A Bi-Objective Stochastic Mathematical Model for Agricultural Supply Chain Network

Mohammad Mahdi Paydar, Armin Cheraghalipour, Mostafa Hajiaghaei-Keshteli

***Abstract*—**Nowadays, in advanced countries, agriculture as one of the most significant sectors of the economy, plays an important role in its political and economic independence. Due to farmers' lack of information about products' demand and lack of proper planning for harvest time, annually the considerable amount of products is corrupted. Besides, in this paper, we attempt to improve these unfavorable conditions via designing an effective supply chain network that tries to minimize total costs of agricultural products along with minimizing shortage in demand points. To validate the proposed model, a stochastic optimization approach by using a branch and bound solver of the LINGO software is utilized. Furthermore, to accumulate the data of parameters, a case study in Mazandaran province placed in the north of Iran has been applied. Finally, using ε-constraint approach, a Pareto front is obtained and one of its Pareto solutions as best solution is selected. Then, related results of this solution are explained. Finally, conclusions and suggestions for the future research are presented.

***Keywords*—**Perishable products, stochastic optimization, agricultural supply chain, ε-constraint.

I. INTRODUCTION

THE supply chain of agricultural products has been widely paid attention in recent decades ([1]-[5] etc.). Ahumada and Villalobos [1] in a comprehensive research considered two main types of agricultural supply chains consisting of non-perishable agri-foods and fresh agri-foods supply chain and focused on fresh products in terms of shelf life, logistical complexity, and safety of products. The present study also analyses fresh agri-foods supply chain, which includes highly perishable crops such as fresh fruits and vegetables whose useful life can be measured in days. Coinciding with a previous study, Audsley and Sandars [3] developed a model in agriculture for British developments. Also, Mergenthaler et al. [6] investigated demand patterns of fresh fruits and vegetables in Vietnam. Moreover, several studies have applied mathematical modelling techniques to optimize fruit and vegetable supply chain performance indicators.

In particular, Rong et al. [7] provided a mixed-integer linear programming model used for production and distribution planning in a food supply chain. On the other hand, price variability in fruit and vegetable supply chain has not been thoroughly investigated.

Mohammad Mahdi Paydar is an assistant professor of industrial engineering, University of Babol Noshirvani University of Technology, Babol, Iran (e-mail: paydar@nit.ac.ir).

Armin Cheraghalipour is a master student and Mostafa Hajiaghaei-Keshteli is an assistant professor of industrial engineering, University of Science and Technology of Mazandaran, Behshahr, Iran (e-mail: a.cheraghalipour.ie@mazust.ac.ir, mostafahaji@mazust.ac.ir).

In another research, Teimoury et al. [8] considered a perishable supply chain for fruits and vegetables. They used a simulation based system dynamics approach to measure the interactions of some related parameters such as demand on the supply chain. Their paper provided the overall agricultural system with considering the influence of import quota policies. To achieve this propose, a multi-objective model is formulated that considered price mean, price variation, and mark-up. To verify the proposed framework, a case study related to the Tehran Municipality Organization of Fruits and Vegetables is applied. Their used analysis provides a set of non-dominated solutions to satisfy the multiple objectives simultaneously. The decision makers with the help of achieved Pareto fronts can develop an agile import policy with considering multiple objectives. This occurs because Pareto fronts provide a range of available alternatives and decision makers can analyze them to select the best approach.

Recently, a transportation planning model for a fruit SC, in which a fruit logistic center was supplied by several storing centers considering the demand during the non-harvesting season, is formulated by Nadal-Roig and Plà-Aragonés [9]. Also a model for the fresh fruit supply chain along with a brief review was presented by Soto-Silva et al. [10]. Borodin et al. [11] reviewed previous researches considering uncertainty in agriculture supply chain. They provided an overview of the latest advances and developments in use of OR methodologies for handling uncertainty occurring in the ASC problems. Etemadnia et al. [12] proposed an optimal wholesale facility location for fruit and vegetable supply chain by using bimodal transportation options and proposed a heuristic approach to obtaining results. As is clear, since the real world issues and decisions are often complex, hence they cannot be solved by the exact methods in a proper time and cost especially in high dimensional problems [13]. Thus, some research used approximation approaches instead of exact methods such as [12], [14].

Todays, providing needed food of the people as one of the basic problems in all over the world is considered and governments attempt to increase the quality of them. Agriculture as one of the main economic sectors of developing countries such as Iran is considered [2], [15]. The existence of many natural benefits and special geographic locations in Iran caused each point of it has one or more strategic product, so that other region cannot compete with them in terms of quality and performance, and by focusing on the production of these products in each region, agriculture can be boosted as it is economical for farmers. The potential of agricultural improvement in Iran is so significant that various exported agricultural products in 2010 have the value of more than 3.7 billion dollars. Also, the amount of total exported agricultural products of Iran was near 3.4 million tons in 2010. Meanwhile, exports of fruits and vegetables include 70% of these total agricultural product exports [8].

