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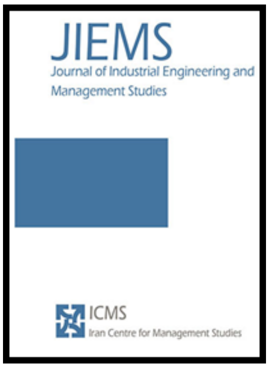

Tactical and operational planning for socially responsible fresh agricultural supply chain

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Abstract

Addressing an integrated decision-making structure for planting and harvesting scheduling may lead to more realistic, accurate, and efficient decision in fresh product supply chain. This study aims to develop an integrated bi-objective tactical and operational planning model for producing and distributing fresh crops. The first objective of the model is to maximize total revenue of supply chain. Over the past few years, there has been a considerable shift in emphasis in social responsibility of supply chains. Therefore, a key purpose of this article is to plan a socially responsible fresh agricultural supply chain as the second objective function. The proposed bi-objective model seeks to make optimal decisions on planting, harvesting scheduling (harvesting pattern), selecting the transport fleet type, and products supply channel to the consumers. To conduct the analysis, numerical examples are provided based on a real case study and the true Pareto front is achieved with augmented ε-constraint method. The results indicated the applicability of the proposed model and verified its validity. Moreover, comparison between total weighting and ε-constraint method is provided to ensure the efficiency of Pareto solutions.

Keywords: agriculture supply chain; social responsibility; fresh fruit; crop planning; harvest pattern.

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1. Introduction

Agriculture is regarded as one of the main sources of wealth in the economy. Nowadays, the agriculture sector plays an important role in supplying food, social welfare and ultimately, national economic growth and consequently, developing countries develop their economic programs based on agriculture to deal with the economic crisis (Abedinpour, et al., 2019). In recent years, there has been a growing interest in the use of advanced planning tools for the supply chain of fresh crops (Rafiei, et al., 2018). However, it is difficult to adapt the current planning techniques to the supply chain of new crops and its complexity will increase with the perishable nature of crops (Ahumada and Villalobos, 2011). Generally, fruits and vegetables often

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face complex planning problems such as deciding on the level of applied technology, how to produce a particular crop, and planting and harvesting time (Ahumada and Villalobos, 2011). On the other hand, the producer deals with planning problems at different levels in traditional planning. For example, farm location and other infrastructure decisions can be among the problems of strategic planning. Further, the decisions made by the producer in each year, including planting time and resource allocation, can be considered as tactical-level problems among competitive products. In effect, operational planning is applied when a crop is planted and short-term decisions related to cultivation are harvesting and distribution (Ahumada and Villalobos, 2009). However, the above articles have mainly focused on only single objective such as maximizing profits while the objectives are different in many real-world issues and programmers should consider them in some conflicting situations such as social, government issues, and water consumption, resulting in increasing the complexity of the decision on the agri-food supply chains (AFSC) problem (Ahumada and Villalobos, 2009).

This paper proposes a multi-objective integrated modelling approach for the tactical and operational planning in the production and distribution of perishable crops, aiming to follow two objectives in this way. The first objective of this research is the economic benefit of the whole chain and the second objective is the attention to social issues by considering labor employment. In this regard, tactical decisions include actions that need to be implemented at the beginning of the season, such as what to plant and when to plant it, and the operational decisions include when to harvest it and what potential target markets to distribute. Pepper and tomato are the products considered in this research. The reason for using tomatoes as a case study is that crops such as cucumbers and eggplants can be planned in the same way (Ahumada and Villalobos, 2011). Among the most important issues in short-term harvest, planning is managing workforce costs, maintaining product value, and using transportation methods, in order to find the best time to obtain market (product quality) and cost. For example, a consumer demands a special quality at the time of the production of fresh crops. This research has attempted to consider the integration of the planting and harvesting decisions and the crop's harvest pattern, in order to improve the level of decision-making and optimize the level of profitability.

The remainder of this paper is organized as follows. Section 2 considers literature review, Section 3 describes problem assumptions and mathematical model, Section 4 introduces the proposed solution method, Section 5 represents the computational results, and the discussion and conclusions are presented in Section 6 and 7, respectively.

2. Literature review

Nowadays, due to its special features such as climate change, demand-supply importance, food quality importance, and price variations, AFSC is of great importance. Three reviewing papers, i.e. (Ahumada and Villalobos, 2009), (Glen, 1987), and (Lowe and Preckel, 2004), assist us to get acquainted with AFSC. The research (Glen, 1987) has classified and listed the studies conducted on animal and agricultural product supply chains and their modeling methods. The research (Lowe and Preckel, 2004) complements (Glen, 1987) on the categorization of the studies on agricultural-commercial products supply chains carried out by 2004. They have mentioned to the fields of future study, the need to regard uncertain parameters, as well as the significance of the short shelf life nature of products with regard to long production time in their study. In (Ahumada and Villalobos, 2009), ASC applications and its modeling approach in various studies are thoroughly evaluated and reviewed. Also, the studies carried out in this field have been classified from different perspectives. They differentiated the works concentrated on perishable products and those concentrated on non-perishable items in terms of product storage. In terms of decision level, they categorized the conducted studies into three categories of operational, tactical, and strategic. In terms of parameter nature perspective, they classified the works into two categories: probable and certain ones. Given the modeling method, some studies are classified into dynamic planning and linear planning (LP), whilst probable studies are classified into dynamic probabilistic planning and probabilistic planning.

In (Caixeta-Filho, 2006), an LP model is suggested to manage orange gardens to maximize the sales. Given the deterioration of quality, they analyzed making a choice between delivering fresh oranges to customers (end users) or delivering lower-quality products to fruit juice manufacturers. In (Ferrer, et al., 2008), the grape harvesting operation planning has been investigated by taking into account the costs associated with harvesting, quality loss due to delayed harvesting, and processing costs. In (Bohle, et al., 2010), a complex integer-programming model has been developed to examine the impact of the fruit's quality at the harvesting time.

Various studies, including (Sornprom, et al., 2019), (Graf Plessen, 2019), have examined harvesting and cultivation considerations. In (Ahumada and Rene Villalobos, 2011), cultivation has been examined in terms of the considerations for space limitations as well as decision-making details about the allocation of spaces for cultivation of crops. The present study has not taken harvesting into consideration, which is positively correlated with crops cultivation and real-world considerations at harvesting time influencing the harvested amounts. The reference (Jonkman, et al., 2018) adopted an identical approach to the direct relationship between harvesting and cultivation. In (Ahumada and Villalobos, 2011), the harvesting schedule pattern and considerations have been taken into account more precisely (e.g., daily or every other day basis) by assuming an already scheduled cultivation. This pattern of harvesting is a parameter affecting the product flow to the next stage within the chain (namely, packing facilities). Provided that harvesting and cultivation considerations are taken into account simultaneously and comprehensively, the model will certainly manage to present more realistic decisions.

