Science Arena Publications
Specialty Journal of Engineering and Applied Science
ISSN: 2520-5943
Available online at www.sciarena.com
2019, Vol, 4 (1): 45-59

Network of Supply Chain in Uncertainty Condition and Disturbances of Suppliers (Case Study: The Steel Supply Chain)

Hossein Jannatifar

Department of Management, Faculty of Literature and Humanities, Islamic Aazad University, Qom branch. Qom, Iran.

Email: H.janatifar@ut.ac.ir

Abstract: *This paper designs a three-level green chain network in uncertainty condition and random disturbances of suppliers. The under evaluated supply chain is the steel supply chain which has three levels of iron ore suppliers, producers of three products of billet, bloom and slab (steel products) and consumers. In this problem, it is assumed that the customers' demands, supply capacity of suppliers and capacity of production and casting have uncertainty. The Robust Optimization Approach has been used for modeling uncertainty of parameters. Also in this network, it is assumed that supplier can be stationary or non-stationary against random disturbances, purchase cost from a stationary supplier is more but this supplier can supplies orders of producers completely both in normal and disturbance conditions. In the under evaluated question, two functions of cost of whole network and total environmental effects are minimized. A solving method has been used which has been founded based on fuzzy concepts to combine two objective functions. At the end, after solving problem for the steel supply chain, operation of the proposed robust model has been evaluated against the deterministic model.*

Keywords: *The Steel Supply Chain, the Environmental Effects of Supply Chain, Stationary and Non-Stationary Suppliers, Robust Optimization*

INTRODUCTION

The supply chain is a network of facilities including suppliers, manufacturing units, assembly and distribution centers in order to satisfy all customer demand, material and information going on within and between them. The supply chain not only includes the activities of production and supply, but also includes activities, transportation, warehousing and retail as well. making-Decision in the field of supply chain management like any other decision-making process, according to the rotation and frequency of taking that decision as well as the affected time horizon takes place in three strategic levels) long-term (tactical) medium-term (operational) Short term. Recently, many studies have been done in the field of designing supply chain network, but environmental issues in designing a supply chain network has considered less. In one of these studies Pishvaee et al. (2011) have been designed closed-loop supply chain network in conditions of demand uncertainty, transportation cost and rate of return. In another studies, they designed supply chain network of perishable goods in perky environment by using this approach to optimize) Hasani et al., 2012 (In this research demand and the cost of purchase were considered as uncertain parameters. Finally, the necessity of using optimization model rests against deterministic model was demonstrated by using numerical experiments. Vahdani et al. (2012a) by using a combination of rests optimization, theory and fuzzy multi-objective programming has designed a direct-reversed logistics network in the industry. In this research, demand, transportation costs, cost of construction and facility capacity are considered as uncertain parameters. In another study, Tabrizi and Razmi (2013), designed a distribution network of multi-product, multi-source and multi- capacities by using this optimization approach of a model rests. In another recent research, Baghalian et al (2013) has been presented a designing model of multi- product supply chain network due to demand uncertainty. The authors used a stochastic programming for modeling demand uncertainty. A linear programming model of multiple-objective possibility integer has been presented for designing closed-loop and multi-period supply chain network in uncertainty conditions .The authors designed a direct supply chain network and inverse to the environmental and social considerations by using possibility of credit -based programming and possible programming. (Pishvaee et al., 2012a,c).(Salehi Sadeghiani, 2015) designed supply chain network with respect to operational risk and the risk of disturbances. A proposed model of the authors is a scenario-based programming model possibility.

In another conducted research in a two-fuzzy model is presented for design problem of supply chain network. The presented model has been caused increasing the elasticity of network) Kristianto et al. 2014. Another researches that have been used the programming possibility to design a network, can be refer to (Vahdani et al., 2012b; Vahdani et al., 2013a, b).

