_i Plt_i^t + \sum_{i \in I_{PS}} \sum_{t \in T} CoS_i Plt_i^t \quad (22)$$

where the first term expresses the fixed harvesting cost in self-owned areas and the second term expresses the fixed purchasing cost of the third-party farms.

The inventory holding cost at the warehouse must be defined. Let $CoIN$ be the cost per volume stored of fresh tangerines and let $CoIC$ be the corresponding cost for products. The total inventory costs can be calculated as:

$$C^{Inv} = \sum_{t \in T} CoIN(InI^t) + \sum_{t \in T} CoIC(InII^t + InIII^t) \quad (23)$$

where the first term expresses the cost of storing in the warehouse for tangerines from harvested areas and the second terms expresses the cost of keeping product in the warehouse.

Finally, let $CoLT$ be the labor cost per volume for the harvested areas and let $CoLP$ be the corresponding labor cost for the packaging section. The total labor cost can then be determined using Equation 24:

$$C^{Lab} = \sum_{i \in I_P \cup I_{PS}} \sum_{t \in} CoLT(LabI_i^t) + \sum_{t \in T} CoLP(LabII^t) \quad (24)$$

where the first term expresses the labor cost for the harvested areas of both self-owned areas and third-party farms and the second term expresses the labor cost for the packaging sector.

COMPUTATIONAL STUDY AND RESULTS

The test problem has been derived from one of the largest companies in the northern region of Thailand; therefore, the company has a large number of harvested areas which can be considered as self-owned. Information regarding the size of the test problem is given in Table 2.

Solution methods

The mixed-linear programming formulation described in the previous section was implemented using the model language AMPL (Fourer *et al.*, 2003). In addition, the problem was solved with standard mathematical programming software with the branch-and-bound algorithm called ILOG CPLEX 8.0 (2003). The computational tests were performed on a computer

using an Intel CORE™ i5 with 3.30 GHz processor and 4.00 GB of RAM.

The modeling language AMPL was used to model the problem. The default setting was used to solve the mixed-integer linear programming problem directly by utilizing CPLEX. The tolerance from the optimal integer solution was set to 0.05%.

Computational results

The computational results are given in Table 3. The objective function value is presented as a cost in THB.

Table 3 shows that the quality of the solution is very high as it represents diminutive gaps in the optimal integer solution (0.05%). The optimal total cost of the operations for this scenario is THB 380,400. This total cost was 10.16% lower when compared to the total cost configuration of the base case (THB 423,400).

The optimal total cost was mainly due to the harvesting cost which was estimated as 70%. Other costs were 15% for labor and 15% for inventory cost. The differences between the total costs from the base case are clearly due to the harvesting cost. It is an important and major cost; if the harvesting cost has more uncertainty then the company would select tangerines from third-party farms where variances exist. As a result, the total cost will be high as well. During periods when the harvesting cost is lower, the company can allocate large amounts of tangerines to be processed or stored for further processing.

The problem for a one year scheduling horizon involves 21,230 constraints and 86,323 variables, of which 44,332 are linear variables. The proposed tool was utilized to calculate the optimal production schedule for a year, for which the example list of data are shown in Tables 4–5.

Table 2 Size of the test problem.

Parameter	Size of the test problem
Number of self-owned areas	2,378
Number of third-party areas	1,632
Number of customers	31
Number of laborers	842
Number of time periods	52

Table 3 Computational results of the test problem.

Data	Solution result
Objective function (THB)	380,400
- Harvesting cost	266,280
- Labor cost	58,476
- Inventory cost	55,644
Total number of variables	86,323
- Number of binary variables	11,845
- Number of integer variables	30,146
- Number of linear variables	44,332
Total number of constraints	21,230
Solver memory used (megabytes)	4,630
Solution time in CPU (seconds)	1,254
Gap tolerance (%)	0.05

The model considers the tradeoff between the operating cost and the time of harvesting, including keeping the tangerines in the storage which represents a major operational cost. Thus, better levels of sale prices can be expected. In such a mode, the model becomes a valuable tool for the manager of the tangerine exporting company to estimate future resource requirements and the processing capacity as well as to identify potential bottlenecks in the system in order to establish sales commitments for the next business year.

