Planning models for floriculture operations

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Abstract: This paper proposes planning models that will assist a flower grower with the land and flower variety allocation decisions in such a way that the revenues (or profits) are maximized over a given planning period. In particular, this paper presents models where the mix of flowers is modified throughout the planning horizon to accommodate market fluctuation such as changes in demand and price for the different varieties being planted and harvested. The problem considers capacity and workforce constraints and demand, yield, and price variability across time. The models developed are applied to a case study of flower growing in Ecuador. The results of these models are presented, including one based on a heuristic strategy that renders in most cases rapid and close to optimal solutions.

Keywords: floriculture; agriculture; production planning; mathematical programming; Ecuador.

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1 Introduction

The planting and growing of flowers, in particular roses, is a large industry in Ecuador, where more than sixty thousand workers labor for companies that sell more than 565 million dollars in flowers every year to North America, Europe, and Russia. Roses from Ecuador are among the best in terms of their quality, thanks to ideal conditions that include year-round favorable temperatures and daily sun exposure of about 12 hours. In addition, labor and other costs in Ecuador are competitive with other global producers as Colombia, Kenya, and China. Furthermore, new markets are opening up, for example, Ecuadorian roses are now being shipped to Japan via de Los Angeles airport, where just in the first two months of this operation over 45 tons of roses were shipped (Prnewswire, 2009).

While the flower industry has grown significantly in Ecuador, other countries have also increased their production capacity. This increased competition has placed significant pressures in Ecuadorian growers to improve their efficiencies and to offer the right products at the right time. Furthermore, several growers have recently shut down their operations and those still standing are looking for ways to capture some of the market share previously held by these growers.

Because of the state of the global economy and other external factors the demand for flowers (and for flower varieties) varies significantly across the year and from year to year. Thus, the successful trader of flowers is constantly analyzing the market to detect future demand for specific 'hot' varieties for the upcoming seasons. This information is passed on to the growers, who must determine the right mix between new varieties and the more established varieties that are demanded during traditional holidays (Christmas, Easter and Valentine's Day) whose demand is 'well known'.

Demand and yield information is critical for the variety planning of flower farms in Ecuador. Many varieties of roses grow all year in the Ecuadorian highlands, although the output measured in flowers per plant is not the same every month, and this output depends on the flower variety. Changes in the long-term demand for some varieties, plus the development of new 'attractive' varieties, requires changes in the allocation of the farm space allocated to each variety. Thus, there is continuous revision process which requires replacing 'obsolete' or low demand varieties with 'stable' or 'promising' varieties. Replacing a variety is not a simple decision, as a new plant takes several months before it reaches full production capability. Thus, there is a significant cost related to lost output which translated into lost revenue. Since roses are very sensitive to the level of demand and offer, their prices are variety and time dependent. Decisions that a flower grower must make include the varieties that must be available and in what quantities, which are directly related to decisions on the removal and addition of plants because the land available for harvesting is limited. Therefore, the research work presented here addresses the planning of flower varieties and quantity per variety given the per period demand, plant productivity, and price are variety and time dependent. The proposed model is different from most presented in the literature given many flower varieties including roses bloom year-round, thus cropping planned for all the periods versus one or a few occasions during the year. We propose a mathematical programming model that addresses the problem considering different constraints that the grower faces such as land and workforce capacity; demand and price variability; and the lead time between planting and flower production.

The paper is organized as follows: Section 2 presents a review of recent literature on scheduling and planning for crop growing operations. Section 3 describes the problem and the proposed models. Section 4 presents an illustrative example of the model and describes the implementation of the model using two approaches. Section 5 provides a summary and discusses future work.

2 Literature review

The use of mathematical models to support production decision making is extensive and well documented. This decision-making process is complex given the many factors that need to be considered in the planning process such as demand uncertainty, time for maturity of the product, production yield, worker skills, environmental conditions, and the need to re-plan the schedule based on market requirements (Arnaout and Rabadi, 2008; Mohebbi, 2010). The development of mathematical programming models addressing these factors has been the subject of extensive research for agricultural products. These models are documented in literature reviews by Lowe and Preckel (2004), Ahumada and Villalobos (2009), and Zhang and Wilhelm (2009), which provide excellent overviews and analysis of the existent literature in production planning models in agricultural settings. The review by Lowe and Preckel was not intended to include all the existing work, but instead to draw attention to relevant issues and to describe the methods used by researchers to address them. The review by Ahumada and Villalobos classified the literature on three factors,

a perishability

b model assumptions about uncertainty

c the scope of decision making (strategic, tactical, and operational).

