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Fuzzy Goal Programming for Linear Facility Location-Allocation in a Supply Chain; The Case of Steel Industry

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A B S T R A C T

This paper presents a mathematical model for a facility location-allocation problem in order to design an integrated supply chain. We consider a supply chain including multiple suppliers, multiple products, multiple plants, multiple transportation alternatives and multiple customer zones. The problem is to determine a number and capacity level of plants, allocation of customers demand, and selection and order allocation of suppliers. A multi-objective mixed-integer linear programming (MOMILP) is presented with two conflicting objectives simultaneously. The first objective is to minimize the total costs of a supply chain including raw material costs, transportation costs and establishment costs of plants. The second objective function aims to minimize the total deterioration rate occurred by transportation alternatives. Finally, by applying the fuzzy goal programming, the model is solved as a single objective mixed-integer programming model. An experiment study shows that the proposed procedure can provide a promising result to design an efficient supply chain.

Keywords: *Supply chain management, facility location-allocation, fuzzy goal programming, Steel industry.*

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1. Introduction

Traditionally, commercial innovations in products, processes and services typically were achieved within vertically integrated industrial corporations. During the 1990's, however, the global competitive environment has shifted towards a horizontal on virtually integrated industry structure involving close interaction among suppliers, manufacturers and customers in a supply chain. Number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to acquire raw materials, convert these

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raw materials into specified final products and deliver these final products to retailers [5].

So far, most attentions in supply chain studies are focused on some well-known problems such as supplier selection [2,9,12], distributor selection [1,10,13], and site selection issues. However, logistic design, reverse supply chain design, location-allocation problem, etc. are the modern issues that are rapidly spreading. One of the most representative examples on a supply chain problem is a well-known facility location-allocation problem that has been a well-established research area within operations research. Facility location is a critical component of strategic planning for a broad spectrum of public and private firms [25]. A general facility location problem involves a set of spatially distributed customers and a set of facilities to serve customer demands (see, e.g. Drezner & Hamacher [7]; Nickel & Puerto [24]). Therefore, possible questions to be answered are: (i) Which facilities should be used (opened)? (ii) Which customers should be serviced from which facility (or facilities) so as to minimize the total costs? In addition to this generic setting, a number of constraints arise from the specific application domain. For this, it is necessary to consider many criteria such as cost or distance from demand points.

The study of facility location–allocation problems has a relatively long history. Cooper [6] presented the basic facility location–allocation problem that is to decide locations of warehouses and allocation of customers demand given the locations and demand of customers. Since then, this problem has received much attention from other researchers and has been analyzed in a number of different ways. Many extensions of facility location–allocation problems have been studied in the literature; for instance, a dynamic multi-period location–allocation problem ([22,28], a continuous site location problem [16], a joint facility location–allocation and production problem [18,20], a capacitated facility location–allocation problem [8,20,28] and a multi-objective facility location–allocation problem [4,17,27,32]. For the detailed literature review on facility location–allocation problems, readers are referred to Drezner and Hamacher [7], Klose and Drexl [19], Melo et al. [23] and Farahani et al. [8].

Harris et al. [14] proposed an efficient evolutionary multi-objective optimization approach to the capacitated facility location–allocation problem (CFLP) for solving large instances that consider flexibility at the allocation level, where financial costs and CO_2 emissions are considered simultaneously. Jamalnia [15] suggested a new use of Quality Function Deployment (QFD) for facility location selection problem. To consider resource limitations and operational constraints, Fuzzy Goal Programming (GP) was combined with fuzzy QFD to present a developed approach to deal with global facility location-allocation decision. Zahir and Sarker [31] combined GP with the Analytic Hierarchy Process (AHP) to determine optimal plant and distribution centre locations in a supply chain with special focus on the operational efficiencies of the Distribution Centres (DCs). Ghorbani et al. [11] proposed a fuzzy goal programming–based (FGP–based) approach for solving a multi–objective mathematical model of reverse supply chain design.