According to the above property, we find the high effect of imports and exports on Iran's agricultural market and governmental decision makers should notice these processes in fruit and vegetable supply chains. This not only leads to a smoothed and reasonable price for the final consumers, but also eventuates in supporting the domestic producers more extensively. Furthermore, so far, there is not a strong plan for harvest time with considering customers' demand, which it causes the destruction of a significant amount of products. Thus, this research tries to enhance this undesirable situation by developing an effective supply chain network. For this purpose, a bi-objective model with the aims of minimizing total costs along with minimizing shortage is formulated. To verify the offered framework, a stochastic optimization method by using the LINGO software is used. Also, in order to parameter setting, a case study in the north of Iran has been utilized. To solve the proposed model, the ε-constraint approach as a well-known exact method is used. Finally, based on experts' considerations, one solution among the Pareto front is selected as the best solution and its related variables are provided.

This paper is organized as follows. Section II represents the model formulation. Section III discusses the proposed solution approach. Section IV presents the quantitative validation and analyses the model by defining some scenarios for various conditions and providing a real world case study. Finally, Section V provides results and conclusion.

II. Model Formulation

Here, an efficient network for agriculture supply chain is developed that "f" farms product "i" products under "s" scenarios in "t" time period and transfer these products to "p" processing center. After sorting and packing these products in processing centers, these products transferred to "c" markets, the processing centers attempt to satisfy their demands via sending stored products in their warehouses. Also in this network, there are inventories in the processing centers. Also, we consider shortage as unsatisfied demand in market level. Moreover, the initial inventory of each level is considered equal to zero. The scheme of the proposed network is illustrated in Fig. 1.

Fig. 1 The scheme of proposed network

The related subscripts, parameters, and decision variables of the proposed mathematical model are presented as follows.

Subscripts:

$f=1,2,\ldots,F$	Index of farms
$p=1,2,\ldots,P$	Index of processing centers
$c=1,2,\ldots,C$	Index of markets
$i=1,2,\ldots,I$	Index of products
$t=1,2,\ldots,t',\ldots,T$	Index of time periods
$s=1,2,\ldots,S$	Index of scenarios

Parameters:

Fix_p	Fixed cost of opening processing center p
P_s	Probability of occurrence scenario s
M	A big positive number
TC_{fp}	Transportation cost of products from farm f to processing center p
TC'_{pc}	Transportation cost of products from processing center p to market c
HC^t_{ip}	Inventory holding cost of product i for processing center p in time period t
MC_{if}	Production cost of product i for farm f
MC'_{ip}	Packing and operation costs of product i for processing center p
φ^s_{if}	Maximum capacity of farm f for producing product i under scenario s
Dem^t_{ic}	Demand of market c for product i in period t
ψ_{ip}	Holding capacity of processing center p for product i in each period

Decision variables:

QFP^{st}_{ifp}	Amount of transferred product i from farm f to processing center p in period t under scenario s
QPM^{st}_{ipc}	Amount of transferred product i from processing center p to market c in period t under scenario s
X^t_p	Is equal with 1 if processing center p is opened in period t
Inv^{st}_{ip}	Inventory level of product i in processing center p in period t under scenario s
U^{st}_{ic}	Shortage (unsatisfied demand) of product i in market c in period t under scenario s

With the help of above property, the proposed bi-objective stochastic model can be formulated. Two objective functions of this model attempt to minimize total cost and minimize total customers shortages simultaneously.

Objective functions:

Min Costs= (1)

$$\sum_p\sum_t Fix_p\times X^t_p+\sum_s P_s\times(\sum_p\sum_t\sum_f\sum_i QFP^{st}_{ifp}\times TC_{fp}$$
$$+\sum_p\sum_t\sum_c\sum_i QPM^{st}_{ipc}\times TC'_{pc}+\sum_p\sum_t\sum_i Inv^{st}_{ip}\times HC^t_{ip}$$
$$+\sum_p\sum_t\sum_f\sum_i QFP^{st}_{ifp}\times MC_{if}+\sum_p\sum_t\sum_c\sum_i QPM^{st}_{ipc}\times MC'_{ip})$$

$$Min\ Shortage=\sum_s P_s \times \left(\sum_i \sum_c \sum_t U_{ic}^{st}\right) \quad (2)$$