In most issues of locating and designing supply chain network it is supposed that manufacture or distribution facilities and… Are always healthy and available. But when they are disordered, the structure of a model or network will change generally and the current developed models can not be responsible to these conditions. Therefore, these models should be designed so that to be efficient in conditions of disorder (Peng et al., 2011). Another study that has considered disordered risk of the issue of statement- integrated locating, has presented by (Aryanezhad et al. 2010) in this study has supposed that distribution centers are suffered random disorder. In two researches that have done recently (Azad et al., 2013, 2014) designed a direct logistics network where facilities and modes of transportation disorder randomly. In these researches have been used reliable strategies to deal with random disorders. (Mary & et al, 2014) has investigated design problem of sustainable supply chain network in the situation of disorder risk. The authors have had special emphasis to dimension of environmental supply chain besides focusing on risks of disorder. Azad & et al (2014) presented a designing model of supply chain network to relief the effect of disorder in distribution center. In other studies closed-loop supply chain network is designed in conditions of disorders in distribution and manufacturing centers in an uncertainty conditions (Hatefi et al., 2014 a,b; Hatefi and Jolai, 2015; Torabi et al., 2015). The evolution of network design literature indicates that integrated design of direct supply chain networks in recent years has attracted the attention of many researchers to itself. In addition, in recent years, models have developed in this area, but it is felt to presenting advanced and more real models that consider parameter uncertainties and random disorders of suppliers, simultaneously. In addition, considering the importance of environmental issues it is felt to design a supply chain network in the conditions of sustainable development.

In the following it will refers to the how to organize the article. In section 2, evaluated to the environmental effects in the supply chain. In section 3 will presents the intended issue. Also, the proposed mathematical model and proposed rests model are presented for target issue in this section. in section 6 The proposed solution method is presented. In Section 5 the steel supply chain and data will be presented. The obtained results of the model solution are presented in Section 6 and in the final section will be discussed conclusions.

Environmental effect evaluation of the supply chain

Standard environmental indicators are numbers that indicate the whole load perimeter of a product or process. With these standard environmental indicators, any designer or product manager can analyze the environmental effect of the production during their lives cycle. Then several design options can be compared to each other. (Rezaee et al, 2015).

Each product somehow will destroy the environment. Raw materials should be extracted, the product should manufacture, distribution and packaging and finally to be discarded. Furthermore, environmental effects often occur during the use of product because the product uses energy or materials. So if we want to evaluate the extent of environmental destruction a product, we should study all phases of life cycle of product. (Talaei et al., 2016). The environmental analysis of all phases of the life cycle is called life cycle assessment1 or for short LCA.

Lots of options may be produced during the process of designing a supply chain .These options have been analyzed by the designer and then, the best design option is selected. These design options should include analysis and selection of the environmental aspects of the product In order to realize the environmental. Standard Eco-indicator values have been developed for designers as an instrument for doing this. The following steps should always be followed to ensure proper use of Eco-indicator. (Goedkoop, and Spriensma, 2001).

Step 1: Determine the purpose of calculating Eco-indicator

In this step it will be determined the product or product component that its environmental effect should be calculated.

Step 2: definition of the product life cycle

Adjust a schematic overview of the product life cycle. Have an equal attention to the production, consumption and processing of waste.

Step 3: the quantification of materials and processes

In the LCA method, «the description of product life cycle and performance," is called applied unit. Now, quantification can be applied to any process in the tree of process based on this applied unit and products data. For the quantification of materials and processes we operate as follows.

- ✓ Determination of an applied unit
- ✓ Quantification of all relevant processes of the process tree
- ✓ Making hypotheses for missed data

Step 4: Calculate the environmental effect of products or processes

- ✓ Bring the materials and processes in the related forms carefully and enter their values.
- ✓ Find the values of Eco-indicator related to each case and enter in the form.
- ✓ Calculate the final numbers by multiplying the values of materials and processes in related index values.
- ✓ Gather the obtained results of the previous step together.

Statement of the problem

In this article a supply chain of three-level has considered including suppliers, manufacturers and customers. The problem includes decisions relating to the selection of steady and unsteady suppliers, determine production levels, the allocation of customers to manufacturers and determine the amount of on transportation freight of each node belonging to a level to a node of another level in a tensile supply chain. The required raw material of producers is in bulk, so that each of them requires iron ore of specific ratio of compatibility and required iron ore of each producer achieved of combination of iron ore offered by the various mines with a certain ratio. Mines also offer an Iron ore with specific ratio of compatibility that may not be usable by any manufacturer alone. The studied steel supply chain network has been shown in the following figure.

