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A scenario-based stochastic programming approach for designing and planning wheat supply chain (A case study)

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C H R O N I C L E

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A B S T R A C T

Agri-food supply chains have received the attention of many researchers in recent years for various reasons, including food security and health-related issues. Wheat, as a staple food in many countries, is the most cultivated crop in the world. Due to the importance of wheat, this paper proposes a mixed-integer linear mathematical model for redesigning and planning of the wheat supply chain. The proposed model determines the location and capacity of new storage facilities while addressing supplier selection, ordering, storing, transportation, and distribution problems. This model considers the differences between long-term and short-term storage facilities and the quality of wheat. Moreover, the proposed model addresses the uncertainties associated with the quantity of domestic supply and demand through a stochastic scenario-based programming approach. Applicability of this model is investigated using real data from the wheat supply chain of Iran. Results show that seven new long-term storage facilities should be opened, which decreases total costs by 3.45 percent.

1. Introduction

Agri-food supply chain is a network of organizations working together in different processes and activities to bring agricultural products from the farm to the table. Agri-food supply chains are currently under public attention due to various reasons, including the changing attitudes of more health-conscious and better-informed consumers. These customers want to have precise information about the farming, marketing, and distribution practices used to bring the agricultural products into the shelves of the neighborhood supermarket (Ahumada & Villalobos, 2009). Wheat is the most important food grain source for humans. It is a major diet component because of its plants' agronomic adaptability, ease of grain storage, and ease of converting grain into flour for making edible, palatable, and satisfying foods (Curtis, 2002). As a result, wheat is the most cultivated crop in the world (FAO, 2017). Iran ranks 13th in the world regarding the quantity of wheat production and 6th regarding consumption per capita (FAO, 2017). Since the wheat supply chain of Iran is very vast, it needs to be planned carefully.

In this paper, a mixed-integer linear mathematical model is proposed for redesigning and planning of the wheat supply chain of Iran. This model can optimize decisions about importing, transportation, storage, and distribution of wheat in addition to determining the location and capacity of new storage facilities that are needed. The proposed model considers the differences between long-term and short-term storage facilities. Also, this model addresses the uncertainties associated with the quantity of domestic supply and demand through a scenario-based programming approach. Since the government of Iran is the manager and the majority owner of the wheat supply chain, the proposed model can serve as a decision support system for the government.

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The rest of this paper is organized as follows: Section 2 provides a review of related studies. The problem is defined and described in Section 3. Section 4 is dedicated to developing and explaining the mathematical model, and Section 5 presents data and results. Finally, section 6 is dedicated to conclusions and recommendations for further research.

2. Literature review

Many researchers have studied the supply chain of agricultural products in recent years. Ahumada and Villalobos (2009) reviewed the papers published from 1985 to 2007 and investigated various aspects of them, including crop type, planning scope, and modeling approaches. Tsolakis et al. (2014) reviewed the papers that were published in this field and classified them based on different strategic, tactical, and operational decisions. Handayati et al. (2015) reviewed the papers that addressed coordination in agri-food supply chains. Kusumastuti et al. (2016) focused on agri-food supply chain activities and classified the papers that were published from 1991 to 2015.

Sheikhi and Nazeman (2004) focused on wheat imports of Iran and proposed a mixed-integer linear model that minimizes total costs. Bilgen and Ozkarahan (2007) concentrated on wheat exports of Turkey and developed a model that addresses shipping and blending decisions. O'Donnell et al. (2009) studied the wheat transportations in the northern U.S. and proposed a model that minimizes greenhouse gas emissions. Thakur et al. (2010) presented a multi-objective model to optimize shipping and blending decisions. The proposed model reduces the number of required storage bins for blending and total costs.

Asgari et al. (2013) focused on domestically-produced wheat in Iran and proposed a mixed-integer linear programming model to optimize storage and transportation decisions. Casals and García (2015) addressed the import-export overlapping problem in Europe. Mahmoudinia et al. (2016) proposed a model to determine the location of multiple hubs in the wheat supply chain network. They also addressed transportation decisions. Nourbakhsh et al. (2016) presented a mathematical model that optimizes transportation decisions and determines the location and capacity of new processing facilities that are needed. Gholamian and Taghanzadeh (2017) proposed a mixed-integer programming model that addresses strategic and tactical decisions of the wheat supply chain of Iran. The storage plan of domestically-produced wheat is predetermined in their model.