Subject to:

$$\sum_p \sum_{t\in t'} QFP_{ifp}^{st} \le \varphi_{if}^{s} \qquad \forall i \in I, f \in F, s \in S \quad (3)$$

$$\sum_i \sum_s \sum_f QFP_{ifp}^{st} \le M \times X_p^t \qquad \forall p \in P, t \in t' \quad (4)$$

$$Inv_{ip}^{st-1} + \sum_f QFP_{ifp}^{st} = Inv_{ip}^{st} + \sum_c QPM_{ipc}^{st} \quad \forall i, P, s, t \quad (5)$$

$$Inv_{ip}^{st} \le \psi_{ip} \qquad \forall i \in I, p \in P, s \in S, t \in T \quad (6)$$

$$\sum_p QPM_{ipc}^{st} + U_{ic}^{st} = Dem_{ic}^{t} + U_{ic}^{st-1} \qquad \forall i, c, s, t \quad (7)$$

$$X_p^t \in \{0,1\} \quad \forall p \in P, t \in T \quad (8)$$

$$QFP_{ifp}^{st}, QPM_{ipc}^{st}, Inv_{ip}^{st}, U_{ic}^{st} \ge 0\ \&\ \text{int} \quad \forall i, f, p, c, s, t \quad (9)$$

The first objective function (1) minimizes the total cost which includes of fixed opening costs, transportation costs, holding cost of processing centers, production and processing cost. On the other hand, the second objective function (2) minimizes the total shortages. Constraint (3) ensures that amount of the produced products is more than equal to the quantity of products shipped from producers to processing centers. Constraint (4) expresses the fact the products may be shipped from a farm to processing center only if this processing center is opened in a potential location. Equation (5) ensures that each processing center's inventory level in each period is equal to previous period inventory level plus the quantity of products received from producers minus the quantity of products shipped to markets. Constraint (6) shows that processing center inventory in each period is less than or equal to holding capacity of processing center. Equation (7) shows the balance equation for the shortage. Finally, the binary and integer restrictions on the corresponding decision variables are shown in constraints (8) and (9).

III. Solution Approach

In this paper, we used an exact method called ε-constraint to solve the suggested mathematical model. The ε-constraint method is one of the efficient approaches in comparison with traditional weighting approaches to solve the multi-objective problems. This method was firstly presented in 1971 and a brief review of the ε-constraint method is presented here. More information on this method can be found in [16], [17]. The basic concept of ε-constraint method is optimizing one objective function as the main objective; while the other objectives are considered as model constraints. Obtained solutions create Pareto (a set of non-dominated) solutions. As a result, this method in the problem with minimization objectives is declared as below:

$$\begin{aligned} & Min\ f_1(x) \\ & subject\ to: \\ & f_2(x) \le e_2 \\ & f_3(x) \le e_3 \\ & \dots \\ & f_p(x) \le e_p \end{aligned}$$

where the vector of satisfaction levels is denoted by $\varepsilon_2, \varepsilon_3, \dots, \varepsilon_p$ which explain the maximum requirements on the constrained objectives. Also, *S* is the solution space, *p* is the number of competing objective functions, and *x* is the vector of decision variables. The purpose of this method is selecting proper values of *ε*, so that the feasibility of the problem can be ensured. Hence, the solutions are found by parametrical variations in satisfaction levels $\varepsilon_2, \varepsilon_3, \dots, \varepsilon_p$ in the right side of constraints. The normalized objective function is reformulated as (10) and (11) where *ri* is the range of objective function *i*:

$$Min\left(f_1(x) - \varepsilon \times \left(\frac{s_2}{r_2} + \frac{s_3}{r_3} + \dots + \frac{s_p}{r_p}\right)\right) \quad (10)$$

$$\begin{aligned} & subject\ to: \quad (11) \\ & f_2(x) + s_2 = e_2 \\ & f_3(x) + s_3 = e_3 \\ & \dots \\ & f_p(x) + s_p = e_p \end{aligned}$$

where by way of example (12) and (13) calculates r_2 and e_2. Here, *Ni'* is the number of grid points.

$$r_2 = f_2^{\max} - f_2^{\min} \quad (12)$$

$$e_2 = f_2^{\min} + \left(\frac{r_2}{n_2}\right) \times n_i' \qquad n_i' = 0,1,2,\dots,(N_i' - 1) \quad (13)$$

IV. Case Study

In this section, a case study in Mazandaran province placed in the north of Iran is provided. For this purpose, ten gardens in Sari, Babol, and Behshahr cities are selected that products three types of products include lemon, orange, and tangerine. These products transfer from gardens to three potential processing centers in Sari, Babol, and Behshahr and after processing and packing, final products shipped to four markets placed in Noor, Amol, Sari, and Ramsar cities. In this case, six time periods are considered that gardens just in three time periods can be harvested and processing centers satisfied markets demands via its saved inventories in other times. Moreover, three scenarios include good condition, middle condition, and bad condition are considered that amount of production and other parameters are related to these scenarios. In this paper, we consider one type of transportation vehicles for transferring products among these zones. Other parameters are presented in Tables I-III. Some of researches such as [18] used LINGO software to run the model, thus this problem is solved by the Lingo 09 software on a PC equipped with *4GB* RAM and *2.2 GHz* CPU.