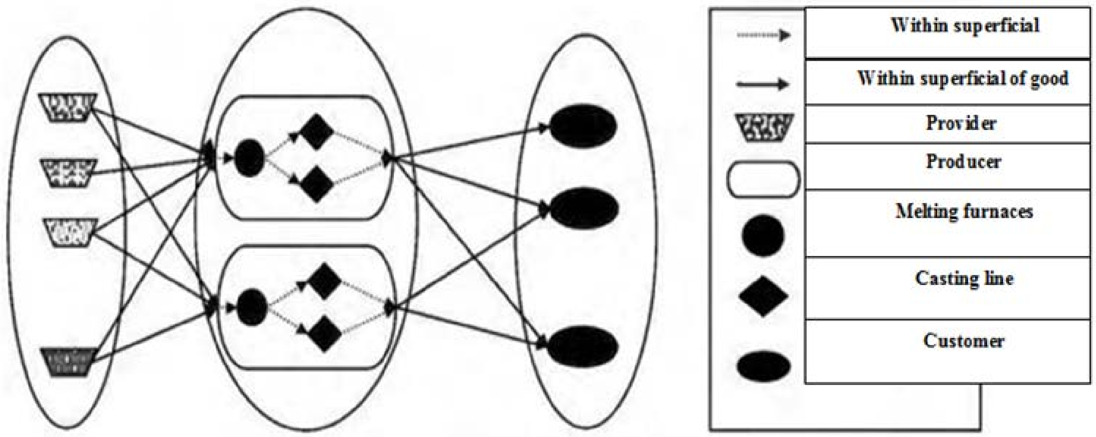


Figure 1: the supply chain of three-level including suppliers, manufacturers and customers

Product manufacturing system in the manufacturers, flow workshops is flexible that in the first stage number of a melting furnace is in parallel and in the second stage also, there is the number of products, casting line in parallel. In order to create flexibility in the production of various products and the possibility to produce a wide range of products, processes of crude steel production it is usually designed so that the total capacity of casting lines become more than furnace.

The planning horizon is single-period and demand of each consumer is associated always with uncertainty. Each customer demand can be determined interval. In this chain customer demand, supply capacity of suppliers, production capacity, capacity casting products are considered as uncertain parameters in the chain. In order to guarantee a minimum rate of profitability of each of the producers, minimum acceptable ratio of amount of production to the production capacity) exploitation factor is considered (for each of them). The planning horizon is limited to the phase of long-term and medium-term, although the possibility of changing the network configuration to the horizons of operational planning is also available. In this chain, suppliers of iron ore are considered to both steady and unsteady and producers can purchase their required quantity of iron ore from steady or unsteady suppliers. Disorders are affected on unsteady suppliers, while steady suppliers are resistant against disorders and disorders have no effect on them. In other words, in the event of occurrence random disorders, suppliers should surely provide the orders of producers.

It is clear that the cost of purchasing of a steady suppliers is more than the cost of purchasing of an unsteady supplier ($PR_i \geq PU_i, \forall i$). Because the steady supplier is obliged to provide producers orders both in normal conditions and in conditions of disorder due to its capacity, But in condition of disorder the capacity of a unsteady suppliers may be decreased and could not satisfy the producers demand. In this research, it is assumed that unsteady suppliers lose a percent of their supply capacity by minor disorders and be able to service producers by their rest capacity. In this case for any steady suppliers is defined a percent failure of supply capacity that is the amount of capacity destroyed by disorder. Sign of pd_i indicates percent failure of the supply capacity of an unsteady supplier. the following signs and symbols has used to the development of mathematical programming model.

Mathematical programming model of the problem

Sets		
I		Suppliers (iron ore mines)
J		Producers
K		Consumers
P		Type of products