Mogale et al. (2017) studied the transportation and storage decisions of bulk wheat in India. Hajikhani et al. (2018) addressed the supplier selection and order planning problems in a fuzzy environment. The proposed model is Np-hard, and the Multi-Objective Particle Swarm Optimization Algorithm is employed to obtain the results. Mogale et al. (2018) presented a multi-objective model for the location-allocation problem of grain silos that considers costs and lead-times. Maiyar & Thakkar (2018) studied the grain transportation problem in the presence of hub disruption. They proposed a nonlinear programming model and used the particle swarm optimization algorithm to obtain the results.

Mohammadi et al. (2020) developed a sustainable multi-objective model to design the supply chain network of the processed food industry. They considered the perishability of food products and employed the augmented ε-constraint method to solve the multi-objective problem. Irtyshcheva et al. (2020) addressed the theoretical and practical aspects of managing business processes in the food industry. Jifroudi et al. (2020) developed a mixed-integer linear mathematical model for designing and planning of the rice supply chain. They showed the applicability of the developed model through a case study of Iran farmlands in Gilan.

Table 1
Comparison of this paper with previous studies regarding the grain and wheat supply chain

Authors	Model	Objective function(s)	Uncertainty	Decisions					Considerations		
				FL	IP	EP	TSP	B	Q	SP	DSF
Sheikhi & Nazeman (2004)	LP	Min cost			✓		✓				
Bilgen & Ozkarahan (2007)	MILP	Min cost				✓		✓	✓		
Asgari et al. (2013)	MILP	Min cost					✓	✓	✓	✓	
Mahmoudinia et al. (2016)	MILP	Min cost		✓	✓		✓				
Gholamian & Taghanzadeh (2017)	MILP	Min cost	Scenario-based	✓	✓	✓	✓	✓	✓		
Mogale et al. (2017)	MINP	Min cost					✓				
Mogale et al. (2018)	MINP	Min cost, Min lead-time		✓			✓		✓		✓
Maiyar & Thakkar (2018)	MINP	Min cost	Disruption	✓			✓				
This paper	MILP	Min cost	Scenario-based	✓	✓		✓	✓	✓		✓

FL: Facility location, IP: Imports planning, EP: Exports planning, TSP: Transportation and storage planning, B: Blending, Q: Quality, SP: Sleep period, DSF: Differentiation between storage facilities, LP: Linear programming, MILP: Mixed-integer linear programming, MINP: Mixed-integer non-linear programming.

Table 1 demonstrates the contributions of this paper in comparison to similar studies in the literature. In this paper, a mixed-integer linear programming model is developed that addresses the following problems: 1) supplier selection and order planning, 2) transportation and storage planning, 3) blending, and 4) locating and determining the capacity of new storage facilities. To the best of our knowledge, this research is the first one that addresses designing and planning problems while differentiating between long-term and short-term storage facilities. Short-term storage facilities can hold wheat for three months, and existing wheat in these facilities must be relocated or sent for consumption before it deteriorates. Also, this model considers the uncertainties associated with the quantity of domestic supply and demand through a scenario-based programming approach.

3. Problem description

The considered supply chain is shown in Fig. 1. In Iran, wheat is supplied by domestic farmers and foreign suppliers. Farmers, who are independent of the government, decide how much to plant and sell to the government based on the wheat guaranteed prices, which are announced before the beginning of the next crop year. The government is obliged by law to purchase all the quantity that farmers want to sell. Domestic supply is always less than production since farmers keep a part of their production for their consumption as well as next year's seed. Domestic wheat has different qualities and is classified into three quality groups. If the quality of wheat is not suitable for intended use, it is blended with another quality group.

The government imports wheat to cover the gap between domestic supply and consumption and provide high-quality wheat for blending. Imported wheat is delivered at northern and southern seaports, as shown in Fig. 2. Imported wheat from countries like Australia can only be delivered at the southern ports, while wheat from countries like Russia can be delivered at the northern ports. Imported wheat is stored in storage facilities alongside domestically-produced wheat.