The studies mentioned above seek only a single objective (e.g., profit maximization), whereas the organizers of most real-world problems seek differently and sometimes opposing objectives (e.g., public, social, and water consumption problems) (Abedinpour, et al., 2019). This leads the AFSC decisions to become more complicated (Liu, et al., 2017), (Yousefi, et al., 2017). In (Sarker and Ray, 2017), a multi-objective mathematical model has been developed to minimize investment and maximize production. This model considers the limitations including the number of imports and the budget available. There existed some limitations in (Hu, et al., 2015) including meeting demands and the consumption of water resources available. The study was conducted in Qijiang River in Southwestern China. Besides the criteria taken into account by preceding authors for their objectives, (Adeyemo and Otieno, 2010) described the workforce employment limitations. To solve their model, they considered product diversity and used the MDEA (multi-objective differential evolution algorithm) in South Africa. To overcome their problem, (Zhang and Guo, 2017) made use of their presented technique (namely, two-stage stochastic chance-constrained fractional programming (TSCFP)) by building on previous studies and including the existing uncertainties in the model as probabilities. Their study was conducted in Linze County located in Gansu province, Northwestern China. Table 1 summarizes the literature review of previous research efforts in AFSC.

Table 1. Literature review

Researches	*Decision Levels*			*Context of objective function*				*Context of constraints*				*Model*		*Modeling approach*
	S	*T*	*O*	*CP*	*HP*	*HR*	*PD*	*TW*	*YP*	*IC*	*SR*	*SO*	*MO*	
(Bohle, et al., 2010)	✓					✓		✓				✓		*SP*
(Ahumada & Rene Villalobos, 2011)		✓		✓		✓	✓	✓	✓	✓		✓		*ILP*
(Ahumada & Villalobos, 2011)			✓		✓	✓	✓	✓	✓	✓		✓		*ILP*
(Ahumada, et al., 2012)		✓		✓		✓	✓	✓	✓			✓		*SP*
(Boyabatlı, 2015)							✓						✓	*MM*
(Noparumpa & Kazaz, 2015)							✓						✓	*MM*
(González-Araya, et al., 2015)		✓	✓			✓						✓		*ILP*
(Nadal-Roig & Plà-Aragonés, 2015)			✓				✓					✓		*ILP*
(Babaee Tirkolaee, et al., 2019)	✓									✓			✓	*MOMILP*
(Babaee Tirkolaee, et al., 2019)	✓	✓								✓			✓	*MILP*
(Babaee Tirkolaee, et al., 2019)			✓							✓			✓	MOMILP
(Goli, et al., 2019)	✓						✓			✓	✓		✓	*PP*
This Work		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	*MOLP*

Note: S=Strategic, T=Tactical, O=Operational, CP=Cultivating Planning, HP=Harvest Planning, HR=Harvest Resource Allocation, PD=Planning and Distribution, TW=Time Window, YP=Yield Perishability, IC=Inventory Control, SR= Social Responsibility, SO=Single Objective, MO=Multi Objective, SP=Stochastic Planning, MM=Mathematic Model, ILP=Integer Linear Planning, MOLP=Multi Objective Linear Planning, MOMILP=Multi-Objective Mixed-Integer Linear Programming, MILP= Mixed-Integer Linear Programming, PP=Possibilistic Programming

In this research, several considerations were addressed to develop a comprehensive model for planting and harvesting planning. Furthermore, the modeling approach was associated with the augmented ε -constraint method to explain the multi-objective AFSC planning problem. This method can produce unsupported efficient solutions without scaling the objective functions. For a detailed study on ε-constraint and its advantages over other methods, the interested reader is referred (Mavrotas, 2009).

In summary, review of the literature suggests that, it is necessary to develop a comprehensive model which is taking into account harvest pattern in integrated tactical-operational AFSC model. Furthermore, we can conclude that, there is a need to develop socially responsible AFSC.

By addressing these gaps, the present study contributes to the related body of knowledge mainly in three ways as follows:

1. Considering a tactical and operational model for integrated planting planning along with a harvest pattern
2. Applying a bi-objective model, by considering the whole chain profit and social responsibility (use of workforce)
3. Solving the bi-objective model with augmented ε -constraint method

3. Problem Definition

Producers are an important part of the fresh crops supply chain in the fresh production industry. There is a difference between operational planning and tactical planning in terms of harvesting and distributing perishable goods. That is, when tactical planning is employed, decision managers exert more control on the chain circumstances in the medium term. However, when operational planning is employed, farmers obtain quite more comprehensive information on market conditions and products compared to when tactical planning is employed (Liu, et al., 2017). Figure 1 shows some factors that influence operational planning. According to the figure there are two types of external and physical inputs that directly affect the operating model. External inputs include yield, market price and lot acceptance, and physical inputs include Distribution, Postharvest Decay and Loss Function and Operational Model include Daily Harvest, Distribution and Customer. Weather also affects external input and physical input, and tactical decisions directly affect the operational model. Given both types of decision-making, this article attempts to integrate the supply chain of fresh produce.

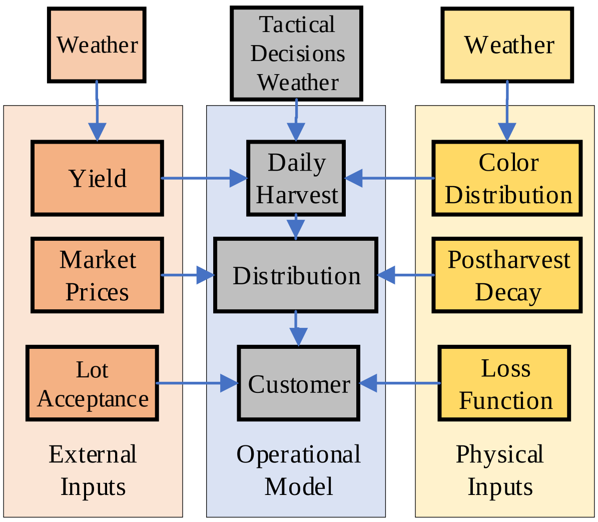

Figure 1. Planning problem diagram (Ahumada & Villalobos, 2011)

To enhance the decision-making process in AFSC problems, the proposed planning model should consider both harvesting and cultivation conditions and considerations, as well as the factors affecting the product quality after they are harvested. Product quality depends on transportation time and type and the product distribution process within the chain. As the time passes, the product freshness and quality decreases, imposing product deterioration costs on the chain. Hence, the selection of an appropriate procedure and transportation mode seems necessary with regard to the costs and time considerations. Therefore, the proposed model includes road, railway, and air transportation modes, with the latter being the most expensive, but shorter length in time compared to other transportation modes. Fig. 2 provides a schematic overview of the conventional supply chain for fresh products, which is used to develop a planning model. Nevertheless, the details may vary from country to country; for example, products can be sold by contract (sold before preparation) or in the open market in the products supply chain. The final destination of the products is another issue that needs to be considered in the operational planning model, as consumers are more sensitive to their needs. Tomato can be mentioned as an example of such products. Different types of tomatoes such as mature green and vine ripe tomatoes are usually supplied to fast-food restaurants and retailers' markets, respectively. Mature green tomatoes are harvested before coming to maturity (almost every two weeks) and they are ripened just before shipment. However, vine ripe types are harvested at the breaker stage, which require 2–3 harvests/week. Thus, producers should compare market demand with their price and operational constraints. Totally, many issues should be considered in planning models. Table 2 presents the harvesting plans, which may take several weeks, therefore, the proposed model can be considered as a monthly or seasonal-time horizon one.