In this paper we consider several suppliers, several plants, and several customer zones with different transportation alternatives (TAs). The supply chain produces two kinds of different products to fulfill the customers' demands, in which the information is given for one period (i.e. planning period). Two main objectives are minimizing the total cost of supply chain and minimize the deterioration rate caused by different TAs. but these objectives are conflict with each other. So using FGP, these two objectives are then combined and the single objective programming is solved. Thing that is more important in this paper, is developing a model to determine the best position for plants with respect to whole supply chain parts under uncertain customer demands and cost parameters. While in other papers, this matter is studied just with one or two part of supply chain. Furthermore, to enable the model to deal with real situations, different TAs are considered in the whole supply chain. The results show that the proposed model enables decision makers to design an effective supply chain and provide with a global insight to plan for a whole supply chain.

The remainder of the paper is organized as follows. Section 2 presents the problem description and formulation. Then, solution procedure is described in Section 3. Case study and computational results are presented in Section 4. Discussion the case results are in the Section 5. Finally, conclusions and future work are presented in Section 6.

2. Model description

The proposed multi-objective mathematical model can be described as follows. There are I potential plants, J suppliers and C customers. The problem is to determine the set of plants to be opened and the capacity level of these plants. Also, the quantity of raw materials r provided by supplier j to fulfill requirement of plant i and quantity of end products m shipped to customers are determined in a way that the total cost and the deterioration rate of transportation are minimized simultaneously. It is worth noting that different TAs are allowed in the whole supply chain network. In other words, this paper is going to determine the best position for plants and the capacity level of these plants with respect to whole supply chain parts.

2.1. Indices and Parameters

i	Index for plants ($i = 1, \dots, I$)
j	Index for suppliers ($j = 1, \dots, J$)
r	Index for raw materials ($r = 1, \dots, R$)
q	Index for TAs ($q = 1, \dots, Q$)
m	Index for end products ($m = 1, \dots, M$)
c	Index for customer zones ($c = 1, \dots, C$)
P_{mc}	Selling price of product m in customer zone c
TCS_{jirq}	Transportation cost of raw material r from supplier j to plant i using TA q
TCC_{icmq}	Transportation cost of product m from plant i to customer zone c using TA q
CM_{rj}	Purchasing cost of raw material r supplier j
ES_{in}	Establishing cost of plant i in capacity level n
D_{mc}	Demand for product m in customer zone c
Y_{rm}	Number of units of raw material r required for each unit product m
C_{jr}	Maximum number of raw material r supplier $j$could produce
b_{in}	Capacity level n for plant i

α_{rq} Deterioration rate for raw material r using TA q
β_{mq} Dterioration rate for product m using TA q

2.2. Decision variables

SUP_{jirq} Number of units of raw material r shipped from supplier j to plant i using TA q
CUS_{icmq} Number of units of product m shipped from plant i to customer zone c using TA q
X_{mi} Number of product m produced in plant i
S_{in} Equal to 1, if plant i established in capacity level n.

2.3. Mathematical model

$$\text{Min } Z_1 = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q} CM_{rj}.SUP_{jirq} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q} TCS_{jirq}.SUP_{jirq} + \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{q=1}^{Q}\sum_{m=1}^{M} TCC_{icmq}.CUS_{icmq} + \sum_{i=1}^{I} ES_{in}.S_{in} - \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{q=1}^{Q}\sum_{m=1}^{M} P_{mc}.CUS_{icmq} \quad (1)$$

$$\text{Min } Z_2 = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q} \alpha_{rq}.SUP_{jirq} + \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{m=1}^{M}\sum_{q=1}^{Q} \beta_{mq}.CUS_{icmq} \quad (2)$$

The first objective (Eq. 1) aims to minimize costs of supply chain including, purchasing costs, transportation costs, establishment costs. The second objective (Eq. 2) tries to minimize the deterioration rate caused by different TAs.