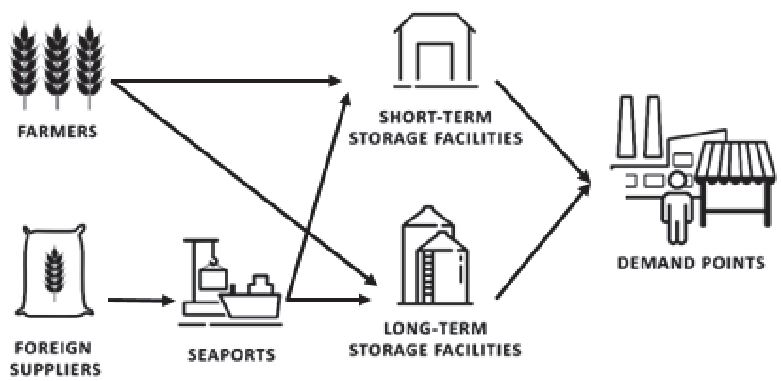

Fig. 1. The wheat supply chain considered in this paper

Vertical silos and automated horizontal silos are long-term storage facilities, while simple horizontal silos and ground warehouses are short-term storage facilities. Long-term storage facilities can hold wheat for three years, and short-term storage facilities can hold wheat for three months. Wheat is distributed among flour factories based on demand. In Iran, the capacity of flour factories in each province is almost twice the demand, thus demanded flour of each province is produced inside that same province. For this reason, flour factories are considered as actual demand zones in this paper.

Fig. 2. Location of Iran's seaports that have the necessary equipment for importing wheat

Assumptions are as follows:

- Production points, storage facilities, and demand points are located in the center of provinces.
- Potential points for opening new storage facilities with four capacity levels are considered.
- Short-term storage facilities can hold wheat for three months.
- Long-term storage facilities are not empty at the beginning of the planning period, but short-term storage facilities are.
- Imported wheat is delivered at seaports after lead time is passed.
- The capacity of seaports for importing wheat is unlimited.
- Wheat can be transported through rail and road.
- For strategic reasons, the total inventory of wheat at the end of each period must be greater than or equal to the average demand of six months.
- Shortage is not allowed.
- Each period equals a month.

4. Model formulation

Indices, parameters, and variables used to formulate the mathematical model are introduced in the following:

Sets and indices:

I Foreign suppliers, $i \in I$;

J Seaports, $j \in J$;

P Production points, $p \in P$;

S Storage locations, $s \in S$;

K Demand points, $k \in K$;

N Storage facility types: short-term and long-term, $n \in N$;

L Capacity levels for opening new storage facilities, $l \in L$

M Transportation modes: rail and road, $m \in M$;

T Periods, $t \in T$;

Θ Scenarios, $\theta \in \Theta$.

Parameters:

y_{ij} Equal to 1 if supplier i can deliver wheat at port j, 0 otherwise;

$price_{it}$ Price of wheat purchased from supplier i in period t;

LT_{ij} Lead time: wheat purchased from supplier i in period t will be delivered at port j in period $t + LT_{ij}$;

FC_i Fixed cost of supplier selection;

c_{ij} Transportation cost form supplier i to port j;

c_j Handling costs at port j;

c_{jsm} Transportation cost from port j to storage facility s using transportation mode m;

c_{psm} Transportation cost from production point p to storage facility s using transportation mode m;

c_{skm} Transportation cost from storage facility s to demand point k using transportation mode m;

h_n Holding cost in a storage facility of type n;

$Initial_s$ Initial inventory of long-term storage facility s;

cap_{it} The supply capacity of supplier i in period t;

cap_{sn} Holding capacity of storage facility type n at location s;

cap_{mt} The capacity of transportation mode m in period t;

OC_{snl} The cost of opening new facilities of type n at location s with capacity level l;

cap_{nl} The capacity of new facilities of type n with capacity level l;

sup_{pt}^{θ} Domestic supply at production point p in period t under scenario θ;

q_i The quality of wheat from supplier i;

q_p The quality of wheat from production point p;

Q Acceptable quality level;

$demand_{kt}^{\theta}$ The demand of point k in period t under scenario θ;

M A big number;

π^{θ} Probability of scenario θ;