The review by Zhang and Wilhelm (2009) focuses on operation research applications in the specialty crop industry; where flowers, fruits and vegetables are classified. Their review aims to provide a perspective of the models available to assist growers and supply chain managers to select the most appropriate according to their needs. In light of the existence of recent literature reviews, our discussion of the literature focuses especially on a few papers particular to the flower growing/planning area and papers about closely related models.

There are only a few research articles which deal with floriculture business operations and planning. The paper by Schuhmacher and Weston (1983) introduces linear programming as a tool for production planning in glasshouse floriculture, while Caixeta-Filho et al. (2002) describe an LP based decision support tool designed to assist in the production planning of Lily flowers. At the macro level, the paper by Gatrell et al. (2009) examines the floriculture industry in a region of the USA, analysing the industry's constraints and as well the strategies required to promote industry competitiveness. This previous literature dealing with floriculture operations does not present the models required to support planning, nor evaluate the performance of heuristics that are capable of providing solutions for real sized problems. This paper provides both the full description of a model that support flower planning and evaluates the performance of a heuristic approach.

As per the Ahumada and Villalobos (2009) classification, our planning model falls under the perishable, deterministic, and tactical levels. Works in similar classifications that are related to our problem include Caixeta-Filho (2006), Ferrer et al. (2008), and Ahumada and Villalobos (2011a, 2011b). The harvesting model proposed by Caixeta-Filho (2006) supports the decision process of what groves to harvest over a multi-period harvesting season for oranges. The model aims to maximise revenue subject to harvesting capacity constraints and that each harvested grove meets a quality ratio, which considers for example the juice yield and the acid content. The work by Ferrer et al. (2008) presents a Mixed Integer Programming (MIP) model that supports the scheduling of harvesting operations of wine grapes. The model considers several factors including the loss of quality of the grapes for delaying harvesting. The decisions include what grapes to harvest and the harvesting capacity controlled by the hiring and layoff of workers. The models by Ahumada and Villalobos (2011a) provide tactical decision support models for the production and distribution of fresh produce, assuming that the producer has control over the logistic decisions related to the distribution of the crops. As in the case of Caixeta-Filho model, the model's objective is to maximise revenues.

Some relevant recent work in crop planning includes Sarker and Ray (2009), Guan et al. (2009) and Bohle et al. (2010). Sarker and Ray (2009) formulate the crop planning problem as a multi-objective optimisation model and solve two versions of the problem. They use three approaches to solve the problem, including one proposed by the authors, and analyse their performance, which supports that their approach works well for the non-linear version of the crop-planning problem. Guan et al (2009) address the problem of developing cropping schedules for the sugarcane industry in Japan. Their model supports the development of real time schedules that plan the allocation of workers and considers issues as equipment breakdowns, in combination with long term schedules that considers issues as the condition of farmland and the option to lease additional land. Bohle et al. (2010) builds on the work by Ferrer et al. (2008), addressed planning in wine grape harvesting operations. The paper by Bohle et al. (2010) proposes several robust optimization models for the problem, and use the data from Ferrer et al. to explore the effect of modeling robustness on the schedule and objective function.

3 A flower planning model

This section describes a mathematical model for flower planning developed based on the needs of several flower growers in Ecuador. The model is centered on the tactical planning needs of the growers to allocate the different scarce resources among the different flower varieties. The scarce resources include land and workforce capacity over a multi-period planning horizon. Demand and price changes over time require growers to continuously evaluate the need to replace flower varieties, and in some cases, to even stop using some of their farm space (removal of plants with no addition). Similarly, these changes in demand and the need to remove/add plants require modifications to the workforce. Clearly the target is to maximize profits by having varieties with high demand and prices; adding plants of those varieties with enough lead time to meet future demand increases (removing varieties with low demand, low prices), and by managing the workforce as to meet the demand.

3.1 The base model

The relevant factors considered by the proposed base model are described next. Each flower variety has different productivity levels (e.g., number of blooms per week per plant), and their productivity varies over the year due to weather changes, in particular temperature and sun exposure levels. The time for a newly added plant to reach its regular productive level also depends on the particular variety. Adding and removing plants requires labor, which is also variety dependent. The cost of adding plants relates to royalty costs payable by the grower to the variety developer, and this is a per-plant cost. The proposed model does not consider inventory costs since flowers are shipped out of the facility at most four days after being cut and the minimum applicable time scale for this model is assumed to be weeks. This makes carrying of inventory across time periods not representative of the observed environments.

