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Research Article

Application of the Mixed-Integer Programming Method in Fishery Supply Chain Network Management: A Case Study of Shrimp in Golestan Province

Javad Mahdavi Varaki[1], **Iraj Mahdavi**[1], **Shahrzad Mirkarimi**[2,*]

[1]Department of Industrial Engineering, University of Science and Technology, P.O. Box. 85635-47166, Mazandaran, Babol, Iran.
[2]Department of Agricultural Engineering, University of Agricultural Sciences and Natural Resources, P.O. Box. 48181-66996, Mazandaran, Sari, Iran.

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Abstract. Social, economic, and environmental issues such as population growth, reduction of natural resources, climate change, market fluctuations, and changing consumer behavior have attracted the attention of politicians to the supply chain of agricultural products. Designing an effective supply chain for each product can lead to optimal management of the agricultural sector and create coordination and links between activities. In this article, the design of a two-echelon supply chain network of shrimp in Golestan province is investigated. The objective is to minimize the total cost associated with fixed opening and operating costs of shrimp farming companies and to determine the target market for these producers. Also, this study involves deciding on the amount of inputs purchased by each company and determining the best mode of transport. To characterize and solve this problem, we developed a mixed-integer programming (MIP) model that solves with GAMS software. The results show that with the implementation of the MIP model, the total costs of the chain are reduced by nearly 20 percent compared to the current situation. In addition, without increasing production, it is possible to supply 0.053 percent of global market demand, which is 76 percent more than before.

Keywords. Programming optimization, Supply Chain, Golestan province, Farmed shrimp.

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* Corresponding author
Javadmahdavivaraki@gmail.com, Irajmahdavi@gmail.com, shahrzadmirkarimi@yahoo.com
http://mathco.journals.pnu.ac.ir

1 Introduction

One of the most fundamental and essential challenges of the present and future is the issue of food and food security. Nearly 800 million people in the world's population are currently hungry or suffering from severe malnutrition. The growing world population and the growing need for protein require optimal solutions in providing food resources. Of the four billion tons of food consumed by humans, 97 percent comes from 3 to 5 percent of the land level, which can be cultivated, but from 71 percent of the land, which is the sea, only 3 percent of human food is supplied. Given the global constraints of agriculture and livestock, humans must increase aquaculture [1]. In recent years, uncontrolled fishing in the Caspian Sea, the Persian Gulf, and the Oman Sea has resulted in drastic decreases in the reserves of these water resources. The expansion of aquaculture farms not only has contributed to the development of a sustainable source of food for the country but also has been highly effective in the preservation of species that are endangered for whatever reason. Today, seafood and related products have been known for job creation and earning foreign exchange [23]. The high nutritional value of shrimp, on the one hand, and the demand of global markets, on the other hand, has caused shrimp production to play a special role in aquatics. Shrimp as a well-known, rich, and sought-after seafood, is generally obtained from either marine environments or aquaculture [16]. According to the acceptable efficiency of the shrimp industry in the world and its hidden talents in Iran, actions have been taken to utilize shrimp farms in the country [7]. In 2018, about 10 percent of the country's aquatic production has been allocated to shrimp products [10]. Shrimp farming, in addition to currency, in border areas is effective in eliminating smuggling, increasing the security of areas, protecting border residents, creating jobs, and preventing migration of villagers [9]. Therefore, the development of the shrimp industry and related industries has favorable economic consequences [5]. In addition to the reproduction of this product, its distribution, domestic sales, and exports are very important. In 2018, 47.9 thousand tons of shrimp were produced in the country, of which 31.8 tons, equivalent to 66 percent, were exported. Also, the total export revenue of fishery products (caviar, shrimp, and types of fish) is reported to be 528.3 million dollars, of which shrimp exports account for 159 million dollars, about 30 percent of the total export revenue of total aquatic products [10].