Decision variables:

x_{ijt}^{θ} The quantity of wheat purchased from supplier i in period t that will be delivered at port j under scenario θ;

x_{ijsnmt}^{θ} The quantity of wheat transported from port j to storage facility type n at location s using transportation mode m in period t and is originally from supplier i under scenario θ;

x_{psnmt}^{θ} The quantity of wheat transported from production point p to storage facility type n at location s using transportation mode m in period t under scenario θ;

x_{sknmt}^{θ} The quantity of wheat transported from storage facility type n at location s to demand point k using transportation mode m in period t under scenario θ;

I_{snt}^{θ} The total quantity of wheat available in storage facility type n at location s at the end of period t under scenario θ;

y_{it}^{θ} Binary variable: Equals 1 if supplier i is selected in period t under scenario θ, 0 otherwise.

y_{snl} Binary variable: Equals 1 if a new facility of type n is opened at location s with capacity level l, 0 otherwise.

The objective function and constraints of the proposed mathematical model are as follows:

$$Min\ E[Z] = \sum_{\theta} \pi_{\theta} \cdot \left(\sum_i \sum_t FC_i \cdot y_{it}^{\theta} + \sum_i \sum_j \sum_t \left(price_{it} + c_{ij} + c_j\right) \cdot x_{ijt}^{\theta} + \sum_i \sum_j \sum_s \sum_n \sum_m \sum_t c_{jsm} \cdot x_{ijsnmt}^{\theta} + \sum_p \sum_s \sum_n \sum_m \sum_t c_{psm} \cdot x_{psnmt}^{\theta} + \sum_s \sum_k \sum_n \sum_m \sum_t c_{skm} \cdot x_{sknmt}^{\theta} + \sum_s \sum_n \sum_t h_n \cdot I_{snt}^{\theta} + \sum_s \sum_n \sum_l OC_{snl} \cdot y_{snl}\right) \quad (1)$$

$s.t.$:

$$\sum_j x_{ijt}^{\theta} \le cap_{it} \cdot y_{it}^{\theta} \qquad \forall i,t,\theta \quad (2)$$

$$y_{it}^{\theta} \le \sum_j x_{ijt}^{\theta} \qquad \forall i,t,\theta \quad (3)$$

$$x_{ijt}^{\theta} \le M.y_{it}^{\theta} \qquad \forall i,j,t,\theta \quad (4)$$

$$x_{ijt}^{\theta} = \sum_s \sum_n \sum_m x_{ijsnm,t+LT_{ij}}^{\theta} \qquad \forall i,j,t,\theta \quad (5)$$

$$\sum_s \sum_n \sum_m x_{psnmt}^{\theta} = sup_{pt}^{\theta} \qquad \forall p,t,\theta \quad (6)$$

$$I_{snt}^{\theta} = Initial_s + \sum_p \sum_m x_{psnmt}^{\theta} + \sum_i \sum_j \sum_m x_{ijsnmt}^{\theta} - \sum_k \sum_m x_{sknmt}^{\theta} \qquad \forall s,\theta,n = longterm, t = 1 \quad (7)$$

$$I_{snt}^{\theta} = I_{sn,t-1}^{\theta} + \sum_p \sum_m x_{psnmt}^{\theta} + \sum_i \sum_j \sum_m x_{ijsnmt}^{\theta} - \sum_k \sum_m x_{sknmt}^{\theta} \qquad \forall s,\theta,n = longterm, t \ge 2 \quad (8)$$

$$I_{snt}^{\theta} = \sum_{t'=t-2\ge 1}^{t'=t} \sum_p \sum_m x_{psnmt'}^{\theta} + \sum_{t'=t-2\ge 1}^{t'=t} \sum_i \sum_j \sum_m x_{ijsnmt'}^{\theta} - \sum_{t'=t-2\ge 1}^{t'=t} \sum_k \sum_m x_{sknmt'}^{\theta} \qquad \forall s,t,\theta,n = shortterm \quad (9)$$

$$\sum_k \sum_m \left(x_{sknm,t+1}^{\theta} + x_{sknm,t+2}^{\theta}\right) \ge I_{snt}^{\theta} \qquad \forall s,t,\theta,n = shortterm \quad (10)$$

$$I_{snt}^{\theta} \le cap_{sn} + \sum_l cap_{nl} \cdot y_{snl} \qquad \forall s,n,t,\theta \quad (11)$$