Although new laws in Ecuador make it expensive to hire workers for short periods of time, modifications to the workforce are included in the proposed model. The number of workers to hire or layoff is modeled as an integer variable to properly account for hiring and layoff costs. Costs associated with labor are constant for the duration of the planning horizon (e.g., cost to hire a worker is the same in the first and last periods under analysis). Furthermore, it is assumed there is a large labor pool available. Given shipments are FOB-airport, and a third-party provider hands daily shipments to the airport, all distribution and transportation issues are not considered in the proposed models.

Variables and constants

Sets

J set of all plant types (varieties) currently planted and under consideration for planting

T set of all the time periods.

Plant bed and unit constants

$TotalSpace$ total space of the facility

$SpacePlant_j$ space required per plant of type j

$Demand_{jt}$ demand for flowers of type j during time period t

$UnitsPlant_{jt}$ number of units that can be harvested per plant for type j during period t

$CapAdd_j$ capacity in hours required to add a plant of type j

$CapRemove_j$ capacity in hours required to remove a plant of type j

$CapHarvest_j$ capacity in hours required to harvest a plant of type j.

Time constants

$TimetoProduce_j$ number of time periods required for a newly added plant of type j after planting to produce at their regular rate

$CapWorker$ capacity in hours per worker per time period.

Revenue and cost constants

$SellPrice_{jt}$ expected selling price for a unit of type j during time period t

$CostPlantAdd_j$ cost to add a new plant of type j

$CostPlantMaintain_j$ maintenance, irrigation, and other recurring costs related to one plant of type j per time period

$CostWorkerAdd$ cost to hire a worker

$CostWorkerLayoff$ cost to layoff a worker

$CostperWorker$ cost per time period per worker.

Intermediary variables

$PlantsHarvest_{jt}$ number of producing plants of type j during period t

$PlantsTotal_{jt}$ number of plants of type j during period t (producing and non-producing)

$SatisfiedDemand_{jt}$ demand for units of type j during period t that is satisfied

$WorkersAvailable_t$ number of workers available during period t.

Decision variables

$PlantsRemove_{jt}$ number of plants of type j to be removed during period t

$PlantsAdd_{jt}$ number of plants of type j to be added during period t

$WorkersLayoff_t$ number of workers to layoff at the start of period t

$WorkerHire_t$ number of workers to hire and have available at the start of period t.

Constraints

$$SatisfiedDemand_{jt} \leq UnitsPlant_{jt} \cdot PlantsHarvest_{jt} \quad \forall T \; \forall J \tag{1}$$

$$SatisfiedDemand_{jt} \leq Demand_{jt} \quad \forall T \; \forall J \tag{2}$$

$$PlantsHarvest_{jt} = PlantsHarvest_{j(t-1)} + PlantsAdd_{j(t-timetoproduce_j)} - PlantsRemove_{jt} \quad \forall T \; \forall J \tag{3}$$

$$PlantsTotal_{jt} = PlantsHarvest_{jt} + \Sigma_{x=(t-timetoproduce_j+1)\ \ldots\ t} \left[PlantsAdd_{jx}\right] \quad \forall T \; \forall J \tag{4}$$

$$Sum_{\forall J} \left[SpacePlant_j \cdot PlantsTotal_{jt}\right] \leq TotalSpace \quad \forall T \tag{5}$$

$$\Sigma_{\forall J} \left[CapAdd_j \cdot PlantsAdd_{jt} + CapRemove_j \cdot PlantsRemove_{jt} + CapHarvest_j \cdot PlantsHarvest_{jt}\right] \leq WorkersAvailable_t \cdot CapWorker \quad \forall T \tag{6}$$

$$WorkersAvailable_t = WorkersAvailable_{(t-1)} + WorkersHire_t - WorkersLayoff_t \quad \forall T \tag{7}$$

$$PlantsAdd_{jt},\ PlantsRemove_{jt}, PlantsHarvest_{jt},\ SatisfiedDemand_{jt} \geq 0 \quad \forall T \; \forall J$$

$$WorkersHire_{jt}, WorkersLayoff_t \geq 0 \text{ and integer} \quad \forall T$$

Objective function

The objective of the model is to maximise profits defined as follow.