Constrains are as follows:

$$\sum_{j=1}^{J}\sum_{q=1}^{Q} SUP_{jirq} = \sum_{m=1}^{M} X_{mi}.Y_{rm} \qquad \forall i, r \quad (3)$$

$$\sum_{i=1}^{I}\sum_{q=1}^{Q} CUS_{icmq} = D_{mc} \qquad \forall C, m \quad (4)$$

$$X_{mi} = \sum_{c=1}^{C}\sum_{q=1}^{Q} CUS_{icmq} \qquad \forall i, m \quad (5)$$

Constraints 3-5 are balance equations for the raw materials, demand of customers and end products.

$$\sum_{i=1}^{I}\sum_{q=1}^{Q} SUP_{jirq} \leq C_{jr} \qquad \forall j, r \tag{6}$$

This equation specifies the maximum available raw material that can be produced by supplier *j*.

$$\sum_{m=1}^{M} X_{mi} \leq \sum_{n=1}^{N} b_{in}.S_{in} \qquad \forall i \tag{7}$$

$$\sum_{m=1}^{M} X_{mi} \geq \sum_{n=1}^{N} S_{in} \qquad \forall i \tag{8}$$

Eqs. (7) and (8) defines the relationship between product quantities and capacity level of plants. In this equation, index "n" shows capacity level of each plant.

$$\sum_{n=1}^{N} S_{in} \leq 1 \qquad \forall i \tag{9}$$

Finally, Eq. (9) ensures that each plant can only have one capacity level.

3. Solution procedure

Goal Programming (GP) is one of the most powerful, multi-objective approaches in real-world decision-making. The FGP is an optimization tool to incorporate uncertainty and imprecision into the formulation. FGP has an extensive application in the literature [21,26,29]. Consider a problem with the following minimization objectives [30]:

$$Z_l(X) \leq g_l \quad l = 1,2,\dots,b \tag{10}$$

s.t.

$$d_j(X) \leq D_j \quad j = 1,2,\dots,m \tag{11}$$

Where b is the number of fuzzy minimum goal constraints and m is the number of system constraints. Let p_l denote the maximum tolerance limit to g_l set by the DM. Thus, using the concept of fuzzy sets, the membership function of the objective functions can be defined as follows [33]:

$$\mu_{Z_l}(X) = \begin{cases} 1 & \text{if } Z_l(X) \leq g_l \\ 1 - \frac{Z_l(X)-g_l}{g_l} & \text{if } Z_l(X) \geq g_l + p_l \\ 0 & \text{if } g_l \leq Z_l(X) \leq g_l + p_l \end{cases} \tag{12}$$

The term $\mu_{Z_l}(X)$ indicates the desirability of the DM to solution X in terms of objective l. Figure 1 shows the corresponding graph of Eq. 12.

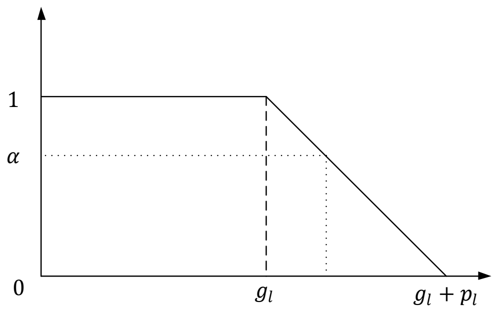

Fig.1. Membership Function Related to Objectives

The optimal solution, X^*, must maximize $\mu_Z(X)$ by solving the following mathematical programming:

$$\begin{aligned} &\max \alpha \\ &\alpha \leq \mu_{Z_l}(X) \quad ; \quad l = 1,2,\dots,b \\ &d_j(X) \leq D_j \quad ; \quad j = 1,2,\dots,m \end{aligned} \tag{13}$$

4. Case study and computational results

In this section, a real world industrial case from steel industry in Iran is considered to show the applicability of the proposed model. At first we describe case study and finally results have computed.