TABLE I
THE VALUES OF SOME PARAMETERS

Parameter	p	i/s 1	i/s 2	i/s 3
ψ_{ip}	1	600	600	400
	2	400	500	400
	3	600	400	400
MC'_{ip}	1	100	150	120
	2	130	140	150
	3	100	110	120
Fix_p		20000000	18000000	19000000
P_s		0.35	0.4	0.25

TABLE II
THE VALUES OF SOME PARAMETERS

Parameter	i	c/p	t = 1	2	3	4	5	6
Dem^t_{ic}	1	1	40	45	47	50	50	45
		2	30	30	35	30	40	40
		3	50	55	60	50	50	45
		4	40	42	42	45	45	47
	2	1	50	55	60	70	75	65
		2	80	85	50	80	75	65
		3	70	65	90	82	85	80
		4	50	55	60	65	75	60
	3	1	80	85	75	70	80	90
		2	75	70	65	70	85	72
		3	50	60	60	65	75	62
		4	45	60	65	75	75	60
HC^t_{ip}	1	1	100	150	120	140	110	120
		2	130	140	150	125	140	150
		3	100	110	120	135	150	123
	2	1	100	150	120	140	110	120
		2	130	140	150	125	140	150
		3	100	110	120	135	150	123
	3	1	100	150	120	140	110	120
		2	130	140	150	125	140	150
		3	100	110	120	135	150	123
			c = 1	2	3	4		
TC'_{pc}		1	100	150	120	140		
		2	130	140	150	125		
		3	100	110	120	135		

After solving the problem using ε-constraint method, the Pareto front is achieved that the view of it is illustrated in Fig. 3 and Table IV. For this purpose, at first, we run the second objective function separately that the values F_2^{min}=349 and F_2^{max}=14938 are achieved. Also, we consider n=15 and ε=0.000001 to make Pareto front.

Fig. 2 Map of Mazandaran province of Iran

TABLE III
THE VALUES OF SOME PARAMETERS

s	i/p	f = 1	2	3	4	5	6	7	8	9	10
		φ^s_{if}									
1	1	170	170	180	160	170	155	160	180	170	163
	2	150	140	145	154	150	160	143	145	156	162
	3	162	145	140	140	170	150	160	165	160	156
2	1	80	80	90	70	80	65	70	90	80	73
	2	60	50	55	64	60	70	53	55	56	72
	3	72	55	50	50	80	60	70	75	70	66
3	1	60	60	70	50	60	45	50	70	60	53
	2	40	30	35	44	40	50	33	35	46	52
	3	52	35	30	30	60	40	50	55	50	46
		TC_{fp}									
	1	100	150	120	140	110	120	120	132	110	120
	2	130	140	150	125	140	150	110	120	115	125
	3	100	110	120	135	150	123	120	135	115	112
		MC_{if}									
	1	100	130	100	180	100	130	100	180	100	130
	2	150	140	110	150	150	140	110	150	150	140
	3	120	150	120	140	120	150	120	140	120	150

TABLE IV
THE OBTAINED PARETO FRONT ARCHIVE

Solution	Cost	Shortage
1	2.00E+07	446.26
2	1.97E+07	1321.6
3	1.95E+07	2294.2
4	1.93E+07	3266.8
5	1864756	4239.4
6	1517490	5212
7	1303754	6184.6
8	1134924	7157.2
9	979374	8129.8
10	830750	9102.4
11	684860	10075
12	541912	11047.6
13	3.99E+05	12020.2
14	262488	12992.8
15	129680	13965.4

Finally, based on obtained Pareto front, experts and managers select a fifth Pareto solution as a proper manner and the related results of this solution such as the opened processing centers along with their allocated quantities are presented in Table V.