Today, due to the size of global markets and the existence of some major social and economic differences between countries and consumer groups, the use of a principled method to identify or so-called determine and prioritize export target markets is one of the requirements to achieve an export leap [12]. Consequently, designing and optimizing the shrimp supply chain network can help governments, investors, and active parties to satisfy market demands, and to overcome obstacles in the supply chain, and in general, can boost the performance of the whole chain [16]. Traditional supply chain practices may be under revision due to issues related to food security [2]. To keep up with the changes occurring in agricultural supply chains, all parties involved must be considered. So, planning models will become of increasing importance to suppliers, farmers, intermediaries, and final distributors of agricultural commodities. Planning tools for each of these people must become increasingly refined to drive extra costs out of the value chain [22]. The above highlights reveal the need to pay attention to the shrimp supply chain. The supply chain is a network of facilities and distribution options for the procurement of materials; the transformation of materials into intermediate and finished products; and the distribution of these finished products to customers. The Agri-food supply chain comprises all the stages that food products go through, from production to consumption. These activities include inputs, production, conversion, processing, packaging, warehousing, transportation, cross-docking, distribution, marketing, and consumption [11]. In other words, the Agri-food supply chain network is typically a multi-echelon supply chain network with multiple products, including four stages: primary production, production of semi-products by plants, production of finished products, and distribution. Decisions on determining the optimal number, location, and capacity of the production companies, product type produced by each company, selecting transportation mode and the corresponding amount of items shipping from supplier to the company, between two companies, and from companies to distribution centers are made given the market demand, such that the total costs are minimized [26]. The existence of diverse activities causes supply chain planning issues to exhibit a multilevel decision-making network structure. Therefore, it is necessary to optimize the economic flow from input suppliers to manufacturing companies and then to consumers [11].

In this paper, the shrimp supply chain is presented, which reveals the innovation of the present study. It should be noted that shrimp, unlike fish, can be grown only in special conditions and places, and therefore its proper location to supply consumer demand, can play a significant role in the reduction of costs. In Section 2, the literature review on the supply chain is reviewed. In Section 3, the problem model is presented with emphasis on the mixed integer programming (MIP) method. Due to the NP-hardness of supply chain problems and the large-sized data in the real world, meta-heuristics such as genetic algorithm and particle swarm optimization have been widely used. However, as well as in other optimization problems, the solution technique of MIP models can be employed in supply chain problems. In Section 4, we show the computational results, and conclusions are provided in Section 5.

2 Literature Review

According to a review of the research literature mentioned below, the use of mathematical models and operations research tools for agricultural planning is not a new concept. Instead, optimization models for applications in crop planning can be found since the early 1950s, even in a tenuous way. This solution technique became more widespread during the decade of 1980, with growing interest in the 1990s [2]. Ayoughi et al. (2022) in [4] presented a stable multi-objective model of location, inventory, and supply chain routing under conditions of uncertainty and using a passive defense approach. Parameters such as demand, cost of setting up the facility and cost of maintaining inventory were considered uncertain and in the form of triangular fuzzy numbers. The results of validation showed that the proposed model was valid and feasible, and the proposed algorithm was also valid and converged to the optimal solution. Mosallanezhad et al. (2021) in [16] considered Shrimp Supply Chain (SSC) as a set of distribution centers, wholesalers, shrimp processing factories, markets, shrimp waste powder factories, and shrimp waste powder market. In this paper, a mathematical model was proposed for the SSC, whose aim was to minimize the total cost through the supply chain. The SSC model was NP-hard and was not able to solve large-size problems. Therefore, three well-known meta-heuristics accompanied by two-hybrid ones were exerted. Moreover, a real-world application with 15 test problems was established to validate the model. Finally, the results confirmed that the SSC model and the solution methods were effective and useful to achieve cost savings. Salehi and Jabarpour (2020) in [20] discussed a multi-objective model for multi-period location-distribution-routing problems considering the evacuation of casualties and homeless people and fuzzy paths in relief logistics. Some parameters were considered uncertain, including demand, the capacity of vehicles and time. What distinguishes humanitarian logistics from ordinary logistics is that under critical conditions, the relief supply chain must act at high speed and aim to preserve human lives. While under ordinary circumstances, the supply chain operates at the lowest cost according to the schedule. In this paper, the small sample size problem solved by the GAMS software was solved by these algorithms, which showed the high efficiency of the algorithms in obtaining efficient responses. Tabrizi et al. (2017) in [23] presented a bi-level optimization modeling for the perishable food supply chain. They designed a warm-water-farmed fish supply chain in Iran. This study aimed to maximize the profitability of farms based on the meta-heuristic particle swarm optimization method. The results showed the efficiency of the proposed model in solving the real problems of the perishable food supply chain.