4.1. Case description: Steel industry in Iran

Nowadays, different technologies can be used to get the molten or crude steel. In 2011, over 1.4116 billion tons of crude steel has been produced in the world. About 70 percent of this amount has been produced by blast furnace technology. China, as the largest crude steel producer in the world in 2010, has produced about 90 percent of its total crude steel production by using blast furnaces. On the other hand, among 19.3 million tons of produced crude steel in the Middle East, about 12.4 percent has been produced by this technology. Iran, as one of the major producers of crude steel in Asia, also produces about 12 million tons of crude steel yearly and over 12 percent of its production is produced by blast furnaces. Zobahan Isfahan plant as one of the largest steel producers in Iran also uses this technology. In the following the process of production is described concisely.

After mining, the ores are delivered to a steel mill except for some non-ferrous metals that use electro-chemical means to make the non-ferrous metal. When the ore is delivered to the steel mill they are prepared by crushing and grinding to a smaller size to increase the surface area to the volume. Unfortunately, the ground iron ore must be sintered. Sintering is done by partial pre-cooking the iron ore in the presence of coke oven gases. The ore is now called sintered and is used to charge the blast furnace.

Now the sintered iron ore is prepared to be heated to a very-very high temperature where the ore melts in the presence of gases. Knowing what temperatures the components in the ore melt at is critical. Iron ore's principal component in the mined rock is Fe_2O_3. This iron oxide also known as iron-oxide-III is plentiful enough to be commercially feasible to make steel. In the rock we will have small amounts of silica, sulfur and other undesirable ones. Some can be removed in the steel making process and others we tolerate.

In the second step, after mining and crushing the ore into manageable sizes is to make iron in the steel making process from the iron ore laden Fe_2O_3. Blast furnace is used to strip away the O_3 (oxygen) in the Fe_2O_3 laden ore by adding a great amount of heat in the presences of coke, which is a pure form of carbon (C), and limestone ($CaCO_3$) principally calcium carbonate. Limestone principally removes the silica from the iron ore in the steel making process. Using coke and limestone, which is heated to high temperatures with great amounts of compressed air in the presences of the iron ore we cause two-types of chemical reactions. Then, the oxygen is reduced out of the iron ore and transformed by oxidation to (carbon dioxide) CO_2. Stripping away O_3 (oxygen) is called reducing. In the following, our proposed model and results are presented.

4.2. Model application and experimental results

Consider a supply chain with two products, six customer zones, five potential locations for plants, four raw materials, two TAs and eleven suppliers. According to the above information, raw materials required to produce steel are lime (r1), iron ore (r2), coke (r3) and oxygen (r4). Raw materials are available as ore or via industrial centers. There are several resources for each raw material that is shown in Table 1.

Five potential locations, Isfahan (i1), Bandar Abbas (i2), Ahvaz (i3), Yazd (i4) and Mashhad (i5) are identified to establish plants. Also, six major DCs are selected according to population density, industrial centers and steel consumption rate. Shiraz (c1), Isfahan (c2), Arak (c3), Tehran (c4), Tabriz (c5) and Ahvaz (c6) are these six major DCs. Fig. 2 shows the location of suppliers, plants and DCs. In the majority of steel production centers, two classes of products are delivered, 15-ton coils (m1) and 9-ton slab (m2). Two TAs, railroad (q1) and truck (q2) are available to transport raw materials to plants and also products to DCs. Demand and selling prices of each customer zone are shown in Table 2. Table 3 and Table 4 show transportation cost of products and raw materials. Data related to purchasing cost of raw materials and maximum capacities of suppliers are shown in Table 5. Finally, capacity level and establishment costs of plants are depicted in Table 6. It should be mentioned that the deterioration rate of products and raw materials due to TAs are 0.15 and 0.1 respectively.