$$Revenue = \Sigma_{\forall T \forall J}\left[SellPrice_{jt} \cdot SatisfiedDemand_{jt}\right]$$

$$Maintenance\ costs = \Sigma_{\forall T \forall J}\left[CostMaintain_j \cdot PlantsTotal_{jt}\right]$$

$$Plant\ addition\ costs = \Sigma_{\forall T \forall J}\left[CostAdd_j \cdot PlantsAdd_{jt}\right]$$

$$Workforce\ costs = \Sigma_{\forall T}\left[CostHire_t \cdot WorkersHire_t + CostLayoff_t \cdot WorkersLayoff_t + CostperWorker_t \cdot WorkersAvailable_t\right]$$

$$Profit = Revenue - Maintenance\ costs - Plant\ addition\ costs - Workforce\ costs.$$

Constraints 1 and 2 are used to determine the level of demand that is satisfied. Constraint 3 establishes the number of producing plants during period *t*, which is equal to the number of producing plants in the previous period, plus any plants that were added $timetoproduce_j$ periods before minus any plants being removed this period. Constraint 4 calculates the total number of plants of type *j* in the farm, producing plants plus those having been already added but not producing, including those being added in the current period. Constraint 5 limits the total space used by the total available in the farm. Constraint 6 limits the total workforce capacity used (capacity required to harvest, add, and remove plants) by the total available per period. It must be noted that the model assumes here that the removal and addition of plants can happen in the same time period for a plant. Constraint 7 determines the number of workers available; the number available the previous period plus any hires minus any layoffs.

It is assumed that flowers that are harvested but not required (by the demand) are not sold in secondary markets as the local demand is small and provides little or no economic benefit. Flower farms are in the most part set up in beds (rectangles measuring anywhere from 22 meters to 55 meters and about 0.6 meters in width), and typically hundreds of beds are located inside greenhouse type structures. Beds share irrigation and fertilization schedules and 'programmes' therefore only one variety is planted in a bed. However, in the proposed model the planting space is considered as a continuous variable that can be divided among the flower varieties (called types) in any quantity. Therefore, the model would result in a solution that assigns more than one flower variety to a bed and also, given that the proposed decision variables are continuous, the number of plants could include a fraction of a plant. However, given the large size of most flower farms and therefore the large number of beds (often thousands of beds in one farm), the error (deviation from optimality) from these assumptions is small and not a concern to the floriculture managers. Considered demands are in the thousands of flowers, thus fraction results are considered irrelevant. For example, the model recommends that 3,000.45 plants of the *Love Story* variety be added and that an equal number of the *Kardinal* variety be removed. Currently, *Love Story* has 12,000 plants in 70 beds of diverse sizes. The implementation of the solution will require the selection (by the managers) of multiple beds from *Love Story* in physical proximity (as to keep the farm organized) of a total size that allows 3,000 plants (as close as possible to that number) to be planted. The implementation of this recommendation from the model could be the selection of 18 beds in Greenhouse B which together can 'hold' 3,200 plants. While the implementation of these solution is suboptimal (from the model's standpoint), is 'possibly' the best implementation possible.

3.2 A simplified version of the model for a single flower operation

This section presents a simpler version of the model for a floriculture operation with a single family of flowers, for example roses, such that many of the parameters are not variety specific. The non-variety specific parameters are: the space per plant ($SpacePlant_j$), the time to add, remove, and harvest plants ($CapAdd_j$, $CapRemove_j$, $CapHarvest_j$), and the cost to maintain ($CostPlantMaintain_j$), and therefore excluded from the decision-making process. Another simplification is that farm space will not be left unused and the amount available will not change during the planning horizon. Therefore, the model provides a replacement plan; for each period *t* the number of plants from a variety *j* to be removed and replaced by variety *j**. The time from planting to production ($TimetoProduce_j$) and the output per plant per time period are still variety specific ($UnitsPlant_{jt}$).

The final change in this simplified model relates to the workforce options/planning; there is a fixed workforce capacity that can dedicated to plant *exchanges*, and the variable *ExchangeMax* is used to model the maximum number of plants that can be exchanged per time period. The simplified model is presented next.