A review of previous studies indicates that supply chain network design has been considered in various issues. Some authors have addressed the issue of location-allocation ([4], [15], [19]-[24]). Some studies have developed these models by considering multiple echelons [17] and multiple products [21]. Also, considering uncertain parameters in the optimization problems (such as demand) is another popular extension of the classical supply chain network design [24]. Closed-loop supply chain design ([3], [8]-[21]) and sustainable supply chain design [25] are two other popular areas in supply chain literature. In addition, considering specific products such as dangerous and perishable products [18], pricing decisions [3], designing resilience supply chains [19], competitive networks [6], selecting transport modes and integrating them with other decisions chains [22] and considering quantity discounts to reduce costs [11] are the topics that have become very popular in the literature of supply chain network design in recent years. This article designs a mathematical modeling and optimization structure that focuses on a two-echelon shrimp supply chain network. To the best of our knowledge, no prior study involving mathematical modeling for the shrimp supply chain network design considers transportation issues and quantity discounts simultaneously. The main goal of this model is to minimize the total cost.

3 Problem Definition and Modeling

Golestan province, with its potential areas for aquaculture, is considered as one of the important centers of the fisheries industry in the country. In 2018, this province, after Hormozgan and Bushehr provinces with 5.4 percent had the highest production of saltwater-farmed shrimp. Also, 3.7 percent of the number of farms and about 11 percent of the area of shrimp farms in the country are active in this province [10]. Gomishan Shrimp Farming Complex is the only potential complex in this province that, according to the climatic conditions of the region, is considered as one of the most important sectors of development in this province to produce protein materials and create employment. In 2011, the Gomishan Complex started operating with 70 hectares of useful area and a production of 140 tons of shrimp. At present, the first phase of the shrimp farming complex with 50 20-hectare farms is operating under the supervision of 13 companies [13]. Shrimp caught from these farms are supplied to domestic and foreign markets after processing. Before the outbreak of coronavirus, the countries like China, Vietnam, Emirates, Hong Kong, Oman, and Spain were the main export destinations for shrimp from Golestan province. Figure 1 shows the network structure of a two-echelon supply chain of farmed shrimp, where level (1) is between the input suppliers and the shrimp breeders, and level (2) is between the breeders and the consumers.

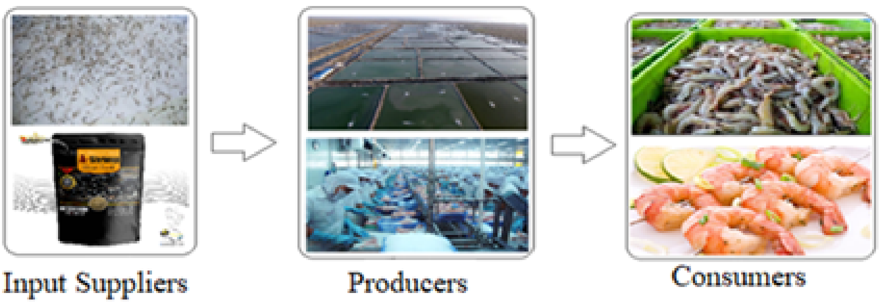

Figure 1: Network structure of a two-echelon supply chain.