Table 2. Patterns for harvesting a crop

Pattern	Days						
	1	2	3	4	5	6	7
I	1	1	1	1	1	1	1
II	1	0	1	0	1	0	1
III	1	0	0	1	0	0	1
IV	1	0	0	0	1	0	0
V	1	0	0	0	0	1	0

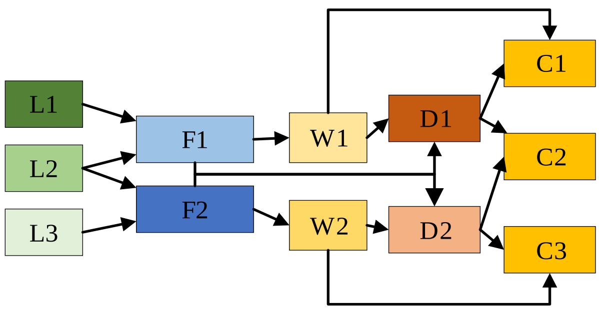

Figure 2. Supply chain of fresh horticultural crops

3.1. Problem Assumptions

The producers of fresh products have several decisions about production and planting, in which planting decisions include selecting the best types of products, choosing the whole area for planting each type of crop, and the time of planting these selected crops. These decisions are largely based on demand forecasts and prices expected in the coming season. The main activities in the production planning begin with the planting of crops and continue with the cultivation and the harvesting activities.

In this paper, it was assumed that strategic decisions such as logistics design have already been taken to develop the model, meaning that when the tactical-operational model is applied, the decision-maker has complete information about the deployed locations and the existing transportation procedures. It is also assumed that demand is in two forms of free market and end market.

3.2. Investigated Model

This section examines the model and defines the indicators, parameters, and variables as follows:

3.2.1. Sets

L	Set of land available for planting ($l \in L$)
T	Set of planning periods (days) ($t \in T$)
J	Set of different crops ($j \in J$)
TP	Set of feasible planting days for crop j in location l ($p \in TP(j,l) \subseteq T$)
TH	Set of feasible harvesting days for crop j in location l ($h \in TH(j,l) \subseteq T$)
Q	Set of quality of products (color) ($q \in Q$)
V	Set of harvesting patterns for crop j ($v \in V(j)$)
K	Set of products of crop j (package, grade) ($k \in K(j)$)
PF	Set of packaging facilities ($f \in PF$)
I	Set of consumers ($i \in I$)
D	Set of distribution centers ($d \in D$)
W	Set of warehouses available for storage ($w \in W$)
TM	Set of transportation mode ($r \in TM$)
Z	Set of objective function ($z \in Z$)

3.2.2. Parameters

AP_l	land available at location *l* (in hectares)
EH_{hlv}	expected harvest at period *h* of plot *l* harvested by pattern *v* (boxes).
VQ_{vjq}	percentage of crop *j* with quality *q* in by pattern *v*
LRH_j	boxes of crop *j* harvested per hour
LAH_h	labor available for harvesting in period *h* (h)
SH_{hv}	if pattern *v* is requires to harvest in period *h*
MOP	extra men-hours available from day laborers
LBH_j	labor hours required to cover one hectare of crop *j*
$Cplant_{jl}$	cost per hectare of production for crop *j* planted in location *l*

$Water_j$	water required per acre of crop *j* in cubic meters (in cubic meters)
Min_j	minimum amount to plant of crop *j* (in hectares)
Max_j	maximum amount to plant of crop *j* (in hectares)
$Clabor$	cost of an hour of labor at the field
VG_{hlk}	percentage of product *k* from plot *l* at period *h*
VS_{hj}	percentage of the crop *j* that is salvaged at period *h* (fraction)
KP_f	capacity of plant *f* (boxes per period)
CK_k	cost of packing a box of product *k*
CH_j	cost of harvesting a box of crop *j*
CSP	cost of transportation a box of crop from location to facility
PS_j	salvage price of crop *j*
CF_j	fixed cost per box of crop *j*
Ti_{fir}	time from packing facility *f* to consumer *i* by transportation mode *r*
$TiPD_{fdr}$	time from packing facility *f* to DC *d* by transportation mode *r*
$TiPW_{fwr}$	time from packing facility *f* to warehouse *w* by transportation mode *r*
CT_{fir}	cost of transportation from facility *f* to consumer *i* by mode *r*
$CTPD_{fdr}$	cost of transportation from facility *f* to DC *d* by mode *r*
$CTPW_{fwr}$	cost from packing facility *f* to warehouse *w* by mode *r*
TiD_{dir}	time from DC *d* to consumer *i* by transportation mode *r*
TiW_{wir}	time from warehouse *w* to consumer *i* by transportation mode *r*
$TiWD_{wdr}$	time from warehouse *w* to DC *d* by transportation mode *r*
CTD_{dir}	cost of transportation from DC *d* to consumer *i* by mode *r*
CTW_{wir}	cost of transportation from warehouse *w* to consumer *i* by mode *r*
$CTWD_{wdr}$	cost of transportation from warehouse *w* to DC *d* by mode *r*
CID_{kd}	cost of inventory at DC *d* per pallet of product *k* (pallet/day)
CI_{kw}	cost of inventory at warehouse *w* per pallet of product *k* (pallet/day)
PN_{tk}	price per product *k* on period *t* in the open market
DM_{tk}	expected demand (open market) of product *k* in period *t*
DW_{tki}	expected demand from consumer *i* of product *k* in time *t*
SL_{kq}	shelf life of product *k* with quality *q*

PC_{tki}	price per product *k* on period *t* sold to consumer *i*
$PROB_{nkq}$	estimate of the probability that the product *k* with color *q* is not accepted by consumers based in the time elapsed (*n*=*t*-*h*)
COL_{nkq}	expected color product *k* with initial color *q* after *n* days of harvest (*n*=*t*-*h*)
KTC	capacity of container in pallets
KTW	capacity of container in weight
RW_k	amount of crop weight per box of product *k*
RC_k	number of boxes of product *k* in a pallet
$Totinvest$	Investment quantity available (dollars)
$Totwater$	Water restriction (in cubic meters)