Table 1. Resource Place of Each Raw Material

Raw materials	Suppliers
Lime (r_1)	Isfahan (j_1), Ahvaz (j_2), Hamedan (j_3), Kerman (j_4),Yazd (j_5), Bandar Abbas (j_7), Shahrud (j_8) and Sari (j_9)
Iron ore (r_2)	Kerman (j_4), Yazd (j_5), Bandar Abbas (j_7) and Urmia (j_{10})
Coke (r_3)	Kerman (j_4), Shahrud (j_8) and Sari (j_9)
Oxygen (r_4)	Isfahan (j_1), Ahvaz (j_2), Arak (j_6) and Tabriz (j_{11})

Table 2. Demand of customer zones and sales price

Products	Customer zones (Demand)						Customer zones (Sales price)					
	1	2	3	4	5	6	1	2	3	4	5	6
1	9000	50000	40000	90000	10000	30000	12657	12700	12775	12725	12600	12600
2	8000	80000	90000	30000	80000	15000	7450	7400	7500	7470	7500	7480

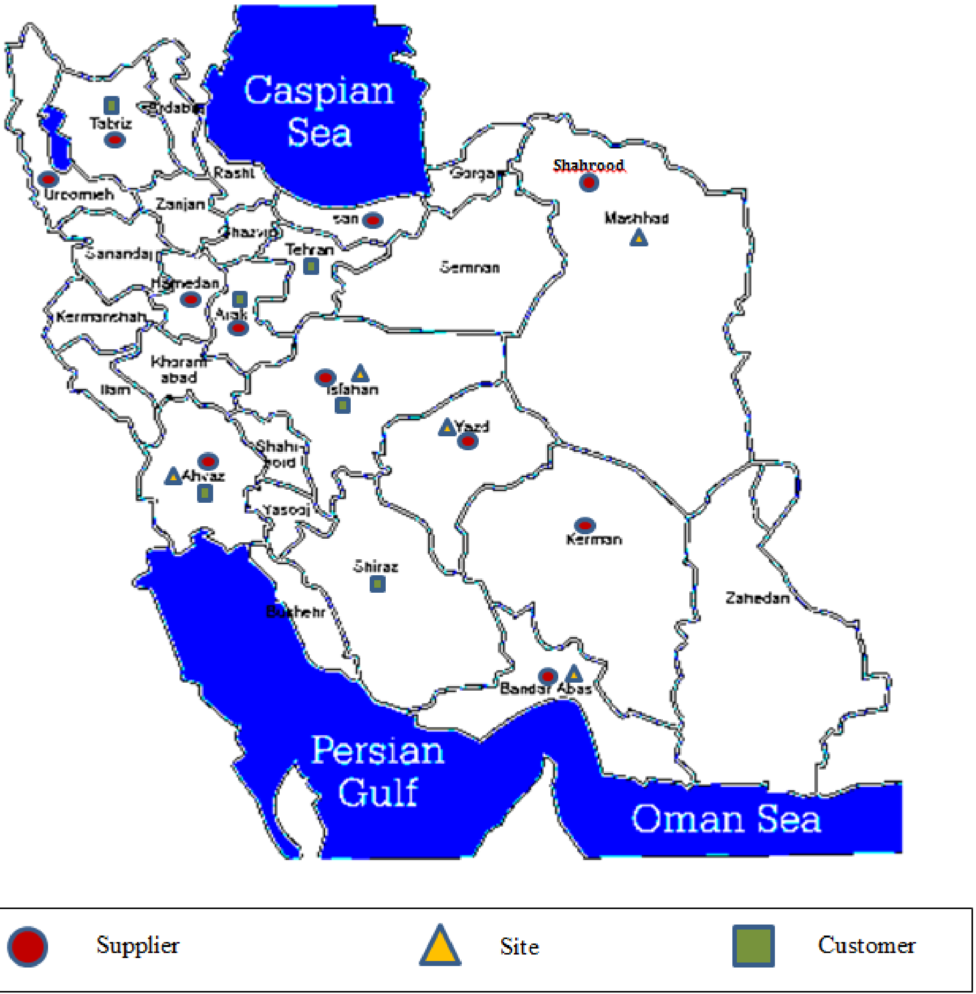

Fig 2. Location of suppliers, plants and distributors

Table 3. Transportation cost of products

Plants	Products	Customer zones 1		2		3		4		5		6	
		q1	q2	q1	q2	q1	q2	q1	q2	q1	q2	q1	q2
1	1	244.7	146.8	81.6	8156.6	224.3	135.9	244.7	146.8	275.3	163.1	254.9	152.3
	2	81.6	48.9	27.2	8156.6	74.8	45.3	81.6	48.9	91.8	54.4	85.0	50.8
2	1	234.5	141.4	254.9	152.3	265.1	157.7	275.3	163.1	305.9	179.4	244.7	146.8
	2	78.2	47.1	85.0	50.8	88.4	52.6	91.8	54.4	102.0	59.8	81.6	48.9
3	1	224.3	135.9	254.9	152.3	265.1	157.7	275.3	163.1	285.5	168.6	81.6	8156.6
	2	74.8	45.3	85.0	50.8	88.4	52.6	91.8	54.4	95.2	56.2	27.2	8156.6
4	1	234.5	141.4	224.3	135.9	228.4	138.1	234.5	141.4	285.5	168.6	275.3	163.1
	2	78.2	47.1	74.8	45.3	76.1	46.0	78.2	47.1	95.2	56.2	91.8	54.4
5	1	275.3	163.1	265.1	157.7	254.9	152.3	244.7	146.8	346.7	201.2	336.5	195.8
	2	91.8	54.4	88.4	52.6	85.0	50.8	81.6	48.9	115.6	67.1	112.2	65.3

Table 4. Transportation cost of raw materials

Suppliers	Raw materials	Plants 1		2		3		4		5	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1	31.7	7936.5	91.3	119.0	103.2	131.0	79.4	107.1	99.2	127.0
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	31.7	7936.5	91.3	119.0	103.2	131.0	79.4	107.1	99.2	127.0