In this study, it is assumed that (1). The inputs required for shrimp farming are provided by two groups of domestic and foreign suppliers. Domestic inputs such as water, labor, and larvae are provided by the first group and imported inputs such as fertilizers, vitamins, supplements, disinfectants, and food are provided by the second group ($s = 1, 2$). It should be noted that among the inputs, feed and released larvae account for 65 and 20 percent, respectively, and play an important role in creating the total cost of this product [10]; so the capacity of suppliers has been assessed on this basis. (2). The processing operation is done inside the complex and by the producers. (3). Consumers of this product are wholesalers who can be divided into three groups; within-province (α), within-country (β) and abroad (γ) ($i = 1, 2, 3$). The position of consumers and suppliers of inputs is clear. (4). All the facilities considered in this network have a certain capacity and demand. (5). Each shrimp farming company serves only one group of consumers (single-sourcing strategy). (6). Each company can refer to any of the suppliers to buy the required inputs (multiple-sourcing strategy). (7). Both transportation modes cannot be used simultaneously for products and raw material transmissions between levels. In other words, only one of the available modes can be selected for transporting goods from suppliers to companies or from companies to consumers ($m = 1, 2$). The first mode of transportation cannot be used when the total quantity of carried raw material from supplier to companies is less than CV^1 or the total quantity of carried products from a farm to a consumer is less than CV^2. (8). The costs of purchasing and transporting inputs are reserved for suppliers. Input suppliers usually offer price discounts to encourage companies to buy larger quantities of inputs. Therefore, the existence of a discount creates an incentive for producers to reduce the cost of each unit of production by buying more. The amount of the discount affects the amount of the order and the amount of the order also affects the mode of transportation.

In this study, suppliers sell their inputs based on an All-Unit discount strategy. In this strategy, a price reduction is applied to all purchased units. Different breakdown points are also introduced by suppliers. We use a piecewise linear purchasing and transportation cost between suppliers and farms. Let Q_{sk} denote the amount of materials carried from supplier s to farm k. We assume that there are $\mid l_s \mid$ purchasing price segments (price breakdown points) for carrying products and BP_{sls} is the quantity of l_s^{th} breakdown point in each supplier. Therefore, we have $\mid l_s \mid$ -1 price intervals in total. If we consider P_{sls} as the unit purchasing and transportation price of raw materials in $(l_s - 1)^{th}$ interval of supplier s, then the total purchasing and transportation cost associated with the purchase between supplier s and company k is as follows:

$$c_{sk} = \begin{cases} 0, & c_{sk} = 0, \\ P_{s2} * Q_{sk}, & 0 < Q_{sk} \leq BP_{s1}, \\ P_{s3} * Q_{sk}, & BP_{s1} < Q_{sk} \leq BP_{s2}, \\ \vdots & \vdots \\ P_{sl_s} * Q_{sk}, & BP_{sl_s - 1} < Q_{sk} \leq BP_{sl_s}, \\ P_{s|l_s|} * Q_{sk}, & BP_{s|l_s|-1} < Q_{sk} \leq BP_{s|l_s|}, \end{cases} \tag{1}$$

where $P_{s1} > P_{s2} > \ldots > P_s \mid l_s \mid$. Figure 2 demonstrates an example of total cost according to all-unit discount and piecewise linear cost function.

The following questions are asked to formulate the problem.

1. Where should shrimp companies be established among the potential places?
2. Which of the modes of transportation should be used to transfer input from suppliers to companies and from companies to consumers?
3. How much input should be purchased from suppliers?

To answer the above questions, the mixed integer programming method is used, which shows the general form of the MIP model in equation (2):

$$\begin{aligned} \min \quad & c_x^t + d_y^t \\ \text{s.t.} \quad & Ax + By \leq b \\ & x \geq 0, \quad x \in X \subset \mathfrak{R}^n, \quad y \in \{0, 1\}^q \end{aligned} \tag{2}$$

Figure 2: All-unit discount cost function.

where x is a vector of n continuous variables, y is a vector of q variables of 0 and 1, c and d are parameter vectors, A and B are coefficient matrices with proportional dimensions and b is the source vector. The objective function of the present problem is to minimize the total costs of the shrimp supply chain, including fixed and variable costs of constructing ponds and startup companies, fixed and variable costs of transportation modes, and the cost of purchasing inputs. Also, there are 20 limitations in the model that guarantee the assumptions of the problem. We note that we represent parameters in the model in upper case and decision variables in lower case. The following notation is used for our proposed model:

- **Sets:**

  I: The set of consumers indexed by $i = 1, 2, \ldots, |I|$,

  K: The set of potential companies indexed by $k = 1, 2, \ldots, |K|$,

  S: The set of potential suppliers indexed by $s = 1, 2, \ldots, |S|$,

  l_s: The set of price break-down points for each supplier s indexed by $l_s = 1, 2, \ldots, |L_s|$,

  TM: The set of transportation modes indexed by $m = 1, 2$.