$$SatisfiedDemand_{jt} \leq UnitsPlant_{jt} \cdot PlantsHarvest_{jt} \quad \forall T \ \forall J \qquad (1b)$$

$$SatisfiedDemand_{jt} \leq Demand_{jt} \quad \forall T \ \forall J \qquad (2b)$$

$$PlantsHarvest_{jt} = PlantsHarvest_{j(t-1)} + PlantsAdd_{j(t-timetoproducej)} - PlantsRemove_{jt} \quad \forall T \ \forall J \qquad (3b)$$

$$PlantsTotal_{jt} = PlantsHarvest_{jt} + \Sigma_{x=(t-timetoproducej+1)\ \ldots\ t} \left[PlantsAdd_{jx} \right] \quad \forall T \ \forall J \qquad (4b)$$

$$\Sigma_{\forall J}\ PlantsAdd_{jt} = \Sigma_{\forall J}\ PlantsRemove_{jt} \quad \forall T \qquad (5b)$$

$$\Sigma_{\forall J}\ PlantsAdd_{jt} \leq ExchangeMax \quad \forall T \qquad (6b)$$

$$PlantsAdd_{jt}, PlantsRemove_{jt}, PlantsHarvest_{jt}, SatisfiedDemand_{jt} \geq 0 \quad \forall T \ \forall J$$

Objective function

The objective of the model is to maximize profits, where labor costs and maintenance are assumed to be not relevant.

Profit = Revenue – Plant addition costs

Constraints 1(b) to 4(b) are the same as in the general model. Constraint 5(b) sets the total number of plants to be added equal to the total number of plants to be removed for each time period. Constraint 6(b) limits the exchange of plants to a maximum value which is used in lieu of workforce capacity constraints.

4 An illustrative example and model implementation

As mentioned earlier the motivation for this research was the flower growing operations in Ecuador. We used a particular rose growing operation to implement the proposed model, specifically the simplified model. The goal of the implementation was to evaluate multiple tactical planning scenarios considering demand, price, and plant exchange options. For the sake of brevity and clarity we present in this section an abbreviated analysis where ten rose varieties are considered in the model application. These represent about 48% of the total number of plants in the analyzed farm.

Data from previous years was used to develop two-year demand and price forecast scenarios. For each rose variety a demand forecasting model and a price forecasting model were developed that had a seasonal effect component and trend component. We refer to the baseline forecast as the generation of demand and price values for two years into the future using the estimated trend and seasonal values. For the creation of possible alternative future scenarios, expert opinions were used to modify the trend effect on the demand and price models, for example a scenario would consider a few flower varieties with a higher positive trend (e.g., 10% higher slope) than that derived from the data, based on the opinion of the sales group that this was an upcoming variety with high sales potential.

The cost of replacing was set at $1.5/plant. Basic information about the varieties and initial data is provided in Table 1. Figure 1 presents the values of $UnitsPlant_{jt}$ (number of units per month per plant) per variety for one year (for the first five varieties to help visualisation). As can be noted, the output per plant for varieties 1 and 4 vary significantly across time, while the others in the Figure have less pronounced output variations.

Table 1 Basic information for the example

Variety	1	2	3	4	5	6	7	8	9	10
Initial number of plants	5,793	23,210	20,787	5,529	14,375	14,878	19,445	26,457	3,732	92,995
Time to produce (months)	6	6	6	8	8	8	7	7	7	8

Sample demand and price forecasts are presented in Figures 2 and 3 respectively (for the first five varieties). In this case varieties 2, 3 and 5 have positive demand slopes and represent the majority of the displayed demand. In regards to the price forecast, the prices for variety 4 has a decreasing slope, while variety 2 has a positive one, with a significant seasonal effect in January/ February. Variety 3 has a flat trend and a remarkable seasonal spike in the month of August due to Russia’s return to school event.

Figure 1 The per variety per plant per month output (yield)

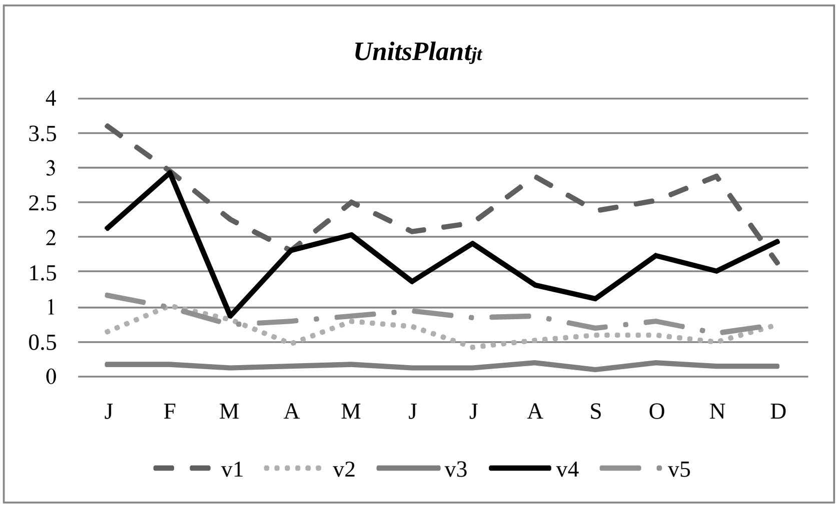


Figure 2 Forecasted demand behaviour for the example case (one year)