2	1	103.2	131.0	95.2	123.0	103.2	7936.5	107.1	7936.5	115.1	7936.5
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	103.2	7936.5	95.2	7936.5	103.2	7936.5	107.1	7936.5	115.1	7936.5
3	1	91.3	119.0	107.1	134.9	99.2	7936.5	95.2	7936.5	103.2	7936.5
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
4	1	91.3	119.0	87.3	115.1	99.2	127.0	79.4	107.1	95.2	123.0
	2	91.3	119.0	87.3	115.1	99.2	127.0	79.4	107.1	95.2	123.0
	3	91.3	119.0	87.3	115.1	99.2	127.0	79.4	107.1	95.2	123.0
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
5	1	79.4	107.1	91.3	119.0	99.2	127.0	31.7	7936.5	79.4	107.1
	2	79.4	107.1	91.3	119.0	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
6	1	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	79.4	7936.5	99.2	7936.5	103.2	7936.5	87.3	7936.5	79.4	7936.5
7	1	91.3	119.0	31.7	7936.5	95.2	123.0	91.3	119.0	111.1	138.9
	2	91.3	119.0	31.7	7936.5	95.2	123.0	91.3	119.0	111.1	138.9
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
8	1	87.3	115.1	103.2	131.0	107.1	134.9	79.4	107.1	87.3	115.1
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	87.3	115.1	103.2	131.0	107.1	134.9	79.4	107.1	87.3	115.1
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
9	1	95.2	123.0	115.1	142.9	119.0	146.8	99.2	127.0	91.3	119.0
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	95.2	123.0	115.1	142.9	119.0	146.8	99.2	127.0	91.3	119.0
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
10	1	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	2	103.2	131.0	115.1	142.9	103.2	131.0	104.8	132.5	116.7	144.4
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
11	1	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	2	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	3	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5	7936.5
	4	107.1	7936.5	115.1	7936.5	111.1	7936.5	108.7	7936.5	112.7	7936.5