- **Parameters:**

  D_i: Product demand from consumer i,

  C_k^2: Maximum capacity of company k,

  C_s^1: Maximum capacity of supplier s for raw material,

  $N\max$: Maximum number of companies which can be established,

  U: Utilization rate of raw material per unit of the product,

  F_k: Annual fixed cost for opening and operating in company k,

CV^2: Upper limit for changing transportation mode in the second echelon (company-consumer),

CV^1: Upper limit for changing transportation mode in the first echelon (supplier-company),

C^2_{km}: Fixed cost of providing transportation mode m for each company k,

C^1_{sm}: Fixed cost of providing transportation mode m in each supplier s,

G_{kim}: Variable cost of products transportation from company k to consumer i via transportation mode m,

P_{sls}: Unit purchasing and transportation cost of raw material in supplier s and l_s^{th} price interval,

BP_{sls}: Quantity of break-down point ls in supplier s,

M: A big real positive number.

- **Decision variables:**

$z_k = 1$ if company k is established, and 0 otherwise.

$r_{ki} = 1$ if company k serves consumer i, and 0 otherwise.

$V^1_{skm} = 1$ if transportation mode m is used for transporting raw material from supplier s to company k, and 0 otherwise.

$V^2_{kim} = 1$ if transportation mode m is used for transporting products from company k to consumer i, and 0 otherwise.

$y_{skls} = 1$ if purchasing and transportation price of raw materials from supplier s to company k is in the l_s^{th} price interval of supplier s except the $(|L_s|)^{th}$ interval due to the problem's assumptions, and 0 otherwise.

We have $|l_s|$ breakdown points. Then, the total number of intervals would be $|l_s| - 1$ and we should assume $y_{sk|l_s|} = 0$ because of this fact.

$X_{skls} \in [0, 1]$ continuous variable between 0 and 1 for determining purchased raw material from supplier s to company k in the l_s^{th} price interval of supplier s.

$tc_{skls} \geq 0$ continuous variable for determining the total purchasing and transportation cost of raw material shipped from supplier s to company k whose quantity falls within the l_s^{th} and $(l_s - 1)^{th}$ breakdown points of supplier s. $l_s \in L_S$ shows price breakdown points of supplier s; therefore, the number of related price intervals is l_s -1 and the quantity of the first break-down point and its related costs is zero.

We present our MIP model for the two-echelon supply chain network design with transportation mode selection and all-unit quantity discount as follows:

$$\min \quad \sum_k F_k Z_k + \sum_k \sum_i \sum_m (A^2_{km} + G_{kim} D_i) V^2_{kim} + \sum_s \sum_k \sum_m A^1_{sm} V^1_{sm} + \sum_s \sum_k \sum_{l_s} tc_{skl_s} \tag{3}$$

s.t.

$$\sum_k r_{ki} = 1 \quad \forall i = 1 \tag{4}$$

$$U \sum_I D_i r_{ki} \leq C^2_k Z_k \quad \forall k \in K \tag{5}$$

$$U \sum_I D_i r_{ki} \leq \sum_S \sum_{l_s} BP_{sls} X_{skls} \quad \forall k \in K \tag{6}$$

$$\sum_k \sum_{l_s} BP_{sls} X_{skls} \leq C^1_s \quad \forall s \in S \tag{7}$$

$$\sum_k Z_k \leq N_{\max} \tag{8}$$

$$tc_{sls} \geq (BP_{sls} X_{skls} + BP_{s,ls-1} X_{skls-1}) P_{sls} - M(1 - y_{skls-1}) \forall s \in S, k \in K, l_s \in L_S | l_s > 1 \tag{9}$$