3.2.3. Decisions variables

$Plant_{pjl}$	area to plant of crop *j* in period *p* at location *l* (in hectares)
AP_{lj}	total area planted in plot *l* (ha) for crop *j*
X_{lvj}	area of plot *l* harvested using pattern *v* for crop *j*
QH_{hlqj}	harvest (boxes) of quality *q* from plot *l* in period *h* for crop *j*
OPL_h	operator hours hired in the field at time *h*
Y_{jpl}	1 if crop *j* is planted at period *p* at location *l*, otherwise ۰
SP_{hlqjf}	quantity of crop *j* with quality *q* to ship from plot *l* to facility *f* in period *h*
QP_{hkqf}	quantity of product *k* with quality *q* packed at facility *f* in period *h*
QS_{hj}	quantity salvaged of crop *j* in harvesting period *h*
SC_{tkqfir}	product *k* of quality *q* shipped from facility *f* to consumer *i* in period *t* by mode *r*
$SPD_{htkqfdr}$	product *k* of quality *q* harvested at *h* shipped from facility *f* to DC *d* in period *t* by mode *r*
$SPW_{htkqfwr}$	product *k* of quality *q* harvested at *h* shipped from facility *f* to warehouse *w* in period *t* by mode *r*
$Invd_{htkqd}$	inventory of product *k* at period *t* with quality *q* in DC *d* harvested at *h*
$Invw_{htkqw}$	inventory of product *k* at period *t* with quality *q* in warehouse *w* harvested at *h*
$SD_{htkqdir}$	product *k* of quality *q* harvested at *h* shipped from DC *d* to consumer *i* in period *t* by mode *r*
$SWD_{htkqwdr}$	product *k* of quality *q* harvested at *h* shipped from warehouse *w* to DC *d* in period *t* by mode *r*

$SW_{htkqwir}$	product *k* of quality *q* harvested at *h* shipped from warehouse *w* to consumer *i* in period *t* by mode *r*
SWO_{htkqw}	product *k* with quality *q* harvested at *h* sold from warehouse *w* in period *t*
Z_{tkw}	quantity to purchase of product *k*, in period *t* for warehouse *w*
NTI_{tfir}	number of containers sent to consumer *i* from facility *f* in period *t* by mode *r*
NTD_{tdir}	number of containers sent to consumer *i* from DC *d* in period *t* by mode *r*
NTW_{twir}	number of containers to consumer *i* from warehouse *w* in period *t* by mode *r*
NTP_{tfwr}	number of trucks sent from facility *f* to warehouse *w* in period *t* by mode *r*
NTK_{tfdr}	number of containers sent to DC *d* from facility *f* in time *t* by mode *r*
NTC_{twdr}	number of containers sent to DC *d* from warehouse *w* in time *t* by mode *r*

$$\begin{aligned}
Max\ Z_1 = &\sum_{t,k,i} PC_{tki}\left(\sum_{h,q,f,r} SC_{htkqfir} + \sum_{t-SL_{kq}\le h\le t,q,w,r} SW_{htkqwir} + \sum_{t-SL_{kq}\le h\le t,q,d,r} SD_{htkqdir}\right) \\
&+ \sum_{t,k} PN_{tk}\left(\sum_{t-SL_{kq}\le h\le t,k,q,w} SWO_{htkqw}\right) + \sum_{j,h} PS_j QS_{hj} - \sum_{k,h,q,f} CK_k QP_{hkqf} \\
&- \sum_{j,h,l,q} (CH_j + CF_j) QH_{hlqj} - \sum_{j,p,l} Cplant_{jl} Plant_{pjl} \\
&- \sum_{l,v,j,h} Clabor\left(X_{lvjh} * SH_{hv} * LBH_j\right) - \sum_{h} ClaborOPL_h - \sum_{j,h,l,q,f} SP_{hlqjf} CSP \\
&- \sum_{h,f} PF_{hf} Clabor - \sum_{f,t,i,r} NTI_{tfir} CT_{fir} - \sum_{f,t,d,r} NTK_{tfdr} CTPD_{fdr} \\
&- \sum_{h,f,t,k,q,w,r} NTP_{tfwr} CTPW_{fwr} - \sum_{t,d,i,r} CTD_{dir} NTD_{tdir} - \sum_{t,w,i,r} CTW_{wir} NTW_{twir} \\
&- \sum_{t,w,d,r} CTWD_{wdr} NTC_{twdr} - \sum_{htkqd} CID_{kd} Invd_{htkqd} - \sum_{h,t,k,q,w} CI_{kw} Invw_{htkqw} \\
&- \sum_{twk} PN_{tk} Z_{tkw} \\
&- \sum_{t,k,i} PC_{tki}\left(\sum_{h,q,f,r} SC_{htkqfir} * PROB_{tkq} + \sum_{t-SL_{kq}\le h\le t,q,w,r} SW_{htkqwir} * PROB_{tkq}\right. \\
&\left. + \sum_{t-SL_{kq}\le h\le t,q,d,r} SD_{htkqdir} * PROB_{tkq}\right) \\
&- \sum_{t,k,i} PC_{tki}\left(\sum_{h,q,f,r} SC_{htkqfir} * COL_{tkq} + \sum_{t-SL_{kq}\le h\le t,q,w,r} SW_{htkqwir} * COL_{tkq}\right. \\
&\left. + \sum_{t-SL_{kq}\le h\le t,q,d,r} SD_{htkqdir} * COL_{tkq}\right)/8 \\
&- \sum_{t,k} PN_{tk}\left(\sum_{t-SL_{kq}\le h\le t,k,q,w} SWO_{htkqw} * PROB_{tkq}\right) \\
&- \sum_{t,k} PN_{tk}\left(\sum_{t-SL_{kq}\le h\le t,k,q,w} SWO_{htkqw} * COL_{tkq}\right)/8
\end{aligned} \tag{1}$$

$$Max\ Z_2 = \sum_{j,p,l} Cplant_{jl} Plant_{pjl} + \sum_{l,v,j,h} Clabor\left(X_{lvjh} * SH_{hv} * LBH_j\right) + \sum_{h} ClaborOPL_h \tag{2}$$

$$\sum_{p\in TP, j\in J} Plant_{pjl} \le AP_l \qquad \forall l \tag{3}$$

$$\sum_{j,p,l} Cplant_{jl} Plant_{pjl} \le Totinvest \tag{4}$$

$$\sum_{j,p,l} Water_j Plant_{pjl} \le Totwater \tag{5}$$

$$\sum_{p} Plant_{pjl} = \sum_{v,h} X_{lvjh} \quad \forall j, h \tag{6}$$

$$QH_{hlqj} = \sum_{v} X_{lvjh} EH_{hlv} VQ_{vjq} \quad \forall h, l, q, j \tag{7}$$

$$\sum_{l,j,q,v} \left(QH_{hlqj}/LRH_j + X_{lvjh} SH_{hv} LBH_j\right) \leq LAH_h + OPL_h \quad \forall h \tag{8}$$

$$\sum_{l,j} MenP_j Plant_{pjl} = OPL_p \quad \forall p \tag{9}$$

$$QH_{hlqj} = \sum_{f} SP_{hlqjf} \quad \forall h,l,q,j \tag{10}$$

$$QP_{hkqf} = \sum_{j,l} VG_{hlkj}\, SP_{hlqjf} \quad \forall h,k,q,f \tag{11}$$

$$QS_{hj} = \sum_{l,v} X_{lvj} EH_{hlv} VS_{hj} \quad \forall h,j \tag{12}$$

$$\sum_{k,q} QP_{hkqf} \leq KP_f \quad \forall f,h \tag{13}$$

$$\sum_{t_1,i,r} SC_{ht_1kqfir} + \sum_{t_2,d,r} SPD_{ht_2kqfdr} + \sum_{t_3,w,r} SPW_{ht_3kqfwr} = QP_{hkqf} \quad \forall h,k,q,f$$
$$t_1 = h + Ti_{fir}$$
$$t_2 = h + TiPD_{fdr} \tag{14}$$
$$t_3 = h + TiPW_{fwr}$$