Parameters	
c_{ij}^{1}	The cost of shipping a ton of iron ore from the mine *i* to producer *j*
c_{jkp}^{2}	The cost of shipping a unit of product p from producer *j* to consumer *k*
PRi	The cost of purchasing a ton of iron ore from stationary mine *i* to producer *j*
PUi	The cost of purchasing a ton of iron ore from non-stationary mine *i* to producer *j*
pc_{jp}	Cost of producing a unit of product p by producer j
Tc_{kp}	Total cost of imports of a unit of product *p* to consumer *k*
GI_{jp}	Net income resulted from exports of a unit of product *p* by producer *j*
$\tilde{D}_{kp}$	Demand amount of consumer *k* for product *p*
$c\tilde{p}_{j}$	The maximum capacity of producing melting by producer *j*
$c\tilde{r}_{jp}$	The maximum capacity of producing product *p* by producer *j*
$c\tilde{m}_{i}$	The maximum capacity of supplying iron ore by mine *i*
et_{ij}	The environmental effect of transportation of a unit of iron ore from mine i to producer *j*
ep_{jp}	environmental effect of producing a unit of product p in producer *j*
ec_{jkp}	environmental effect of transportation of a unit of product *p* from producer *j* to consumer *k*
pd_{i}	failure percent of non-stationary mine capacity *i* non-stationary supplier *i*
pr_{j}	The minimum acceptable ratio of amount of producing to melting production capacity (utilization coefficient) in producer *j*
per_{i}	coefficient of changing iron ore of supplier *i* to a unit of product
$\bar{I}$	the maximum acceptable ratio of imports amount to whole exports
$\underline{E}$	the minimum acceptable ratio of export amount to whole productions

Decision variables		
$AR_{ij} = \begin{cases} 1 \\ 0 \end{cases}$		If *i*-th mine to be considered in stationary supply chain other wise
$AU_{ij} = \begin{cases} 1 \\ 0 \end{cases}$		If *i*-th mine to be considered in non-stationary supply chain other wise
XR_{ij}		Amount of purchasing iron ore from stationary mine *i* to producer *j*
XU_{ij}		Amount of purchasing iron ore from non-stationary mine *i* to producer *j*
V_{jp}		Amount of producing product *p* by producer *j*
W_{jkp}		Amount of shipping product *p* from producer *j* to consumer *k*
Y_{kp}		Imports amount of product *p* by consumer *k*
X_{jp}		Exports amount of product *p* by consumer *j*

Based on defined symbols and signs, the mathematical programming model for proposed supply

$$Min\,Z_1 = \sum_i \sum_j (c^1_{ij} + PU_i) XU_{ij} + \sum_i \sum_j (c^1_{ij} + PR_i) XR_{ij} + \sum_j \sum_p pc_{jp} V_{jp} - \sum_j \sum_p GI_{jp} X_{jp} + \sum_k \sum_p Tc_{kp} Y_{kp} + \sum_j \sum_k \sum_p c^2_{jkp} W_{jkp} \quad (1)$$

$$Min\,Z_2 = \sum_i \sum_j et_{ij} (XU_{ij} + XR_{ij}) + \sum_j \sum_p ep_{jp} V_{jp} + \sum_j \sum_k \sum_p ec_{jkp} W_{jkp} \quad (2)$$

$$AR_i + AU_i = 1 \qquad \forall i \quad (3)$$

$$\sum_j W_{jkp} + Y_{kp} \geq \widetilde{D}_{kp} \qquad \forall k, p \quad (4)$$

$$\sum_i \frac{XU_{ij}}{per_i} + \sum_i \frac{XR_{ij}}{per_i} \geq \sum_p V_{jp} \qquad \forall j \quad (5)$$

$$\sum_j XU_{ij} \leq (1 - pd_i) c\widetilde{m}_i AU_i \qquad \forall i \quad (6)$$

$$\sum_j XR_{ij} \leq c\widetilde{m}_i AR_i \qquad \forall i \quad (7)$$

$$\sum_p V_{jp} \geq pr_j c\widetilde{p}_j \qquad \forall j \quad (8)$$

$$\sum_p V_{jp} \leq c\widetilde{p}_j \qquad \forall j \quad (9)$$

$$V_{jp} \leq c\widetilde{r}_{jp} \qquad \forall j, p \quad (10)$$

$$V_{jp} = X_{jp} + \sum_k W_{jkp} \qquad \forall j, p \quad (11)$$

$$\sum_k \sum_p Y_{kp} \leq \bar{I} \sum_j \sum_p V_{jp} \quad (12)$$

$$\sum_k \sum_p Y_{kp} \leq \underline{E} \sum_j \sum_p V_{jp} \quad (13)$$

$$AR_i, AU_i \in \{0,1\} \qquad \forall i \quad (14)$$

$$XU_{ij}, XR_{ij}, V_{jp}, X_{jp}, Y_{kp}, W_{jkp} \geq 0 \qquad \forall i, j, p, k \quad (15)$$

The objective function (1) minimizes total of costs of whole supply chain network. The first phrase in objective function (1) shows cost of supplying iron ore from non-stationary suppliers and cost of shipping iron ore from these suppliers to production centers. The second phrase in objective function (1) shows cost of supplying iron ire from stationary suppliers and cost of shipping iron ore from these suppliers to production centers.