$$X_{skls} \leq y_{skls} \quad \forall s \in S, k \in K, l_s \in L_S \quad | l_s = 1 \tag{10}$$

$$X_{skls} \leq y_{skls} + y_{skls-1} \quad \forall s \in S, k \in K, l_s \in L_S 1 < l_s < |l_s| \tag{11}$$

$$X_{skls} \leq y_{skls-1} \quad \forall s \in S, k \in K, l_s \in L_S \quad | l_s = |l_s| \tag{12}$$

$$\sum_{l_s=1}^{|l_s|-1} y_{skls-1} \quad \forall s \in S, k \in K \tag{13}$$

$$\sum_{l_s} X_{skls} = 1 \quad \forall s \in S, k \in K \tag{14}$$

$$\sum_{l_s} BP_{sls} X_{skls} \leq M \sum_{m=1}^{2} V^1_{skm} \quad \forall s \in S, k \in K \tag{15}$$

$$\sum_{l_s} BP_{sls} X_{skls} - CV^1 \leq M V^1_{skm} \quad \forall s \in S, k \in K, m = 2 \tag{16}$$

$$\sum_m V^1_{skm} \leq 1 \quad \forall s \in S, k \in K \tag{17}$$

$$D_i r_{ki} \leq M \sum_{m=1}^{2} V^2_{kim} \quad \forall k \in K, i \in I \tag{18}$$

$$CV^2 - D_i r_{ki} \leq M(1 - V^2_{kim}) \quad \forall k \in K, i \in I, m = 2 \tag{19}$$

$$\sum_m V^2_{kim} \leq 1 \quad \forall k \in K, i \in I \tag{20}$$

$$\sum_{l_s} tc_{skls} \geq 0 \quad \forall s \in S, k \in K, l_s \in L_S \tag{21}$$

$$X_{skls} \in [0,1] \quad \forall s \in S, k \in K, l_s \in L_S \tag{22}$$

$$Z_K, r_{ki}, V^2_{kim}, V^1_{skm}, y_{skls} \in 0,1 \forall k \in K, i \in I, m \in TM, l_s \in L_S \tag{23}$$

Function (3) shows the objective function of the model whereby minimizes the total costs of companies including fixed opening and operating, fixed and variable costs of transportation, and purchasing costs of raw materials. Constraint (4) indicates that each consumer must be assigned to one of the companies. Constraint (5) ensures that demand allocation does not exceed the capacity limits. Constraint (6) ensures that the total output of each company is less than its total input. Constraint (7) ensures that buying raw materials does not exceed the capacity limits. Constraint (8) ensures that the number of open facilities does not exceed $N_{\max}$. Constraint (9) computes the total purchasing and transportation cost of raw material shipped from supplier s to company k whose quantity has been located between l_s^{th} and $(l_s-1)^{th}$ breakdown points. $tc_{sk1} = 0$ because the first break-down point is always zero. Constraint sets (10)-(14) determine the price interval of the purchased raw materials. The way price intervals are calculated is by the piecewise linear function and the linear composition method. More specifically, constraints (10)–(12) determine the portion of each breakdown point in the quantity of the shipped raw materials and constraint. Constraints (10)–(12) refer to the first and last breakdown points where there aren't any other defined price intervals before and after them, respectively (l_s starts from 1 which refers to the first breakdown point in X_{skls} or the first interval in y_{skls}. So, we have | l_s | -1 intervals in total). Constraint (11) covers the intervals between the first and last break-down points. Constraint (13) ensures that this quantity can only belong to one interval. Constraint (14) ensures that the sum of the portions related to the beginning and the end points of each interval must be 1 according to the linear composition method. Constraint (15) ensures that only one of the transportation modes can be utilized to connect the company to the consumer. Constraint (16) ensures that the first mode of transportation cannot be used when the total quantity of shipped raw material from a supplier to a company is less than CV^1. Constraint (17) ensures that only one of the transportation modes can be utilized to connect a company to a consumer. Constraint (18) ensures that only one of the transportation modes can be utilized to connect a supplier to a company. Constraint (19) ensures that the first mode of transportation cannot be used when the total quantity of shipped products from a company to a consumer is less than CV^2. Constraint (20) ensures that only one of the transportation modes can be utilized to connect the supplier to the company. Finally, constraint sets (21) to (23) place restrictions on the nature of our variables. The complexity of our MIP model in the presence of binary variables for the transportation model selection and order quantity is in the order of $O(\max[KIM, SKLs])$. The exclusion of these two factors from our MIP model leads to a model with the size complexity of $O(\max[KI, SK])$. A higher number of binary variables makes a MIP model more difficult to solve due to the number of branching operations required to ensure their integrality. Thus, our problem, in the presence of these two new practical features, is a much more difficult optimization problem than when we do not consider them.