$$\sum_l y_{snl} \leq 1 \qquad \forall s,n \tag{12}$$

$$\frac{\sum_p \sum_m x^{\theta}_{psnmt} \cdot q_p + \sum_i \sum_j x^{\theta}_{ijsnmt} \cdot q_i}{\sum_p \sum_m x^{\theta}_{psnmt} + \sum_i \sum_j \sum_m x^{\theta}_{ijsnmt}} \leq Q \qquad \forall s,n,t,\theta \tag{13}$$

$$\sum_s \sum_n I^{\theta}_{snt} \geq 0.5 \cdot \sum_k \sum_t demand^{\theta}_{kt} \qquad \forall t \tag{14}$$

$$\sum_s \sum_n \sum_m x^{\theta}_{sknmt} = demand^{\theta}_{kt} \qquad \forall k,t \tag{15}$$

$$\sum_i \sum_j \sum_s \sum_n x^{\theta}_{ijsnmt} + \sum_p \sum_s \sum_n x^{\theta}_{psnmt} + \sum_s \sum_n \sum_k x^{\theta}_{sknmt} \leq cap_{mt} \qquad \forall m,t \tag{16}$$

$$x^{\theta}_{ijt}, x^{\theta}_{ijsnmt}, x^{\theta}_{psnmt}, x^{\theta}_{sknmt}, I^{\theta}_{snt} \geq 0, y^{\theta}_{it}, y_{snl} \in \{0,1\} \tag{17}$$

The objective function (1) minimizes total opening, purchasing, transportation, and holding costs. Constraints (2) and (3) determine the capacity of foreign suppliers. Constraint (4) assigns seaports to foreign suppliers. Constraint (5) calculates lead-times and guarantees that imported wheat is transported to storage facilities when it is delivered. Constraint (6) determines the storage plan of domestic wheat. Constraints (7) to (9) calculate the amount of wheat in short-term and long-term storage facilities. Constraint (10) makes sure wheat is sent for consumption before it deteriorates in short-term storage facilities. Constraint (11) determines the total capacity of storage facilities (existing and new). Constraint (12) states that only one capacity level can be selected for opening new storage facilities. Constraint (13) makes sure the quality of wheat in storage facilities is better than the acceptable quality level. Note that the first quality group is better than the second and third, so less is better. Constraint (14) guarantees the holding of strategic inventories. Constraint (15) states that all demand must be fulfilled, and shortage is not allowed. Constraint (16) determines the capacity of transportation modes. Finally, Constraint (17) shows decision variables and their types.

The proposed model is a mixed-integer linear programming model since constraint (13) can be rewritten as follows:

$$\sum_p \sum_m x_{psnmt} \cdot q_p + \sum_i \sum_j \sum_m x_{ijsnmt} \cdot q_i \leq Q \cdot \left(\sum_p \sum_m x_{psnmt} + \sum_i \sum_j \sum_m x_{ijsnmt}\right) \qquad \forall s,n,t \tag{18}$$

5. Model implementation and results

We investigated the applicability of the proposed mathematical model using real data of the wheat supply chain of Iran. The data was gathered with the help of different organizations such as "Ministry of Agriculture-Jihad," "Government Trading Organization of Iran," "Iran Road Maintenance & Transportation Organization," "The Railways of Islamic Republic of Iran," and "Ports & Maritime Organization of Iran." Also, we used the expected value approach to obtain the results of the stochastic scenario-based problem.

5.1. Data and information

The size of the problem is presented in Table 2 and wheat is cultivated in all 31 provinces of Iran. The amount of domestic production, domestic supply, imports, and demand from 2014 to 2017 is presented in Table 3. Major foreign suppliers of wheat include Argentina, Australia, Canada, the European Union, Kazakhstan, and Russia based on data provided by "Ports & Maritime Organization of Iran." Iran has about 700 storage facilities with an overall capacity of 17.691 million tonnes for storing wheat, as shown in Table 4.