TABLE V
THE OBTAINED RESULTS OF FIFTH PARETO SOLUTION

Variable	Value	Variable	Value	Variable	Value	Variable	Value	Variable	Value
UU(2,2,2,3)	50	UU(3,4,2,6)	199.75	QFP(2,10,2,3,1)	17	QPC(1,2,3,1,3)	60	QPC(3,2,2,1,1)	75
UU(2,2,2,4)	130	UU(3,4,3,3)	65	QFP(2,10,2,3,2)	35	QPC(1,2,3,2,1)	50	QPC(3,2,2,1,2)	70
UU(2,2,2,5)	205	UU(3,4,3,5)	75	QFP(3,1,1,1,4)	210	QPC(1,2,3,2,2)	55	QPC(3,2,2,1,3)	65
UU(2,2,2,6)	270	UU(3,4,3,6)	135	QFP(3,1,1,2,4)	280.25	QPC(1,2,3,2,3)	60	QPC(3,2,2,2,1)	75
UU(2,2,3,2)	40	QFP(1,1,1,1,4)	145	QFP(3,1,1,3,4)	487	QPC(1,2,3,3,1)	50	QPC(3,2,2,2,2)	70
UU(2,2,3,3)	90	QFP(1,1,1,2,4)	145	QFP(3,1,2,1,2)	162	QPC(1,2,3,3,2)	55	QPC(3,2,2,2,3)	58
UU(2,2,3,4)	170	QFP(1,1,1,3,4)	252	QFP(3,1,2,2,2)	72	QPC(1,2,4,1,1)	40	QPC(3,2,2,3,1)	75
UU(2,2,3,5)	245	QFP(1,1,2,1,3)	170	QFP(3,1,2,3,1)	52	QPC(1,2,4,1,2)	42	QPC(3,2,2,3,2)	70
UU(2,2,3,6)	310	QFP(1,1,2,2,3)	80	QFP(3,2,2,1,3)	145	QPC(1,2,4,1,3)	42	QPC(3,2,3,1,1)	50
UU(2,3,1,4)	82	QFP(1,1,2,3,1)	60	QFP(3,2,2,2,2)	55	QPC(1,2,4,2,1)	40	QPC(3,2,3,1,2)	60
UU(2,3,1,5)	167	QFP(1,3,2,1,2)	166	QFP(3,2,2,3,2)	35	QPC(1,2,4,2,2)	42	QPC(3,2,3,1,3)	60
UU(2,3,1,6)	247	QFP(1,3,2,1,3)	14	QFP(3,3,2,1,2)	20	QPC(1,2,4,2,3)	42	QPC(3,2,3,2,1)	50
UU(2,3,2,3)	90	QFP(1,3,2,2,1)	61	QFP(3,3,2,1,3)	120	QPC(1,2,4,3,1)	40	QPC(3,2,3,2,2)	60
UU(2,3,2,4)	172	QFP(1,3,2,2,2)	29	QFP(3,3,2,2,1)	50	QPC(1,2,4,3,2)	42	QPC(3,2,3,3,1)	50
UU(2,3,2,5)	257	QFP(1,3,2,3,2)	70	QFP(3,3,2,3,1)	30	QPC(1,2,4,3,3)	42	QPC(3,2,3,3,2)	60
UU(2,3,2,6)	337	QFP(1,5,2,2,3)	80	QFP(3,4,2,2,1)	50	QPC(2,1,1,1,4)	70	QPC(3,2,4,1,1)	45
UU(2,3,3,2)	65	QFP(1,5,2,3,2)	60	QFP(3,4,2,3,2)	30	QPC(2,1,1,2,4)	105	QPC(3,2,4,1,2)	60
UU(2,3,3,3)	155	QFP(1,6,2,1,2)	6	QFP(3,5,2,2,1)	80	QPC(2,1,1,3,4)	130	QPC(3,2,4,1,3)	65
UU(2,3,3,4)	237	QFP(1,6,2,2,1)	65	QFP(3,5,2,3,1)	60	QPC(2,2,1,1,1)	50	QPC(3,2,4,2,1)	45
UU(2,3,3,5)	322	QFP(1,6,2,3,2)	42	QFP(3,6,2,1,1)	27	QPC(2,2,1,1,2)	55	QPC(3,2,4,2,2)	60
UU(2,3,3,6)	402	QFP(1,6,2,3,3)	3	QFP(3,6,2,2,3)	60	QPC(2,2,1,1,3)	60	QPC(3,2,4,2,3)	65
UU(2,4,1,4)	65	QFP(1,7,2,1,1)	160	QFP(3,6,2,3,2)	40	QPC(2,2,1,2,1)	50	QPC(3,2,4,3,1)	45
UU(2,4,1,5)	140	QFP(1,7,2,2,2)	70	QFP(3,7,2,1,1)	67	QPC(2,2,1,2,2)	55	QPC(3,2,4,3,2)	60
UU(1,1,1,5)	50	UU(2,4,1,6)	200	QFP(1,7,2,3,1)	50	QFP(3,7,2,1,2)	93	QPC(2,2,1,2,3)	25
UU(1,1,1,6)	95	UU(2,4,2,4)	65	QFP(1,8,2,3,3)	11	QFP(3,7,2,2,2)	70	QPC(2,2,1,3,1)	50
UU(1,1,2,5)	50	UU(2,4,2,5)	140	QFP(1,9,2,2,1)	34	QFP(3,7,2,3,2)	50	QPC(2,2,1,3,2)	55
UU(1,1,2,6)	95	UU(2,4,2,6)	200	QFP(1,9,2,2,3)	24	QFP(3,8,2,2,2)	12	QPC(2,2,2,1,1)	80
UU(1,1,3,3)	47	UU(2,4,3,3)	60	QFP(1,9,2,3,1)	50	QFP(3,8,2,2,3)	63	QPC(2,2,2,1,2)	85
UU(1,1,3,5)	50	UU(2,4,3,4)	125	QFP(1,9,2,3,3)	10	QFP(3,8,2,3,1)	12	QPC(2,2,2,1,3)	50
UU(1,1,3,6)	95	UU(2,4,3,5)	200	QFP(1,10,2,2,2)	73	QFP(3,8,2,3,2)	43	QPC(2,2,2,2,1)	80