Table 5. Purchasing cost and capacity of suppliers for raw materials

Suppliers	Raw material (cost)				Raw material (capacity)			
	1	2	3	4	1	2	3	4
1	235000	1000000	1000000	408000	150000	0	0	300000
2	215000	1000000	1000000	421000	200000	0	0	300000
3	209000	1000000	1000000	1000000	150000	0	0	0
4	271000	185000	180000	1000000	100000	100000	1000000	0
5	245000	149000	1000000	1000000	100000	400000	0	0
6	1000000	1000000	1000000	387000	0	0	0	300000
7	239000	175000	1000000	1000000	150000	100000	0	0
8	215000	1000000	174000	1000000	100000	0	3000000	0
9	248000	1000000	183000	1000000	100000	0	1000000	0
10	1000000	170000	1000000	1000000	0	300000	0	0
11	1000000	1000000	1000000	391000	0	0	0	200000

	Units of raw materials required for products			
Products	1	2	3	4
1	2.3	2.1	9.7	1.1
2	1.4	1.3	5.8	0.6

Table 6. Establishment cost and capacity of plants

Plants	1		2		3		4		5	
	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$
ES. Cost*	150	210	140	220	145	200	135	215	145	215
Capacity	150000	300000	150000	300000	150000	300000	150000	300000	150000	300000

* Cost unit is million Dollars

All computations are run using the branch-and-bound algorithm accessed via LINGO 11.0 on a PC Pentium IV-3 GHz and 4 GB RAM DDR under Windows 7. The presented hereunder are the resulted solution for which we rely on a set of the above-mentioned records in respect of the data presented. Tables 7 to 9 represent the output data characteristics by using the FGP.

Table 7. Production quantity in planning period

Products	Plant1		Plant2		Plant3		Plant4		Plant5	
	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$	$n1$	$n2$
1		80000				149000				
2		200000				103000				

Table 8. Supplier selection and order allocation

Suppliers	Raw materials	Plants									
		1		2		3		4		5	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1								150000		
2	1		200000								
3	1		150000								
4	2								60832		
	3								974490		
5	1		100000								
	2		400000								
6	4	7011	202990						90000		
7	1								150000		
	2								100000		
8	1								100000		
	3		1935000						1065000		
9	1								74300		
10	2		19100						280900		
11	4								131340		

Table 9. Market share for each plant

Plants	Products	Customer zones											
		1		2		3		4		5		6	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1						40000				10000		30000
	2						90000		15000		80000		15000
4	1		9000		50000				90000				
	2		8000		80000				15000				

Table 7 presents the set of the selected plants with their relative capacity level and the quantity that should be produced during the planning period. As shown in Table 7, plant 1 with a capacity of level 2 (i.e., 150000) and plant 3 with a capacity of level 2 are established. Blank cells are equal to 0 in this table and other similar data. The selected suppliers and allocated orders are presented in Table 8. Table 9 presents the market share of each plant considering customer zones.

5. Discussion

The proposed model is a multi-objective mixed-integer linear programming (MOMILP) with completely inconsistent objective functions. So, to solve the problem, FGP, which is one of the well-known methods for solving multi-objective problems, is used. According to this method, a multi-objective problem is solved by considering each objective functions separately, and then a single objective is reformulated that aims at minimizing the summation of the normalized differences between each objective and the optimal values of them.

In our presented model, it is assumed that two objective functions are named Z1 and Z2. As stated before, to present the importance of considering three types of costs and deterioration rates simultaneously, the following models are extracted for a further analysis.

1) Model 1 consists of the total costs of the supply chain (Z_1) subject to the relevant constraints.
2) Model 2 consists of the sum of the deterioration rates considering TAs (Z_2) subject to the relevant constraints.
3) The FGP model which considers both objectives simultaneously (Z_3) subject to the relevant constraints.