Table 2
The values assigned to indexes

Index	Description	Details
i	Foreign suppliers	Argentina, Australia, Canada, European Union, Kazakhstan, Russia
j	Seaports	Imam Khomeini, Shaheed Rajaee, Chabahar, Bushehr, Anzali, Amirabad
p, s, k	Provinces	31
n	Type of storage facilities	Short-term and long-term
l	Capacity levels	50000,100000,150000,200000 (tonnes)
m	Transportation modes	Rail and road
t	Periods	12 months (one year)

Due to currency fluctuations, all of the monetary-related data are presented in Iranian Rial. Wheat prices are obtained from indexmundi.com for corresponding years, and the exchange rate for global prices is considered 42000 (1 United States Dollar equals 42000 Iranian Rials) since wheat is a staple food and the government grants subsidies for its supply to keep the bread prices low.

Table 3
Historical data regarding wheat production, supply, imports, and demand (tonnes)

Year	Domestic production	Domestic supply	Imports	Total Demand
2013	9304246	4820500	3404000	9051900
2014	10578698	6716600	5275800	8930200
2015	11522318	8082000	334000	7465700
2016	14592003	11519700	544200	8955000
2017	12400000	9500000	0	8900000

Table 4
Capacity of storage facilities

Type of storage facility	Capacity (thousand tonnes)
Long-term	12622
Short-term	5069
Sum	17691

5.2. Scenarios

Stochastic scenario-based programming is a popular tool in strategic planning. A scenario is a description of a future situation and the course of events that enables one to progress from the original situation to the future situation (Pishvaee et al., 2008). A good scenario is a relevant, consistent, probable, and transparent scenario. In principle, only a few substantially different scenarios are needed (Nguyen et al., 2007).

Scenario building requires a wide spectrum of knowledge and opinions from multidisciplinary team members (Schwab et al., 2003). In other words, scenarios are usually built on experts' opinions. In this research, the experts were asked to provide pessimistic, realistic, and optimistic values for domestic supply and demand. Based on the historical data and their expertise, while forecasting an increase in demand, they selected three values for total domestic supply and two values for total demand. As a result, six scenarios with equal probabilities were created, as shown in Table 5.

Table 5
The values of uncertain parameters

Uncertain parameters	Values (tonnes)
Total domestic supply	6000000 9000000 12000000
Total demand	9000000 10000000

5.3. Results

The model is coded in GAMS 24.1.2 and is solved by CPLEX solver. Tests are carried out on an Intel Core i7-5500U 2.40 GHz computer with 8.00 GB RAM. This model has 25,411 equations and 837,103 variables. In the optimal solution, seven long-term storage facilities are opened in the following provinces: Bushehr, Khuzestan, Fars, Golestan, Gilan, Lorestan, and Hormozgan. The capacity of the silo that is opened in Hormozgan is 150000 tonnes, while the capacity of other silos is 200000 tonnes. Note that, on average, the capacity of long-term storage facilities in Bushehr, Gilan, and Hormozgan is less than the annual demand. Also, in 2015, the capacity of long-term storage facilities in Bushehr, Khuzestan, Fars, and Golestan was less than the domestic supply. Therefore, historical data supports the results.

The value of the objective function (total costs) in each scenario is presented in Table 6. Scenario 2 has the highest imported quantity and costs, while Scenario 3 has the lowest. This result shows the effects of purchasing and importing costs in increasing total costs and highlights the importance of achieving self-sufficiency. Moreover, in Scenarios 5 and 6, domestic supply can cover demand, but high-quality wheat is required for blending; hence wheat is still imported. Thus, improving the quality of domestic productions can reduce imports and total costs.

Table 6
The values of the objective functions

Scenario	Total domestic supply (tonnes)	Total demand (tonnes)	Total imports (tonnes)	Total costs (million Rials)
1	6000000	9000000	2963723.8	1.994×10^{7}
2	6000000	10000000	4032792	2.641×10^{7}
3	9000000	9000000	924047.1	8.313×10^{6}
4	9000000	10000000	1032792	9.234×10^{6}
5	12000000	9000000	997612.9	9.400×10^{6}
6	12000000	10000000	1081498.7	1.001×10^{7}

Table 7 shows the amount of received wheat at seaports in each scenario. These results are interesting because, in 2014 and 2015, 59 and 45 percent of imported wheat was received at Imam Khomeini port, respectively. However, in the optimal solution, this port is barely selected. In the optimal solution, 84 percent of imported wheat is received at northern ports, and the other 16 percent is received at southern ports, among which Shaheed Rajaee port is the most popular. Fig. 3 presents the results graphically.