4 Computational Results

As mentioned before, MIP can solve only small instances of the problem in some cases. We need substantially higher computational times to solve the MIP model on the medium and large instances of the problem because the size of the MIP grows quickly as the number of binary and continuous variables in the model increases (i.e., up to 2n branching operations are needed for n binary variables). Since the 1970s, researchers have realized that the complexity of many hard optimization problems can be mitigated if a few complicating constraints are removed and their satisfaction is separately ensured by other heuristic or optimization techniques. The removed set of complicating constraints is therefore dualized, producing a Lagrangian problem that is mostly easy to solve. Therefore, in our study, we used CPLEX solver and GAMS software to solve the MIP model (3 consumers (i), 13 companies (k), and 2 suppliers (s)), first. The computational time is 0.08 seconds. The result showed high-quality solutions that can be found within fractions of the time needed when commercial optimization software was applied directly to the MIP model. In the following, consumers' demand and capacities of all facilities are given in Table 1.

Table 1: Consumer demands and capacities of all facilities

i	D_i (Ton)	k	F_k (Million Rial)	k	C_k^2 (Ton)	S	C_s^1 (Ton)
1	5	1	1106	1	948	1	196
2	35	2	1250	2	812	2	248
3	102	3	1103	3	474		
		4	1117	4	550		
		5	2150	5	761		
		6	1198	6	842		
		7	1377	7	931		
		8	1450	8	522		
		9	1108	9	500		
		10	1118	10	550		
		11	1123	11	775		
		12	2118	12	560		
		13	1103	13	769		

We consider an upper bound of 3 for the number of companies that can be established and assume that one final product consists of 2 units of raw materials. Each supplier offers 4 breakdown points for its purchasing and transportation costs. Two types of transportation modes can be used for shipping raw materials and final products but the second type of transportation mode which contains discounts is forbidden for them if the quantity is lower than 400 and 200 units respectively. The cost of providing these transportation modes is given in Table 2.

Finally, unit purchasing and transportation cost of raw materials and variable cost of product transportation are given in Tables 3 and 4.

The results of the model show that to achieve the minimum cost, companies with numbers 1, 2, 7, 9, 11, and 12 must serve the consumers of the group (α) and (β) and

Table 2: Fixed cost of providing each transportation mode in companies and suppliers (Million Rials)

Transportation mode (m)		1	2
Company (k)	1	130	150
	2	125	148
	3	114	140
	4	112.5	132.5
	5	50	73
	6	125	151
	7	62.5	82.5
	8	62.5	85.5
	9	100	126
	10	125	145
	11	100	123
	12	125	151
	13	100	120
Supplier (s)	1	1256	1600
	2	1400	1100

Table 3: Breakdown points in each supplier and unit purchasing and transportation cost

Breakdown Points (l_s)		1	2	3	4
Supplier 1	BP_{sl_s}	0	230	460	751
	P_{sl_s}	0	17	11	4
Supplier 2	BP_{sl_s}	0	430	517	920
	P_{sl_s}	0	13	5	2