$$Invw_{htkqw} = Invw_{h(t-1)kqw} + \sum_{f,r} SPW_{htkqfwr} - SWO_{htkqw} - \sum_{i,r} SW_{ht_5kqwir} - \sum_{d,r} SWD_{ht_6kqwdr} + Z_{tkw}$$
$$\forall t \geq h,k,w,q \tag{15}$$
$$t_5 = t + TiW_{wir}$$
$$t_6 = t + TiWD_{wdr}$$

$$Invd_{htkqd} = Invd_{h(t-1)kqd} + \sum_{f,r} SPD_{htkqfdr} + \sum_{w,r} SWD_{htkqwdr} - \sum_{i,r} SD_{ht_4kqdir}$$
$$\forall t \geq h,k,d,q \tag{16}$$
$$t_4 = t + TiD_{dir}$$

$$\sum_{h,f,r} SC_{htkqfir} + \sum_{h,w,r} SW_{htkqwir} + \sum_{h,d,r} SD_{htkqdir} \leq DW_{kit}$$
$$\forall t,k,i \tag{17}$$
$$t - SL_{kq} \leq h \leq t$$

$$\sum_{h,w,q,t} SWO_{htkqw} \leq DM_{tk} \tag{18}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SC_{htkqfir}}{KTW}\right\rceil, \left\lceil\frac{RC_k SC_{htkqfir}}{KTC}\right\rceil\right\} = NTI_{tfir} \quad \forall t,f,i,r \tag{19}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SD_{htkqdir}}{KTW}\right\rceil, \left\lceil\frac{RC_k SD_{htkqdir}}{KTC}\right\rceil\right\} = NTD_{tdir} \quad \forall t,d,i,r \tag{20}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SW_{htkqwir}}{KTW}\right\rceil, \left\lceil\frac{RC_k SW_{htkqwir}}{KTC}\right\rceil\right\} = NTW_{twir} \quad \forall t,w,i,r \tag{21}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SPW_{htkqfwr}}{KTW}\right\rceil, \left\lceil\frac{RC_k SPW_{htkqfwr}}{KTC}\right\rceil\right\} = NTP_{tfwr} \quad \forall t,f,w,r \tag{22}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SPD_{htkqfdr}}{KTW}\right\rceil, \left\lceil\frac{RC_k SPD_{htkqfdr}}{KTC}\right\rceil\right\} = NTK_{tfdr} \quad \forall t,f,d,r \tag{23}$$

$$\sum_{k} Max\left\{\left\lceil\frac{RW_k SWD_{htkqwdr}}{KTW}\right\rceil, \left\lceil\frac{RC_k SWD_{htkqwdr}}{KTC}\right\rceil\right\} = NTC_{twdr} \quad \forall t,w,d,r \tag{24}$$

The first objective function (1) is the maximization of total revenue of production and sale of the product to the consumers and the free market. In addition, the second objective function (2) expresses the maximization of workforce employment and social problems. Constraints (3), (4) and (5) to satisfy this issue which the resources of the model do not exceed the total availability of land, investment and water resources. The amount of crops to be harvested in constraint (6) is limited to the size of each area. Constraint (7) calculates the amount harvested (*QH*) which is calculated based on the plots harvested according to pattern *v*, the expected production (*EH*) and the expected color distribution of the crops (*VQ*). Constraint (8) represents the labor force required should not exceed total available and hired labor. In Equation (9), it limits the number of laborers employed. Constraint (10) balances the harvest and shipped crop j. The production quantity of product k with quality q packed at facility f in period h (QP_{hkqf}) is dependent on the pounds per crop required by each package and their percentage (*VG*) in (11). It should be noted that the products are formed by the combination of the type of crop , grade and color. Moreover, in (12) the salvaged crops (*QS*) depend on the amount harvested and the historical proportion of salvaged crops (*VS*). Equation (13) states capacity constraints in plant *f*. Flow balance constraint (14) ensures that the quantity packed product is transported from the packing-house directly to consumers (*SC*), to warehouses (*SPW*), or to DCs (*SPD*). Constraint (15) imposes the inventory balance at the warehouses. This constraint indicates that amount of products available at the warehouses can be calculated by the sales of the past period and the arrivals which can be contracted sales (*SW*) and open market sales (*SWO*) at the warehouses. Constraint (16) imposes the same condition at warehouses and DCs. In better word, the amount available at DC depends on products shipped from the packinghouse (*SPD*) and the warehouse (*SWD*) and the sales (*SD*) (17). The contracted sales (*SW*, *SD* and *SC*) are satisfied with products. In addition, they cannot surpass the maximum demand (*DM*) estimated for sales to open the market (18). Finally, constraints (19) – (24) make sure that the products sent between the facilities and to the consumers do not exceed the allowed capacity of the transport fleets in terms of weight and pallets of final products.

4. ε -constraint method

Multi-objective planning is a part of mathematical programming and consists of several contradictory objective functions (Ehrgott and Wiecek, 2005). In a multi-objective programming problem, we are faced with efficient or Pareto solutions, instead of the optimal points, due to the vastness of the answer space. In fact, X represents an efficient solution if and only if there is no solution such as $x' \neq x$ such that $f_k(x') \leq f_k(x)\ \forall k$. In other words, a point is efficient where an improvement in the value of one objective function leads to the deterioration of the performance of other objective functions (Mavrotas, 2009). Accordingly, the optimal Pareto solutions create the Pareto solution set, from which the decision-maker ultimately selects a solution according to its preferences. There are several approaches to multi-objective problems, which can be generally categorized into three categories of deductive, interactive, and inductive methods (Hwang and Masud, 2012). In the deductive method, the decision-maker preferences are determined before solving the problem and accordingly, a solution is given to the decision-maker, such as the weighted sum method (Mavrotas, 2009). In the second method (interactive), efficient solutions are produced and improved in an interactive process to obtain the satisfaction of the decision-maker (Chowdhury and Quaddus, 2015). However, the weakness of the interactive method is that only the decision-maker's preferred methods are created and other efficient solutions are ignored in this process, although they may be appropriate for the decision-maker. In the inductive method, an attempt has been made to create a good picture of the efficient solutions for the decision-maker. Then, the decision-maker selects his/her final solution by observing the efficient solution set, such as the ε -constraint method. Despite the wide use of the three above-mentioned approaches in multi-objective problems, the main problem in developing these methods is that approaches can only provide effective solutions while some approaches also present less-efficient solutions (Ehrgott and Wiecek, 2005).