Table 7
The amount of received wheat at seaports (tonnes)

Scenario	Imam Khomeini	Shaheed Rajaee	Chabahar	Bushehr	Anzali	Amirabad	Total
1	0	311169.7	153787.3	227109.7	824151.5	1447505.6	2963723.8
2	335469.1	298197.5	139171.5	264915.5	1011726.2	1983312.2	4032792
3	0	0	0	0	584548.9	339498.2	924047.1
4	0	0	0	0	568594.0	464198.0	1032792
5	0	0	0	0	769478.0	228134.9	997612.9
6	0	0	0	0	774803.7	306695.0	1081498.7

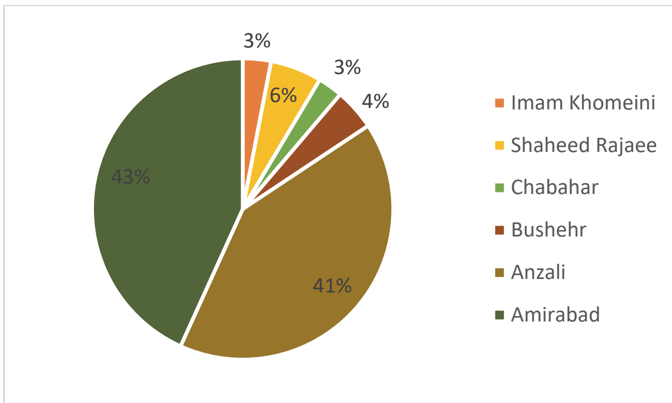

Fig. 1. The share of seaports in importing wheat

Finally, we investigated the effects of opening new storage facilities on total costs. For this aim, we compared the costs of each scenario before and after new storage facilities are established. Total opening costs are 150000 million Rials, and the improvement in costs are always more than opening costs, as shown in Table 8. The improvement in total costs increases when domestic supply grows.

Table 8
The effects of opening new storage facilities on total costs

Scenario	Total costs before opening new silos (million Rials)	Total costs after opening new silos (million Rials)	The improvement (million Rials)	The improvement (percentage)
1	2.00E+07	1.98E+07	2.18E+05	1.09%
2	2.65E+07	2.63E+07	2.72E+05	1.03%
3	8.47E+06	8.16E+06	3.08E+05	3.63%
4	9.41E+06	9.08E+06	3.30E+05	3.51%
5	9.86E+06	9.25E+06	6.12E+05	6.21%
6	1.04E+07	9.86E+06	5.44E+05	5.23%

6. Conclusion

In this paper, a mixed-integer linear mathematical model has been proposed for redesigning and planning of the wheat supply chain of Iran. This model addresses the following problems: 1) supplier selection and order planning, 2) transportation and storage planning, 3) blending, and 4) locating and determining the capacity of new storage facilities. The proposed model considers the differences between long-term and short-term storage facilities. Also, this model takes into account the uncertainties associated with the quantity of domestic supply and demand through a scenario-based programming approach. Applicability of this model is investigated using real data from the wheat supply chain of Iran.

Based on historical data, we have considered six scenarios with equal probabilities. Results show that seven long-term storage facilities should be opened in Bushehr, Khuzestan, Fars, Golestan, Gilan, Lorestan, and Hormozgan. The capacity of the long-term storage facility that should be opened in Hormozgan is 150000 tonnes, while the capacity of other silos is

200000 tonnes. Total opening costs are 150000 million Rials, which improves the costs of scenarios by 3.45 percent, on average.

Moreover, we investigated the imports more thoroughly. In the optimal solution, 84 percent of imported wheat is received at northern ports, and the other 16 percent is received at southern ports, among which Shaheed Rajaee port is the most popular. However, in 2014 and 2015, 59 and 45 percent of imported wheat was received at Imam Khomeini port, respectively. This result states that the current situation is not optimal.

For future research, considering a multi-product supply chain in which different qualities are needed for different purposes is suggested. Second, redesigning and planning of the wheat supply chain through a Robust programming approach is recommended. Finally, considering the possibility of exporting surplus wheat is suggested for future research.

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