Table 4: Variable cost of transportation from company k to consumer i via mode m (Million Rials)

company (k)	Consumer 1 (α)		Consumer 2 (β)		Consumer 3 (γ)	
	$m=1$	$m=2$	$m=1$	$m=2$	$m=1$	$m=2$
1	0.8	1.2	1.5	2.1	15.6	17.8
2	0.6	0.9	1	1.8	11.8	14.3
3	0.6	0.9	1	1.8	11.8	14.3
4	0.4	0.7	0.8	1.3	9.8	13.8
5	0.5	0.8	0.9	1.9	10	14
6	0.8	1.2	1.5	2.1	15.6	17.8
7	0.8	1.2	1.5	2.1	15.6	17.8
8	0.7	0.9	1.2	2	11.1	17
9	0.8	1.2	1.5	2.1	15.6	17.8
10	0.6	0.9	1	1.8	11.8	14.3
11	0.5	0.8	0.9	1.9	10	14
12	0.8	1.2	1.5	2.1	15.6	17.8
13	0.4	0.7	0.8	1.3	9.8	13.8

other companies serve the consumers of the group (γ). In addition, all products should be carried from companies to consumers by transport mode 1 except when carrying products from companies with numbers 3, 5, and 10 to consumers of the group (γ).

Also, all companies receive their inputs through transport mode 1, and only companies 5 and 10 receive their required inputs from supplier 2 and through transport mode 2. Table 5 summarizes the results of the MIP model.

Table 5: The amount of supplied demand by shrimp farming companies in Golestan province

company (k)	The demand of target market (percentage)		
	α	β	γ
1	0	0.9	0
2	54	0	0
3	0	0	0.002
4	0	0	0.002
5	0	0	0.002
6	0	0	0.007
7	0	0.8	0
8	0	0	0.007
9	23	0	0
10	0	0	0.023
11	23	0	0
12	0	0.3	0
13	0	0	0.01
Total	100	2	0.053

As Table 5 shows, shrimp farming companies in Golestan province will be able to supply 100 percent of the needs in the province by implementing the MIP model. In addition, 2 percent of the products will be sent to the domestic market to supply the demand of other provinces. Also, 85 percent of the province's products are exported, which supplies 0.053 percent of global market demand. It should be noted that currently the companies under study supply 100, 1.48, and 0.03 percent of the needs of target markets, respectively. Also, with the implementation of this model, the total costs of the supply chain will reach 125874.100 million Rials, which is nearly 20 percent less than the current cost.

5 Conclusions and Future Works

In recent years, due to the increase in production of the fisheries sector, international markets, and changes in customers' desires, the seafood business has been astoundingly developed. In many countries, seafood constitutes the most critical part of people's daily diet. Shrimp products are desirable seafood among many populations, and represent a significant amount of food intake in different societies. Shrimp products are either caught in a marine environment like seas and rivers or farmed in aquaculture systems. So, designing a proper supply chain network for shrimp production can offer many benefits for decision-makers, organizations, factories, or even markets to improve the functionality of the supply chain. Thus, this paper introduced a mathematical model for the shrimp supply chain to retrieve the desirable goals of optimizing the total cost of the whole network. To solve this problem, we developed a mixed-integer program, which was able to solve our small problem to optimality. To evaluate this model, two performance measures were considered: the optimality gap (GAP) and the relative percentage deviation (RPD). In this paper, the mean of GAP and PRD were obtained as zero, which indicated the proper performance of the MIP model in finding the feasible solution to the problem. In this paper, we considered a two-echelon supply chain, where level (1) was between the suppliers and the producers and level (2) was between the producers and the consumers; so we prefer that future researches consider other sectors like distribution centers, wholesalers, retailers and so on. Also, future research may need to cover social, environmental, and economical aspects and include them in terms of constraints in the model. Moreover, in real-world settings uncertainty and ambiguity are common for different aspects of the supply chain network especially the demand of markets. For future considerations, the model can be formulated as a stochastic model under the uncertain conditions of demands and other important parameters. Finally, the performance of other exact techniques, including the logic-based Benders decomposition algorithm can be examined for the current work.

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