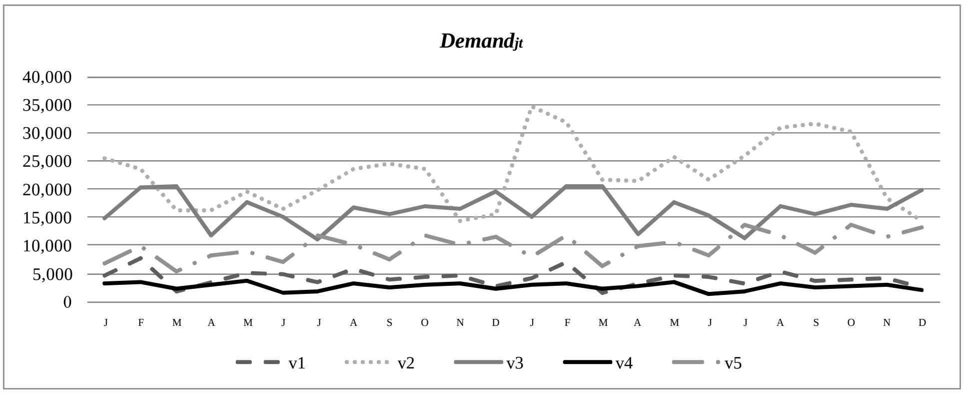
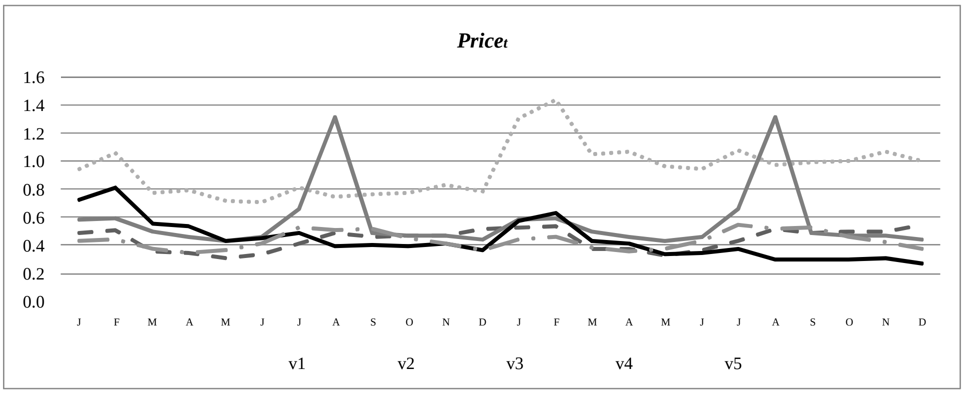


Figure 3 Forecasted price behaviour for the example case



4.1 Implementation

We used two 'technologies' to implement the model and generate solutions, observing the importance of providing a practical and low-cost solution to the floriculture operation. The first approach was to setup the model using Excel and to generate the optimal solution using Frontline's Premium Solver ®. The second approach was to develop a prototype application using Excel's Visual Basic for Applications (VBA). The benefit of developing a VBA application for this model/problem is that it easily scalable to include a changing number of rose varieties, it can be designed to automatically run multiple scenarios and that Excel (with VBA) is a software available at most businesses, including the floriculture operation in question, requiring no additional investment. The major drawback of the use of VBA and Excel is that it depends on heuristic approaches to solve the problem, therefore no guarantee of optimality (versus a solver-engine based solution). The use of heuristic solutions is justified by the high complexity of the described problem and part of many real-world problem-solving cases (Satya et al., 2008).

While the replacement value (the decisions made by the model) found using Solver could be any number larger than 0 (constrained by the maximum number that could be replaced at a time period), the implementation of the heuristic was based on a fixed number of plants that will be considered for exchange at each iteration of the process, called *RQ*. Using a fixed number reduces the search space and therefore keeps computational times for the heuristic relatively small. When the number of plants left for a variety is less than *RQ*, then this is the amount considered for replacement (from the 'remove' side of the analysis). For the sake of implementability the selected *RQ* value should be closely linked to the most frequent bed size (in number of plants). Furthermore, it is intuitive that *MaxExchange* is an integer multiple of *RQ*, otherwise every period will have excess replacement capacity.