The ε-constraint method, as one of the inductive methods, has been widely used by researchers. According to this method, the objective function with the highest priority is selected as the main objective function and the other objectives are transferred to the problem constraints such that a ε vector, as the right-hand side value of the objectives, is assigned to each of the objectives and effective solutions are created by changing the ε values (Sahebjamnia, et al., 2015).

$$\begin{aligned} &Min\ f_1(x) \\ &f_i(x) \leq \varepsilon_i \qquad \forall\, i = 1,2,\ldots,k \end{aligned} \tag{۲۵}$$

This method has two major weaknesses: 1) Optimized solutions are not necessarily efficient and less-efficient solutions are produced in some cases. 2) The range of objective function variation (calculating the best and the worst values of each of the objective functions) is not necessarily optimally efficient. In fact, the solutions obtained by solving each of the objective functions should be Pareto optimal solutions. In order to resolve the problems of the ε-constraint method, (Mavrotas, 2009) introduced the generalized ε-constraint method that generates only the optimally efficient solutions. The generalized ε-constraint method is as follows:

$$\begin{aligned} &Min\ f_1(x) - eps\left(\sum_{i=2}^{k} \frac{s_i}{r_i}\right) \\ &f_i(x) + s_i = e_i \qquad \forall\, i = 1,2,\ldots,k \end{aligned} \tag{۲۶}$$

where s_i represents a surplus variable related to functions in constraints, eps indicates a parameter varying between 10^{-3} and 10^{-6}, e_i shows the right-hand side value of each of the objective functions, and r_i parameter is the range of each of the objective functions, which is defined as $r_i = f_i^{NIS} - f_i^{pIS}$ (the difference between the worst and best values of the objective function). The above model ensures the efficiency of the solutions obtained by solving the problem such that the values of the surplus variables (s_i) in the objective functions are equal to zero (Ehrgott and Wiecek, 2005), resulting in eliminating the first problem of the ε-constraint method.

In addition, the lexicographic approach was used to find the ideal positive and ideal negative values and to ensure that the best and worst values of the objective functions calculated in the pay-off table were from the set of optimal solutions. In order to create a lexicography pay-off table, the first objective function with the highest priority is optimized at the first step and its solution value is determined as $f_1(x) = z_1^*$. Then, the second objective function is optimized by assuming a constant optimal value for the first objective function. In other words, when solving the second objective function, the constraint $f_1(x) = z_1^*$ is added to the problem constraints, in order to obtain the optimal value of the second objective function $f_2(x) = z_2^*$. Accordingly, the third objective function is optimized by adding the constraints $f_1(x) = z_1^*$ and $f_2(x) = z_2^*$. This process is repeated in the same way to optimize the last objective function. Thus, the first column of the pay-off table (p*p) is completed. In order to create the ith column of the Table, we first start by optimizing the ith column of the objective function, i.e. $f_i(x) = z_i^*$. Then, the first function is optimized by adding the constraint $f_i(x) = z_i^*$. This process is repeated for each of the columns to complete all cells in the Table. Finally, the best value and the upper efficient bound of the $i$the objective function are obtained from the best and worst values on the ith line of the Table (Mousazade, et al., 2018).

Regarding the above explanation, since the first objective function, i.e. the maximization of the profit, is the first priority of the crop supply chain, it is chosen as the main objective function and the second objective function, maximizing the use of workforce, is transferred to the constraints of the problem.

5. Computational results

To solve the model, CPLEX 12.6 on a Corei7 6GB RAM computer was used. The required information and data were obtained from (Ahumada and Villalobos, 2011). The presented statistics were from 2011 when the U.S. was analyzed with respect to harvesting and cultivation of agricultural crops. This research included four plots of which three were employed to grow tomatoes, and the last one was employed to grow peppers. The study problem was scheduled for an 18-month period. Tomatoes and peppers were considered as the cultivation products of the plan.

Based on Table 3 and Fig. 3, the Pareto solution obtained by ε-constraint is presented for the desired model. The results indicate that the objective functions are in conflict. Table 4 and Fig. 4 provide the analysis of the problem costs based on the Pareto output solution of the ε-constraint. As shown in Fig. 4, the overall process is ascending in the Pareto obtained from the total costs, although the total costs appear descending in ε 7, 11, and 17. Considering the costs table and Pareto table of the objective function, it is assumed that the decision-maker chooses ε 11, due to its relatively low total cost and high objective function. Now, we evaluate the harvest and harvest pattern for this selection. As presented in Table 5 and Fig. 5, each farm is represented by individual colors in proportion to the harvested patterns. We considered ten harvest patterns in this issue, including one pattern for every one days harvest pattern (v1), two patterns for every two days harvest patterns (v2, v3), three patterns for every three days harvest patterns (v4, v5, v6) and four patterns for every four days harvest patterns (v7, v8, v9, v10) according to Table 2. The obtained harvest pattern is reported in Table 5 and Figure ٥. As it cabs observed in the Figure, 46.4 hectares of T2 available land (53 hectares) are planted with pattern v4 and 6.6 hectares planted with pattern v10.

Table 3. Analysis of Pareto results

	z1	z2	CPU time (s)
ε_1	16083421	8184	52
ε_2	16072457	10194	51
ε_3	16062417	12204	50
ε_4	16052999	14214	51
ε_5	16050220	16224	52
ε_6	16050024	18234	50
ε_7	16066672	20244	53
ε_8	16042306	22254	53
ε_9	16030286	24264	52

ε_{10}	15981093	26274	54
ε_{11}	15960281	28284	52
ε_{12}	15903620	30294	51
ε_{13}	15838331	32304	55
ε_{14}	15748224	34314	53
ε_{15}	15649705	36324	54
ε_{16}	15560999	38334	47
ε_{17}	15457916	40344	46
ε_{18}	15369399	42354	48
ε_{19}	15293442	44364	48
ε_{20}	15202380	46374	47
ε_{21}	15091889	48384	41

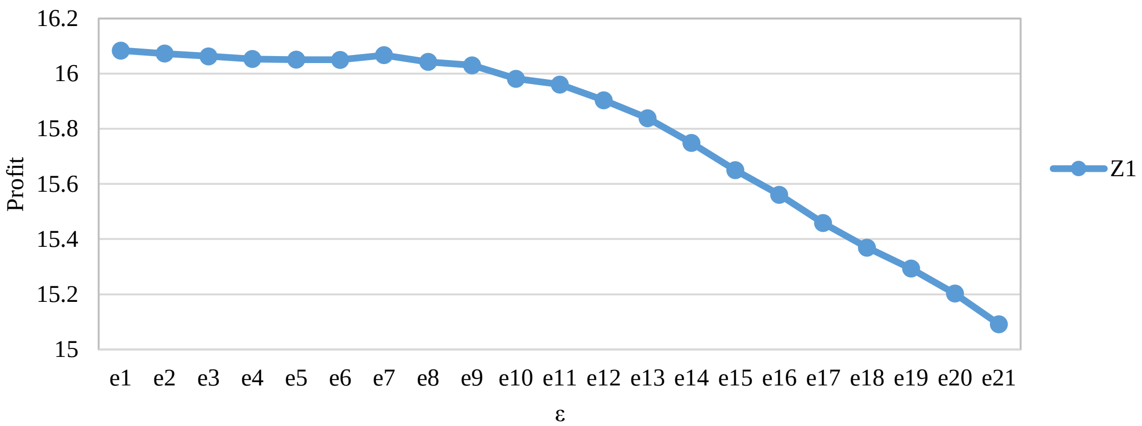

Figure 3. Illustration of the obtained profit in the case study

Table 4. The contribution of each cost component to the total supply chain cost according ε values