The third phrase in objective function (1) shows total of producing costs in production centers. The fourth and fifth phrases respectively show income from exports with negative coefficient and imports costs. The last phrase in objective function (1) shows cost of transportation of products from producers to consumers.

The objective function (2) minimizes the environmental effects of the steel supply chain network. For this purpose, the evaluation methodology of environmental life cycle has been used. The first phrase in objective function (2) shows total of environmental effects of shipping iron ore from suppliers to producers. The second phrase in objective function (2) shows total of environmental effects of casting and producing products and the third phrase in objective function (2) shows total environmental effects of transportation producing products from producers to consumers.

Limitation (3) shows that a supplier in the under evaluated network to be considered as stationary or non-stationary. Limitation (4) guarantees that demand of each consumer to be provided completely. Limitation (5) guarantees that mixed ratio of purchased raw materials by each one of producers to be in accordance with required ratio of demand. Limitation (6) shows supply capacity of non-stationary suppliers. Based on this limitation capacity of a non-stationary supplier which has failed is reduced according to failure percent equal to pd_i.

Limitation (7) shows supply capacity of stationary producers. Limitation (8) guarantees the minimum acceptable amount of production to production capacity of melting for each one of producers. In another word, this limitation shows guarantor of minimum utilization rate from production capacity in each one of chain's producers. Limitations (9) and (10) respectively apply maximum production capacity of melting and casting lines for each one of producers. Limitation (11) shows balancing the flow of each kind of product in their producers. Limitation (12) provides policy of imports that whole amount of imports in each period should be lower than a specified percent of whole production.

Limitation (13) applies policy of exports that whole exports should be more than a specified percent of whole production. Finally limitations 14 and 15 show variables of Binary decision and flow and non-negative being of decision variables.

The proposed robust counterpart problem

In this part, the introduced robust optimization approach (Ben-t et al, 2009) is explained briefly and then the uncertain parameters in the mentioned proposed model are modeled based on this approach. For this purpose first consider the following programming problem that A, c and B belong to uncertainty set U.

$$\begin{aligned} &\text{Min } cx \\ &\text{s.t.} \\ &\quad Ax \le b \\ &\quad x \in X \end{aligned} \tag{16}$$

In this model, x shows the vector of decision variables. The above uncertain linear optimization model includes a set of linear optimization models that its parameters belong to uncertainty set U. Based on this optimization approach, the robust counterpart problem is formulated as following

$$\text{Min } \left\{ \sup_{(c,d,A,b\in U)} [cx] : Ax \le b,\ \forall c,d,A,b \in U \right\} \tag{17}$$

The x vector is a valid robust solution if fulfills all senses and limitations according to the uncertainty set U. Also this vector is a robust optimal answer if there is no other valid answer with the better objective function. When the uncertainty set to be considered as box uncertainty (U_{box}), the robust counterpart problem can be written in a tractable form that upper and lower bounds of the uncertainty set are used instead of whole set U_{box}.

In the box uncertainty, each uncertain parameter such as $\tilde{a}_{ij}$ is unknown and bounded and is written in the form of $U_{box} = \{a_{ij} \in R : | a_{ij} - \bar{a}_{ij} | \leq \rho_a G_{ij}^a\}$. Signs of $\bar{a}_{ij}$ nominal value, the respectively show G_{ij}^a and ρ_a ، level of uncertainty and scale of uncertainty. Scale of uncertainty is a positive value and also relation $0 < \rho_a \leq 1$ should be always confirmed. If $G_{ij}^a = a_{ij}$, then the relative deviation of nominal value is maximally equal to ρ_a. Based on this, the robust counterpart problem (17) is written as following.