The steps for the implemented heuristic are as follows:

1 Calculate the *BaselineRevenue* with no plant replacement. Let *CurrentRevenue* = *BaselineRevenue* and $ReplacementCapacity_t = ExchangeMax \ \forall T$

2 Let $LostRevenue_{jt}$ be the lost revenue of variety *j* at time *t* (clearly 0 if demand ≤ output available). This is estimated only for periods > $timetoproduce_j$ and let *tmax* be the last time period ($T = \{1, \ldots, tmax\}$). Let $SumLostRevenues_{jt}$ be the sum of all the lost revenues from *t* to the last period under analysis ($\sum_{x = t \ldots tmax} LostRevenue_{jx}$).

3 Select the variety and period with largest $SumLostRevenues_{jt}$ that still has a non-zero $ReplacementCapacity_k$ at time $k = t - timetoproduce_j$. Let this variety be j^* and the time be t^*. Consider adding *RQ* plants to variety j^* at time $t^* - timetoproduce_{j^*}$. Consider removing *RQ* plants at time $t^* - timetoproduce_{j^*}$ for all varieties (not j^*) that still have at least *RQ* plants for all the subsequent time periods. Let j^e the variety with the 'exchange' that results in the largest farm revenue, *NewRevenue*.

4 If *NewRevenue* > *CurrentRevenue* reduce $ReplacementCapacity_{t^*}$ by *RQ* units, remove *RQ* plants from j^e and add *RQ* plants to j^* at period $t^* - timetoproduce_{j^*}$ (therefore these plants will be producing at period t^*), let *CurrentRevenue* = *NewRevenue*, and return to step 2.

5 End

The logic behind this procedure is to find the variety and period that has the most significant potential to increase profits, and that still has capacity to add/remove plants. It then considers all other varieties to determine the removal that has the least effect. The process is repeated until no replacement (exchange) improves on the current solution. An important parameter in the search process is variable *RQ*. Based on multiple pilot experiments, the value of *RQ* was set to 200 (i.e., *RQ* = 200). This value was selected in order to reduce computational time (minutes to seconds). The use of smaller values for *RQ* (i.e., *RQ* = 100) produced very small improvements in performance, although it increased computational times.

The optimal and heuristic solution for the baseline forecast cases are presented in Table 2. In the optimal solution varieties 2 and 9 are the only that 'receive' plants, while varieties 1, 4, 5, 7, and 8 'give up' plants. Varieties 3, 6 and 10 maintain the original number of plants for the overall plan. By comparison, in the heuristic solution variety 2 is the only one that 'receives', while the same ones are selected to 'give up' plants, although at different points in time. The exchange is also different, with variety 9 having the largest difference in planning. While in the optimal plan exchanges are completed by December, in the heuristic the exchanges are done earlier, by August. The objective function value (*Ofv*) for the baseline forecasts and with no exchanges is $1,981,000; the solution generated by heuristic improves the *Ofv* by 2.12% ($2,024,000) with 15,329 plants being exchanged, while the optimal solution improves the *Ofv* by 2.33% ($2,028,000), with 16,238 plants being exchanged.

4.2 Experimentation

We performed fifteen modifications to the baseline forecasts based on the opinion of the planners and managers, with some random iterations generated to further test the performance of the proposed heuristic. The error of the heuristic is based on the size of the gap; heuristic error = (Optimal *Ofv* – heuristic *Ofv*) / (Optimal *Ofv* – no exchanges *Ofv*). Therefore, the heuristic error for the baseline forecast is 9.3%. Table 3 presents a description of the tested cases and the average results found for the objective function value and the number of plants exchanged (each row provides average for five experiments that fit the description). The tested cases are 'experience based' modifications of the demand and price data, where in one set of experiments the demand and prices for a subset of the varieties increases, on a second set some there is a mix of effects where the demand and price of some varieties increases, while for a second subset of varieties these decrease, while finally in the third set of experiments the demand and prices for a subset of the varieties decrease.