	ε	Harv. Cost	Inv. Cost	Lab. Cost	Tran. Cost	Total Cost
ε_1	8184	55761	28.951	20460	5320200	5396449.95
ε_2	10194	56245	27.712	25485	5328000	5409757.71
ε_3	12204	55761	50.833	30510	5331200	5417521.83
ε_4	14214	56245	43.753	35535	5336200	5428023.75
ε_5	16224	56245	11.269	40560	5336500	5433316.27

ε_6	18234	56245	29.699	45585	5331700	5433559.70
ε_7	20244	51931	80.572	50610	5296300	5398921.57
ε_8	22254	54599	12.405	55635	5327600	5437846.41
ε_9	24264	68783	21.752	60660	5335500	5464964.75
ε_{10}	26274	86090	85.83	65685	5340700	5492560.83
ε_{11}	28284	54727	63.924	70710	5295400	5420900.92
ε_{12}	30294	63978	155.28	75735	530600	670468.28
ε_{13}	32304	91080	151.1	80760	5335800	5507791.10
ε_{14}	34314	91080	150.87	85785	5335200	5512215.87
ε_{15}	36324	82271	130.95	90810	5328700	5501911.95
ε_{16}	38334	85333	124.74	95835	5331200	5512492.74
ε_{17}	40344	69078	102.2	100860	5315800	5485840.20
ε_{18}	42354	81010	105.07	105890	5330900	5517905.07
ε_{19}	44364	91080	152.38	110910	5334300	5536442.38
ε_{20}	46374	91080	174.38	115930	5332000	5539184.38
ε_{21}	48384	91080	127.64	120960	5361400	5573567.64

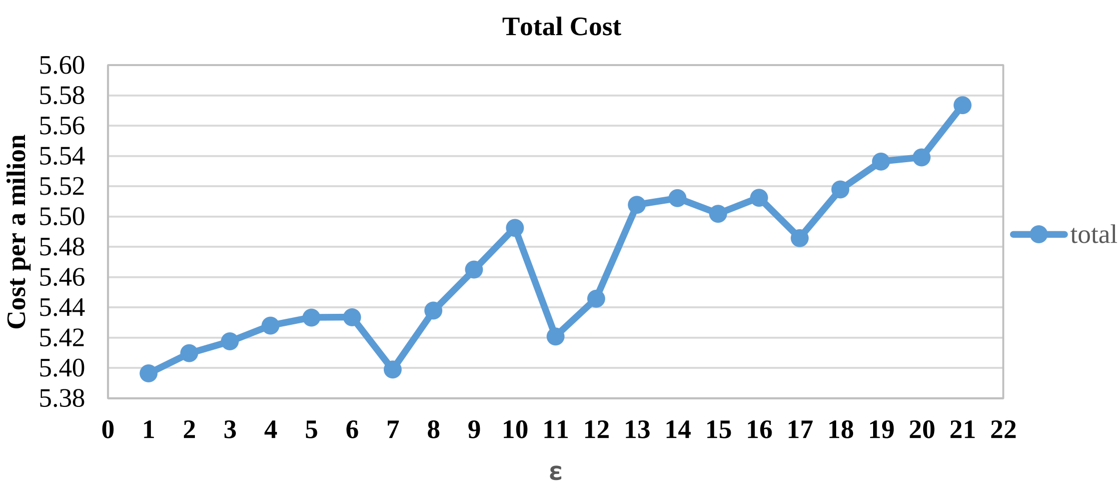

Figure 4. The effect of ε value on the total supply chain cost

Table 5. The final results of the harvest patterns

location	pattern	crop	Value
C2	v7	CA	21.86296
C2	v10	CA	0.137041
T1	v8	TA	66.40356
T1	v10	TA	59.86898
T1	v7	TA	7.72746
T2	v7	TA	46.36196
T2	v10	TA	6.63804
T3	v9	TA	62.75853
T3	v8	TA	22.24147
T4	v9	TA	47

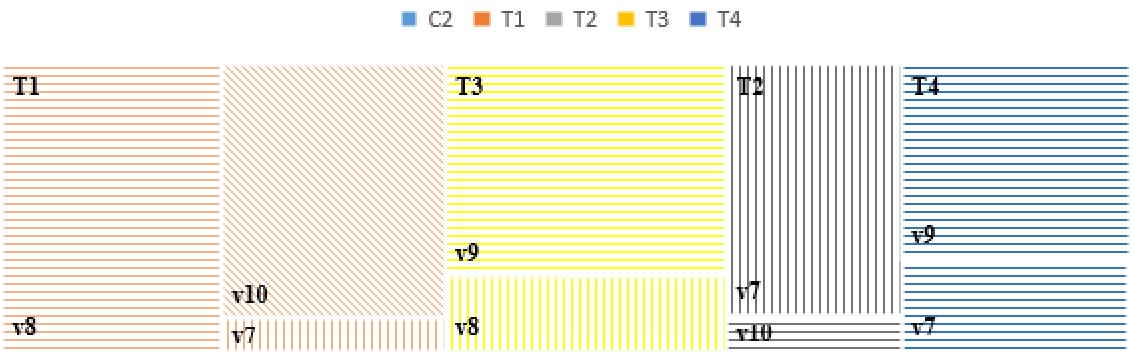

Figure 5. The final results of the harvest patterns (word "T" indicates land and word "v" indicates harvest pattern)

Figure 6 illustrates comparison between total weighting and ε-constraint method. In the weighted-sum method, the weight of the first objective function was considered from 0.95 to 0.05. As can be seen, obtained values of first objective is less than in the ε-constraint method in most cases.

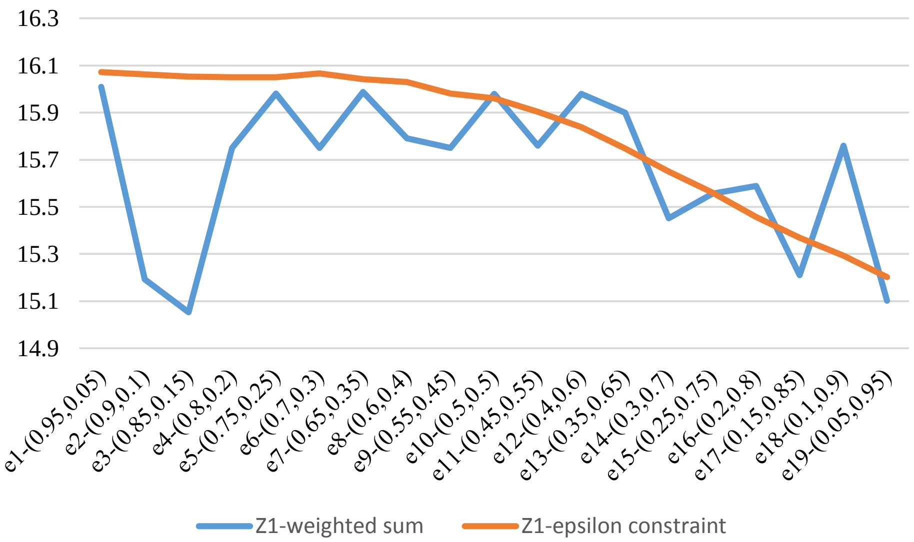

Figure 6. Comparison of ε-constraint method with weight-sum method

6. Discussion

The model presented in this study provides some managerial implications for supporting crop supply chain planners. In the first stage, the proposed model crop planning and harvest pattern is considered which can be mentioned as one of main issue in the field of agricultural planning. The Pareto frontier of proposed multi-objective model can be fund within a very acceptable time range for the real case-study problem. Moreover, this model is implemented for tomato and pepper product in five specific areas, and the results obtained are unique in this regard. Other management results may be obtained if agricultural products (and product life) and cultivation area are changed.