$$
\begin{aligned}
&\text{Min } z \\
&\text{s.t.} \\
&\quad \sum_j (\bar{c}_j x_j + \eta_j) \leq z \\
&\quad \rho_c G_j^c \leq \eta_j, \ \forall j \\
&\quad \rho_c G_j^c \geq -\eta_j, \ \forall j \\
&\quad \sum_j (\bar{a}_{ij} + \rho_a G_{ij}^a) x_j \leq \bar{b}_i - \rho_b G_i^b, \ \forall i \\
&\quad x \in X
\end{aligned}
\tag{18}
$$

Because in the under evaluated chain network in this research, parameters related to customers' demands and capacity of suppliers and producers are always with uncertainty, to develop the proposed robust counterpart problem model, consumers' demands $(\tilde{D}_{kp})$, supply capacity of suppliers $(c\tilde{m}_i)$, production capacity $(c\tilde{p}_j)$ and casting capacity in producing centers $(c\tilde{r}_{jp})$ have been considered uncertain can adopt a value in the box uncertainty set. Based on this in the proposed robust counterpart problem, limitations related to uncertain parameters means limitations (4), (6-10) are respectively written as following:

$$\sum_j W_{jkp} + Y_{kp} \geq \bar{D}_{kp} + \rho_D G_{kp}^D \qquad \forall k, p \tag{19}$$

$$\sum_j XU_{ij} \leq (1 - pd_i)(c\bar{m}_i - \rho_{cm} G_i^{cm}) AU_i \qquad \forall i \tag{20}$$

$$\sum_j XR_{ij} \leq (c\bar{m}_i - \rho_{cm} G_i^{cm}) AR_i \qquad \forall i \tag{21}$$

$$\sum_p V_{jp} \geq pr_j (c\bar{p}_j + \rho_{cp} G_j^{cp}) \qquad \forall j \tag{22}$$

$$\sum_p V_{jp} \leq (c\bar{p}_j - \rho_{cp} G_j^{cp}) \qquad \forall j \tag{23}$$

In this model $\bar{*}$ ، ρ_* and G^* respectively nominal value, level of uncertainty and scale of uncertainty are related to uncertain parameters of the model.

The solution method

In the subject literature, different methods have been used to solve multi-objective programming problem. Fuzzy approaches have been used in many researches among these methods. One of first fuzzy methods to solve multi-objective optimization problems is method of Min-max, which has been provided by Zimmermann

(8791). But this method sometimes produces inefficient answers. An interactional fuzzy approach has been provided by Sakawa et al, (1987) to solve problem of Min-max method.
In addition to this approach, Lai and Hwang (1993) has suggested the strengthened method of Min-max also Torabi and Hassani (2008) have provided a one-stage approach based on fuzzy concepts to solve multi-objective linear optimization problems that has become famous in subject literature as TH method. These authors have proven the efficiency of their method in their research. In another research Vahdani et al (2012) provided a combined approach based on robust optimization method and TH method to solve multi-objective optimization problems in a case that parameters of the model have uncertainty. In this problem, the combined method is used to solve the intended two-objective problem. The implementation steps of the mentioned combined approach are as following:

First step: in this step, all uncertain parameters of the problem and distribution functions related to each one are specified.

Second step: in this step, the intended uncertain problem is prepared and written according to uncertain parameters of equal robust counterpart problem.

Third step: in this step, positive ideal solution (PIS) and negative ideal solution (NIS) are determined for each one of objective functions. To obtain positive ideal solution for each one of objective functions which are shown with $\left(f_1^{PIS}, x_1^{PIS}\right), \left(f_2^{PIS}, x_2^{PIS}\right)$, the robust counterpart problem is solved for each objective function separately and optimization values are determined, therefore we have:

$$\left.\begin{array}{l} f_1^{PIS} = \min f_1 \\ s.t. x \in X \end{array}\right\} \Rightarrow \left(f_1^{PIS}, x_1^{PIS}\right) \quad (24)$$

$$\left.\begin{array}{l} f_2^{PIS} = \min f_2 \\ s.t. x \in X \end{array}\right\} \Rightarrow \left(f_2^{PIS}, x_2^{PIS}\right) \quad (25)$$

Then, we use following relations to obtain negative ideal solution for objective functions.