Table 2 Optimal and heuristic solutions

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Ending*	*Delta*
Optimal solution														
v1			–1,300		–79								4,415	
v2	1,938	2,000	2,000	2,000	1,846	2,000	2,000	1,459					38,452	
v3													20,787	
v4		–57	–35		–771	–2,000	–2,000	–667					0	
v5	–2,000	–1,943											10,432	
v6													14,878	
v7			–78	–2,000	–1,151			–792			–268	–557	14,599	
v8			–587										25,870	
v9	62				154						268	557	4,773	
v0													92,995	
Heuristic solution														
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Ending*	*Delta*
v1	–400	–400	–200	–200									4,593	178
v2	2,000	2,000	2,000	2,000	2,000	2,000	2,000	1,329					38,539	87
v3													20,787	0
v4	–400	–800	–200	–1,000	–1,200	–1,000	–800	–129					0	0
v5			–400	–600	–200		–1,200	–1,200					10,775	343
v6													14,878	0
v7	–1,200	–800	–1,200	–200	–400	–1,000							14,645	46
v8					–200								26,257	387
v9													3,732	–1,041
v0													92,995	0

Table 3 Experimental results ($'s in 000s)

Description	*Solver*			*Heuristic*		
	Ofv	*Ofv* (% impr)	Plants exch	*Ofv* (% impr)	Plants exch	*Ofv* error
Positive: higher demand and prices for 3–5 varieties.	$3,268	$3,544 (8.93%)	28,262	$3,538 (8.76%)	27,972	2.6%
Mixed: higher demand and prices for 2–3 varieties, lower demand and prices for 2–3 varieties.	$2,189	$2,328 (6.27%)	28,977	$2,316 (5.75%)	27,543	11.1%
Negative: decreased demand and prices for 3–5 varieties.	$1,667	$1,705 (2.37%)	20,541	$1,698 (1.92%)	15,665	30.9%
Average	$2,375	$2,526 (5.86%)	25,785	$2,517 (5.48%)	23,727	14.9%

The experiments demonstrated that the heuristic provides close to optimal results for most of the experimented cases. In particular, when the cases related to higher demands and prices, the error of the heuristic averaged 2.6%, with the worst case having an error of 6.6%. The performance of the heuristic deteriorated as the outlook worsened, with an error averaging 30.9% for the negative outlook cases. However, the $ value of this error is small (average of $7,000) which is associated with the small benefit of exchanging plant types when the demand and price outlooks are negative. The difference in the number of plants exchanged by the heuristic versus the optimal was small, in particular for the first two cases (positive and mixed cases). An analysis of the results showed that in most cases the solutions generated by the heuristic were 'similar' to those generated by the optimal in that the most of the same varieties were added and removed, although the time and quantities varied between the heuristic and the optimal. The worst performance of the heuristic occurred when using pessimistic demand/prices cases, which is explained by the limited opportunities to improve profits under reduced prices and demand. Alternative heuristic approaches need to be developed in future work to address these potential scenarios.

Both the Premium Solver ® and heuristic method were able to generate solutions in seconds/minutes, thus computational times were not an issue. The selected implementation by the rose grower was the VBA prototype, primarily for cost reasons. While the proposed heuristic only addresses the simplified version of the problem, it can be used to generate solutions for the general problem with minor modifications related to modeling the other constraints as variety dependent capacity requirements and workforce flexibility.

5 Conclusions and future work

This study contributes to the literature by developing two planning models specific to the floriculture industry. The model captures demand, price, and yield factors and supports decision related to the dynamic modification of the 'flower' mix in a farm according to changing market conditions. The presented implementation of the model mixed forecasting models with the proposed mathematical formulation to support tactical decision making, including the evaluation of demand and price scenarios. A heuristic is proposed and tested under a variety of scenarios. The results indicated good heuristic performance, except under conditions of negative demand and prices.

The model supports management decision making in several ways. First by considering multiple demand scenarios the robustness of the current allocation (and future allocation) of resources to varieties can be estimated, this considering changes to uncontrollable factors such as yield and price. Management can study the effect on the flower mix of varieties from those that are new to the market and whose price and demand can fluctuate dramatically, to well established varieties with stable demand and prices.

The presented model could be extended to other situations. For instance, the model presented in this paper has applicability to other products, for example sugarcane plantations where some of the similar effects and variables have been observed. Future work revolves around the development of models that support planning considering additional factors that grower's control as for example plant pruning, including the level of pruning and the effort required (capacity requirements and constraints), noting that pruning plans has the effect of increased blooming and higher prices due to longer stems. Also, future work will consider heuristic for negative outlook decision making, and the modeling of characteristics particular to the location of the plants (the plant beds) given each of these beds may have unique characteristics (e.g., age, sun exposure) which influence the yield and growth rate even when beds are of the same variety.

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