UU(1,2,1,4)	30	UU(2,4,3,6)	260	QFP(1,10,2,3,3)	53	QFP(3,9,2,2,1)	70	QPC(2,2,2,2,2)	85
UU(1,2,1,5)	70	UU(3,1,1,5)	80	QFP(2,1,2,2,2)	45	QFP(3,9,2,3,1)	50	QPC(2,2,2,3,1)	80
UU(1,2,1,6)	110	UU(3,1,1,6)	170	QFP(2,1,2,2,3)	15	QFP(3,10,2,1,1)	156	QPC(2,2,2,3,2)	45
UU(1,2,2,4)	30	UU(3,1,2,3)	75	QFP(2,1,2,3,2)	40	QFP(3,10,2,2,2)	66	QPC(2,2,3,1,1)	70
UU(1,2,2,5)	70	UU(3,1,2,5)	80	QFP(2,2,2,2,2)	50	QFP(3,10,2,3,1)	46	QPC(2,2,3,1,2)	65
UU(1,2,2,6)	110	UU(3,1,2,6)	170	QFP(2,2,2,3,2)	30	QPC(1,1,1,1,4)	50	QPC(2,2,3,1,3)	90
UU(1,2,3,4)	30	UU(3,1,3,2)	77	QFP(2,3,2,1,1)	69	QPC(1,1,1,2,4)	50	QPC(2,2,3,2,1)	70
UU(1,2,3,5)	70	UU(3,1,3,3)	152	QFP(2,3,2,1,2)	76	QPC(1,1,1,3,4)	97	QPC(2,2,3,2,2)	65
UU(1,2,3,6)	110	UU(3,1,3,5)	80	QFP(2,3,2,2,1)	55	QPC(1,1,3,1,4)	50	QPC(2,2,3,3,1)	70
UU(1,3,1,5)	50	UU(3,1,3,6)	170	QFP(2,3,2,3,1)	35	QPC(1,1,3,2,4)	50	QPC(2,2,4,1,1)	50
UU(1,3,1,6)	95	UU(3,2,1,4)	70	QFP(2,4,2,1,1)	19	QPC(1,1,3,3,4)	110	QPC(2,2,4,1,2)	55
UU(1,3,2,5)	50	UU(3,2,1,5)	155	QFP(2,4,2,2,1)	64	QPC(1,1,4,1,4)	45	QPC(2,2,4,1,3)	60
UU(1,3,2,6)	95	UU(3,2,1,6)	227	QFP(2,4,2,3,1)	44	QPC(1,1,4,2,4)	45	QPC(2,2,4,2,1)	50
UU(1,3,3,3)	60	UU(3,2,2,3)	7	QFP(2,5,2,2,1)	20	QPC(1,1,4,3,4)	45	QPC(2,2,4,2,2)	55
UU(1,3,3,5)	50	UU(3,2,2,4)	77	QFP(2,5,2,2,2)	40	QPC(1,2,1,1,1)	40	QPC(2,2,4,2,3)	60
UU(1,3,3,6)	95	UU(3,2,2,5)	162	QFP(2,5,2,3,1)	40	QPC(1,2,1,1,2)	45	QPC(2,2,4,3,1)	50
UU(1,4,1,5)	45	UU(3,2,2,6)	234	QFP(2,6,2,2,3)	70	QPC(1,2,1,1,3)	47	QPC(2,2,4,3,2)	55
UU(1,4,1,6)	92	UU(3,2,3,3)	65	QFP(2,6,2,3,2)	50	QPC(1,2,1,2,1)	40	QPC(3,1,1,1,4)	70
UU(1,4,2,5)	45	UU(3,2,3,4)	135	QFP(2,7,1,1,4)	70	QPC(1,2,1,2,2)	45	QPC(3,1,1,2,4)	145
UU(1,4,2,6)	92	UU(3,2,3,5)	220	QFP(2,7,1,2,4)	105	QPC(1,2,1,2,3)	47	QPC(3,1,1,3,4)	222
UU(1,4,3,5)	45	UU(3,2,3,6)	292	QFP(2,7,1,3,4)	130	QPC(1,2,1,3,1)	40	QPC(3,1,3,1,4)	65
UU(1,4,3,6)	92	UU(3,3,1,5)	75	QFP(2,7,2,1,2)	39	QPC(1,2,1,3,2)	45	QPC(3,1,3,2,4)	125
UU(2,1,1,5)	75	UU(3,3,1,6)	137	QFP(2,7,2,1,3)	104	QPC(1,2,2,1,1)	30	QPC(3,1,3,3,4)	125
UU(2,1,1,6)	140	UU(3,3,2,3)	60	QFP(2,7,2,2,2)	53	QPC(1,2,2,1,2)	30	QPC(3,1,4,1,4)	75
UU(2,1,2,3)	35	UU(3,3,2,5)	75	QFP(2,7,2,3,1)	33	QPC(1,2,2,1,3)	35	QPC(3,1,4,2,4)	10.25
UU(2,1,2,5)	75	UU(3,3,2,6)	137	QFP(2,8,2,1,2)	145	QPC(1,2,2,2,1)	30	QPC(3,1,4,3,4)	140
UU(2,1,2,6)	140	UU(3,3,3,3)	60	QFP(2,8,2,2,1)	55	QPC(1,2,2,2,2)	30	QPC(3,2,1,1,1)	80
UU(2,1,3,3)	60	UU(3,3,3,5)	75	QFP(2,8,2,3,1)	35	QPC(1,2,2,2,3)	35	QPC(3,2,1,1,2)	85
UU(2,1,3,5)	75	UU(3,3,3,6)	137	QFP(2,9,2,1,3)	156	QPC(1,2,2,3,1)	30	QPC(3,2,1,1,3)	75
UU(2,1,3,6)	140	UU(3,4,1,5)	75	QFP(2,9,2,2,1)	56	QPC(1,2,2,3,2)	30	QPC(3,2,1,2,1)	80
UU(2,2,1,4)	80	UU(3,4,1,6)	135	QFP(2,9,2,3,1)	46	QPC(1,2,2,3,3)	35	QPC(3,2,1,2,2)	85
UU(2,2,1,5)	155	UU(3,4,2,4)	64.75	QFP(2,10,2,1,1)	162	QPC(1,2,3,1,1)	50	QPC(3,2,1,3,1)	80
UU(2,2,1,6)	220	UU(3,4,2,5)	139.75	QFP(2,10,2,2,2)	72	QPC(1,2,3,1,2)	55	QPC(3,2,1,3,2)	8