Thus, to demonstrate that the supply source cost has more influence on the total cost than other costs, sensitivity analysis was used. The model was tested by an increment of 10% in the harvesting, labor and inventory costs (Blanco *et al*., 2005). The resulting total costs and the percentage changes in the total cost are shown in Table 6.

It can be seen that the total cost is most

Table 4 Sample of production demand during annual scheduling.

Product	Week 1	2	3	4	5	6	7
Retail customers (X_2)	-	-	-	2,100	-	-	-
Non-waxed tangerines (X_8)	1,000	2,000	1,000	1,000	1,000	1,000	1,000
Waxed tangerines (X_9)	5,000	3,000	-	2,400	2,400	-	3,850
Total demand	6,000	5,000	1,000	5,500	3,400	1,000	4,850

Table 5 Sample of volume of tangerines in annual production schedule.

Production schedule	Week 1	2	3	4	5	6	7
X_1	7,261	4,958	2,703	4,354	3,735	3,205	4,241
X_2	0	0	0	2,100	0	0	0
X_3	7,161	4,958	2,203	2,754	3,635	3,305	4,241
X_4	5,610	2,550	1,020	1,530	2,346	2,040	2,907
X_5	1,020	2,040	1,020	1,020	1,020	1,020	1,020
X_6	1,000	2,000	1,000	1,000	1,000	1,000	1,000
X_7	5,500	2,500	1,000	1,500	2,300	2,000	2,850
X_8	1,000	2,000	1,000	1,000	1,000	1,000	1,000
X_9	5,000	3,000	0	2,400	2,400	0	3,850
InI^t	100	0	500	0	100	0	0
$InII^t$	0	0	0	0	0	0	0
$InIII^t$	500	0	1,000	100	0	2,000	1,000

Table 6 Sensitivity analysis of selected operating conditions on total cost.

Percentage change	Increasing harvesting cost		Increasing inventory cost		Increasing labor cost	
	Total cost	Change in total cost (%)	Total cost	Change in total cost (%)	Total cost	Change in total cost (%)
10	392,600	3.2	380,600	0.05	381,300	0.2
20	404,600	6.4	380,780	0.09	382,200	0.5
30	414,800	9.1	380,980	0.15	383,100	0.7
40	426,800	12.2	381,100	0.18	384,000	0.9
50	437,800	15.1	381,240	0.22	385,100	1.2

sensitive to the change in the harvesting cost. Changes in the inventory and the labor costs have a much smaller effect on the total cost. For example, a 10% increase in the harvesting cost will cause a 3.2% increase in the total cost, while a 10% increase in the labor cost and the inventory cost will cause 0.2% and 0.05% increases in the total cost, respectively. The results obtained are reasonable because the harvesting cost is an important cost component in the model's cost structure; the supply sources from the third-party farms have a higher cost than the self-owned areas. Thus, proper harvesting planning can result in large monetary savings.

CONCLUSION

This paper presented a mathematical model and a solution that can be used as an excellent tool to support decision making for production planning of the supply chain of tangerines. The mathematical model developed provides a detailed description of the supply chain problem. It has been applied in the minimum cost mode to estimate the production capacity of the facility as well as presented results for the processing plant where a single processing line was employed.

A commercial linear programming solver (CPLEX) was successful in finding a very high quality solution since the objective function values were within 0.05% of the optimal value. The model was successfully tested utilizing real-world, industrial data. Moreover, it is possible to evaluate a number of strategic analyses. The model provides better and more flexible solutions compared to manual planning. Furthermore, it allows easy testing of different strategies and scenarios. Finally, it is strongly recommended that this model and the approach applied to obtain an optimal solution can be used as an important and excellent tool to support decision making by the planning staff of any entrepreneur in the relevant industry.

Several improvements to address more realistic versions of the system are possible for future work, including the consideration of several parallel processing lines and the issues of transportation modes. A further extension of the present work could include the explicit consideration of the stochastic nature of the system.

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