Based on the FGP model, each objective functions is solved once separately. The optimal values are 1,209,906,000,000 and 672,296.1 for Z1 and Z2. Considering Z1 as an objective function, obtained results of solving proposed model are shown in Table 10-12.

Table 10. Production quantity in planning period

Products	Plant1		Plant2		Plant3		Plant4		Plant5	
	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2
1		80000					44445			104555
2		95000		110000						98000

Table 11. Supplier selection and order allocation

Suppliers	Raw materials	Plants									
		1		2		3		4		5	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1		24300								
2	1		183951		16049						
3	1				132451						17549
4	1								100000		
	2	60832									
5	1										100000
	2				64555						335445
6	4				13151			46666			171523
7	1										150000
	2								93132		6867
8	1										100000
	3		325475		638560				429996		1580460
9	1		100000								
	3		1000000								
10	2		226252		73748						
11	4		143850		56150						

Results of solving proposed model considering just Z2 as objective function are shown in Tables 13 to 15.

Table 12. Market share for each plant

Plants	Products	Customer zones 1		2		3		4		5		6	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1		8999					71001					
	2						65000	30000					
2	1												
	2			80000		15000							15000
4	1								14444			30000	
	2												
5	1			50000			40000		4555		10000		
	2		8000				10000				80000		

Table 13. Production quantity in planning period

Products	Plant1		Plant2		Plant3		Plant4		Plant5	
	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2	*n*1	*n*2
1	77000		12000							140000
2	73000		110000							120000

Table 14. Supplier selection and order allocation

Suppliers	Raw materials	Plants 1		2		3		4		5	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1		97300								
2	1										127000
	4		126840								
3	1										150000
4	1				100000						
	2				100000						
	3				754650						
5	1										100000
	2		253137								107695
6	4				81900						22600
7	1		150000								
	2				63449						36551
8	1										100000
	3		1168740								1051100
9	1		24500		75500						
	3										1000000
10	2										300000
11	4										200000

Considering just one objective may sacrifice the other. Comparison of the results shows that the FGP model makes a trade-off between these two objective functions. Now, the objective functions are formulated using the FGP and the optimal value 0.9964945 is calculated.

Table 15. Market share for each plant

Plants	Products	Customer zones											
		1		2		3		4		5		6	
		*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2	*q*1	*q*2
1	1				37000						10000		30000
	2						58000						15000
2	1		9000		3000								
	2								30000		80000		
5	1				10000		40000		90000				
	2		8000		80000		32000						

6. Conclusion

Iran's steel industry has always been very important to this country from two viewpoints. First, its importance in industrialization and promotion of infrastructures and Second, create sustainable jobs and engagement in the country. Hence, as an important point in the way of developing this industry, location-allocation of plants in a supply chain is considered in accordance with the customer needs, different TAs between DCs, plants and suppliers and their relative deterioration rate.

In this paper, we considered the facility location-allocation problem to design a supply chain in the presence of different transportation alternatives (TAs). The model was applied to the steel industry in Iran. Two main objectives were considered to minimize supply chain costs and deterioration rate. First, each objective was solved separately, and then the FGP was applied to solve the given problem as a single objective problem. The results indicated that the proposed model could provide a promising result to design an efficient supply chain.

The main limitations of this study are as follow:

- Environmental negative effects on the urban population are not considered in choosing the optimal location to establish new plants.
- One of the challenges that the industry is faced with is dealing with the shortage of raw materials. In the proposed model, this possibility is not considered. In other words, lead time of supplying raw materials is not considered to deal with shortages.

In terms of future work, some other objectives can be considered to extend the proposed model, such as scheduling issues, the possibility of export and proximity to ports and borders. Furthermore, using approaches to incorporating uncertainty (e.g., fuzzy programming) seems to be interesting. Metaheuristic approaches can be used to solve similar modelling with more complexity. Other extensions for this research can be considered global issues, such as taxes, tariffs and exchange rates in multiple periods.

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