According to the obtained results of Table IV, it can be understood that two objective functions are satisfied in a balanced range since the F1=1864756 and F2=4239.4 are approximately in a good manner. Moreover, the amount of inventory of processing centers, the amount of shortage of markets, and the amount of allocated quantities are presented in Table V. It should be noted that in Table V, only the variables that have the value have been presented and the value of not mentioned variables is equal to 0. Also, in Table V, the variables as *UU(i,c,s,t), QFP(i,f,p,s,t), QPC(i,p,c,s,t)* are presented. Also, *X(2)=1* as the opened processing center for this solution is achieved.

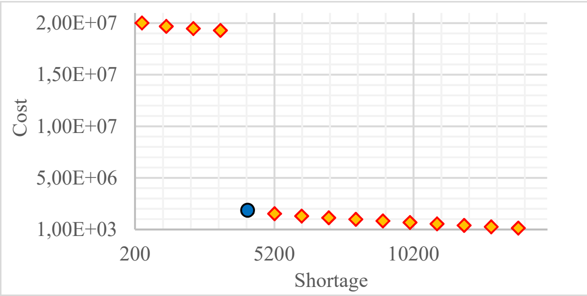

Fig. 3 The obtained Pareto front archive

V. Conclusion

Every year, the huge quantities of agricultural products are destroyed. Farmers due to lack of awareness and the lack of a comprehensive harvest plan are suffering from this issue. Thus, this research by modeling an efficient supply chain network tries to enhance these unsuitable conditions. To this end, a linear bi-objective mathematical model is developed which seek to minimize total costs and minimize shortages caused by unsatisfied demands. To validate the proposed model, a stochastic optimization approach by using the LINGO software is employed. Also, in order to initialize the model parameters, a real case in Iran is used. Since, the ε-constraint approach is applied to solve this model, a non-dominated solution from the obtained Pareto front is selected as best answer and its related variables are provided. For this purpose, at first, we run the second objective function separately that the values F2min=349 and F2max=14938 are achieved. Also, we consider n=15 and ε=0.000001 to make Pareto front. Finally, with the help of obtained Pareto front, experts and managers select a fifth Pareto solution as a proper manner and the related results of this solution such as the opened processing centers along with their allocated quantities are presented in Table V. According to the obtained results of Table IV, it can be understood that two objective functions are satisfied in a balanced range since the F1=1864756 and F2=4239.4 are approximately in good manner. Moreover, opened processing centers, amount of inventory of processing centers, the amount of shortage of markets, and amount of allocated quantities are presented in Table V.