7. Conclusion

In this study considered fresh agriculture supply chain problem aiming to maximize the income and workforce employment. The main contributions of this study are the development of a multi-objective model for tactical and operational planning for integrated planting planning along with a harvest pattern and considering social responsibility (use of workforce) objective. The optimal planting and harvesting areas were obtained and the related supply chain structure was configured by solving the model for the real problem, which was the planning of two types of tomatoes and one type of pepper. Given the bi-objective nature of the problem, the model Pareto frontier was obtained by using the ε -constraint method. The results indicated that most of the cost volume of planning at the tactical and operational levels is related to inter-chain transport, followed by harvesting pattern, which had a significant cost dimension.

Finally, future research could explore the effect of uncertainty arises in real-world information and decision-making environment. In addition, the routing of transport fleets and export issues can be included in the model to bring it closer to the real world.

References

Abedinpour, A. A., Jabbarzadeh, A., and Yahyaei, M., (2019). *An integrated model of agricultural production planning with regard to harvest patterns.* babolsar, International Conference of Iranian Operations Research Society.

Abedinpour, A., Jabbarzadeh, A., and Yahyaei, M., (2019)."A multi-objective mathematical modeling for optimization of crop planning problem under Z-number uncertainty", *J. Water Soil Conserv.*, Vol. 25, No. 5, pp. 1-24.

Adeyemo, J., and Otieno, F., 2010. "Differential evolution algorithm for solving multi-objective crop planning model", *Agric. Water Manag.,* Vol. 97, No. 6, pp. 848-856.

Ahumada, O., and Rene Villalobos, J., (2011)."A tactical model for planning the production and distribution of fresh produce", *Annals of Operations Research,*Vol. 190, No. 1, pp. 339–358.

Ahumada, O., and Villalobos, J. R., (2009)."Application of planning models in the agri-food supply chain: A review", *European Journal of Operational Research,* Vol. 196, No. 1, pp. 1-20.

Ahumada, O., and Villalobos, J. R., (2011)."Operational model for planning the harvest and distribution of perishable agricultural products", *International Journal of Production Economics,* Vol. 133, No. 2, pp. 677–687.

Bohle, C., Maturana, S., and Vera, J., (2010)."A robust optimization approach to wine grape harvesting scheduling", *European Journal of Operational Research,* Vol. 200, No. 1, pp. 245-252.

Caixeta-Filho, J. V., (2006)."Orange harvesting scheduling management: a case study", *Journal Journal of the Operational Research Society,* Vol. 57, No. 6, pp. 637-642.

Chowdhury, M. M. H., and Quaddus, M. A., (2015)."A multiple objective optimization based QFD approach for efficient resilient strategies to mitigate supply chain vulnerabilities: The case of garment industry of Bangladesh", *Omega*, Volume 57, pp. 5-21.

Ehrgott, M., and Wiecek, M. M., (2005)."Multiobjective programming", In: *Multiple criteria decision analysis.* State of the art surveys: Springer, pp. 667-708.

Ferrer, J.-C.et al., (2008)."An optimization approach for scheduling wine grape harvest operations", *International Journal of Production Economics,* Vol. 112, No. 2, pp. 985-999.

Glen, J., (1987)."Mathematical models in farm planning: a survey", *Operations Research,* Vol. 35, No. 5, pp. 641– 666.

Graf Plessen, M., (2019)."Coupling of crop assignment and vehicle routing for harvest planning in agriculture", *Artificial Intelligence in Agriculture,* Volume 2, pp. 99-109.

Hu, Z. et al., (2015)."Integrating Equality and Stability to Resolve Water Allocation Issues with a Multiobjective Bilevel Programming Model", *Journal of Water Resources Planning and Management,* 142(7), pp. 1-12.

Hwang, C.-L., and Masud, A. S. M., (2012)."Multiple objective decision making", In: *methods and applications.* a state-of-the-art survey: Springer Science and Business Media.

Jonkman, J., Barbosa-Póvoa, A. P. and Bloemhof, J. M., (2018)."Integrating harvesting decisions in the design of agro-food supply chains", *European Journal of Operational Research,* Vol. 276, No. 1, pp. 247-258.

Liu, J., Li, Y., Huang, G., and X.W., Z., (2017)."Assessment of uncertainty effects on crop planning and irrigation water supply using a Monte Carlo simulation based dual-interval stochastic programming method", *Journal of Cleaner Production,* Vol. 149, pp. 945-967.

Lowe, T., and Preckel, P., (2004)."Decision technologies for agribusiness problems: a brief review of selected literature and a call for research", *Manufacturing and Service Operations Management,*Vol. 6, No. 3, pp. 201–208.

Mavrotas, G., (2009)."Effective implementation of the ε-constraint method in multi-objective mathematical programming problems", *Applied mathematics and computation,* Vol. 213, No. 2, pp. 455-465.

Mousazade, M., Torabi, S. A., Pishvaee, M., and Abolhassani, F., (2018). "Accessible, stable, and equitable health service network redesign: A robust mixed possibilistic-flexible approach", *Transportation Research Part E: Logistics and Transportation Review,* Vol.111, pp. 113-129.

Rafiei, H., Safaei, F., and Rabbani, M., (2018). "Integrated production-distribution planning problem in a competition-based four echelon supply chain", *Computers and Industrial Engineering,* Vol. 119, pp. 85-99.

Sahebjamnia, N., Torabi, S. A., and Mansouri, S. A., (2015). "Integrated business continuity and disaster recovery planning: Towards organizational resilience", *European Journal of Operational Research,* Vol. 242, pp. 261-273.

Sarker, R., and Ray, T., (2017). "An improved evolutionary algorithm for solving multi-objective crop planning models", *Computers and Electronics in Agriculture,* Vol. 68, No. 2, pp. 191-199.

Sornprom, T., Kachitvichyanukul, V., and Luong, H. T., (2019). "A Multi-objective Model for Integrated Planning of Selective Harvesting and Post-harvest Operations", *Environmental Sustainability in Asian Logistics and Supply Chains,* pp. 245-260.

Yousefi, H., Mohammadi, A., Noorollahi, Y., and Sadatinejad, S., (2017). "Water footprint evaluation of Tehran's crops and garden crops", *Journal of Soil and Water Conservation,*, Vol. 24, No. 6, pp. 67-85.

Zhang, C. L. M., and Guo, P., (2017). "Two-Stage Stochastic Chance- Constrained Fractional Programming Model for Optimal Agricultural Cultivation Scale in an Arid Area", *Journal of Irrigation and Drainage Engineering,* Vol. 143, No. 9, pp. 1-13.

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