For future research, the model can be extended to have multiple fuzzy-objective or robust optimization. In addition, different methods for solving the proposed model can be developed such as heuristics and metaheuristics or others exact methods. Applying the proposed model in similar fields of food, fresh fruits and etc. can be one of the research areas for the future studies. The proposed solution approaches can also be used for the aforementioned cases.

References

[1] O. Ahumada and J. R. Villalobos, “Application of planning models in the agri-food supply chain: A review,” *Eur. J. Oper. Res.*, vol. 196, no. 1, pp. 1–20, Jul. 2009.
[2] N. K. Tsolakis, C. A. Keramydas, A. K. Toka, D. A. Aidonis, and E. T. Iakovou, “Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy,” *Biosyst. Eng.*, vol. 120, pp. 47–64, Apr. 2014.
[3] E. Audsley and D. L. Sandars, “A review of the practice and achievements from 50 years of applying OR to agricultural systems in Britain,” *OR Insight*, vol. 22, no. 1, pp. 2–18, Apr. 2009.
[4] M. Shukla and S. Jharkharia, “Agri-fresh produce supply chain management: a state-of-the-art literature review,” *Int. J. Oper. Prod. Manag.*, vol. 33, no. 2, pp. 114–158, Feb. 2013.
[5] A. Cheraghalipour, M. M. Paydar, and M. Hajiaghaei-Keshteli, “A multi-period and three-echelon supply chain network design for perishable agricultural products using meta-heuristic algorithms,” *J. Oper. Res. Its Appl. (Appl. Math.) - Lahijan Azad Univ.*, vol. 14, no. 3, Oct. 2017.
[6] M. Mergenthaler, K. Weinberger, and M. Qaim, “The food system transformation in developing countries: A disaggregate demand analysis for fruits and vegetables in Vietnam,” *Food Policy*, vol. 34, no. 5, pp. 426–436, Oct. 2009.
[7] A. Rong, R. Akkerman, and M. Grunow, “An optimization approach for managing fresh food quality throughout the supply chain,” *Int. J. Prod. Econ.*, vol. 131, no. 1, pp. 421–429, May 2011.
[8] E. Teimoury, H. Nedaei, S. Ansari, and M. Sabbaghi, “A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: A system dynamics approach,” *Comput. Electron. Agric.*, vol. 93, pp. 37–45, Apr. 2013.
[9] E. Nadal-Roig and L. M. Plà-Aragonés, “Optimal Transport Planning for the Supply to a Fruit Logistic Centre,” in *International Series in Operations Research and Management Science*, Springer Verlag, 2015, pp. 163–177.
[10] W. E. Soto-Silva, E. Nadal-Roig, M. C. González-Araya, and L. M. Pla-Aragones, “Operational research models applied to the fresh fruit supply chain,” *Eur. J. Oper. Res.*, vol. 251, no. 2, pp. 345–355, 2016.
[11] V. Borodin, J. Bourtembourg, F. Hnaien, and N. Labadie, “Handling uncertainty in agricultural supply chain management: A state of the art,” *Eur. J. Oper. Res.*, vol. 254, no. 2, pp. 348–359, Oct. 2016.
[12] H. Etemadnia, S. J. Goetz, P. Canning, and M. S. Tavallali, “Optimal wholesale facilities location within the fruit and vegetables supply chain with bimodal transportation options: An LP-MIP heuristic approach,” *Eur. J. Oper. Res.*, vol. 244, no. 2, pp. 648–661, Jul. 2015.
[13] A. Cheraghalipour and M. Hajiaghaei-keshteli, “Tree Growth Algorithm (TGA): An Effective Metaheuristic Algorithm Inspired by trees behavior,” in *13th International Conference on Industrial Engineering*, 2017, pp. 1–8.
[14] E. Wari and W. Zhu, “A survey on metaheuristics for optimization in food manufacturing industry,” *Appl. Soft Comput.*, vol. 46, pp. 328–343, Sep. 2016.
[15] R. Sarker and T. Ray, “An improved evolutionary algorithm for solving multiobjective crop planning models.,” *Comput. Electron. Agric.*, vol. 68, no. 2, pp. 191–199, 2009.
[16] G. Mavrotas, “Effective implementation of the ε-constraint method in Multi-Objective Mathematical Programming problems,” *Appl. Math. Comput.*, vol. 213, no. 2, pp. 455–465, Jul. 2009.
[17] M. M. Paydar, V. Babaveisi, and A. S. Safaei, “An engine oil closed-loop supply chain design considering collection risk,” *Comput. Chem. Eng.*, vol. 104, pp. 38–55, Sep. 2017.
[18] A. Cheraghalipour, M. M. Paydar, and M. Hajiaghaei-keshteli, “An Integrated Approach for Collection Center Selection in Reverse Logistics,” *Int. J. Eng. Trans. A Basics*, vol. 30, no. 7, pp. 1005–1016, 2017.