$$f_1^{NIS} = f_1(x_2^{PIS}) \quad (26)$$

$$f_2^{NIS} = f_2(x_1^{PIS}) \quad (27)$$

Fourth step: in this step, a linear membership function is obtained based on the following relations for each one of objective functions.

$$\mu_1(x) = \begin{cases} 1 & if\ f_1 < f_1^{PIS} \\ \frac{f_1^{NIS} - f}{f_1^{NIS} - f_1^{PIS}} & if\ \ f_1^{PIS} \le f_1 \le f_1^{NIS} \\ 0 & if\ f_1 > f_1^{NIS} \end{cases} \quad (28)$$

$$\mu_2(x) = \begin{cases} 1 & if\ f_2 < f_2^{PIS} \\ \frac{f_2^{NIS} - f_2}{f_2^{NIS} - f_2^{PIS}} & if\ \ f_2^{PIS} \le f_2 \le f_2^{NIS} \\ 0 & if\ f_2 > f_2^{NIS} \end{cases} \quad (29)$$

In fact, $\mu_h(x), h = 1,2$ shows the satisfaction degree of the objective function h-th.

Fifth step: in this step, the proposed robust counterpart problem is changed to a single-objective mathematical programming model through the aggregation function of TH. It should be noted that the TH method guarantees that the obtained answers are efficient. The aggregation function of TH is achievable through following relations:

8 aggregation function

$$Max\ \lambda(x) = \psi\lambda_0 + (1-\psi)\sum_{h=1}^{2}\phi_h\mu_h(x)$$

s.t.

$$\lambda_0 \le \mu_h(x), h = 1, 2$$
$$x \in F(x), \lambda_0\ and\ \lambda \in [0, 1] \quad (30)$$

In the above model, F(x) shows the valid area related to limitations of the proposed robust counterpart problem.

Also ϕ_h and ψ respectively show the importance of the objective function of h-th and coefficient of compensation. The relationship of $\sum_{h=1}^{2}\phi_h = 1, \phi_h > 0$ is always true. In addition to this, the optimal value of the decision variable shows the minimum satisfaction degree of objective functions. The aggregation function of TH always follows an adaptation value between operators of min and sum based on the value of ψ.

Sixth step: in this step, values of the uncertainty level (ρ), coefficient of compensation (ψ) and relative importance of fuzzy objectives ϕ_h are determined and the above single-objective model is solved. If according to values of these parameters, the obtained answers were acceptable for decision-maker, the algorithm is stopped otherwise by change of these parameters; the other answers should be searched and evaluated.

5- Study case: Iran's steel supply chain

In this part, the proposed model is implemented on Iran's steel supply chain. In this chain, mines of Chadormalu, Golgohar and Choghart are domestic suppliers and mines of six suppliers of SAMARCO, FERTECO, CVRD, CARAJASE, KUDERMUKH and MBR are considered as the foreign suppliers.

In this chain, Khuzestan Steel Company (KSC), Mobarakeh Steel Company (MSC) and Esfahan Steel Company (ESC) have been considered as the suppliers of the chain and (1) Mobarakeh Steel Company (MSC), (2) Esfahan Steel Company (ESC), (3) Kavian Steel, (4) the national industrial group of Iran's steel, (5) Ahwaz's Navard Louleh, (6) Khuzestan's auxin steel, (7) Azerbaijan's Steel, (8) Khorasan's Steel, (9) Steel of Amir Kabir Khazar and (10) Iran Alloy Steel have been considered as consumers of the supply chain.

Each producer needs an iron ore with the specified mixed ratio in order to produce product. The current good is in the first category of the iron ore and three products of billet, bloom and slab with different dimensions are in the second category. So the under evaluated supply chain is a three-product supply chain. The conversion coefficient of each type of iron ore to product depends on its mixed ratios and the lower than 1.66 ton iron ore is needed. Policy of imports of product has been taken in this way that it should be not more than 5 percent of whole demand in that period in each category and policy of the exports is in this way that sum of exports should be at least equal to 10 percent of sum of productions of the whole chain.

Price of purchasing each ton of iron ore from a non-stationary supplier has been considered 456 thousands Toman and if the supplier to be stationary, this price is increasable even to double. Cost of shipping a ton of product in one kilometer has been considered equal to 58 Toman. The multiplication of cost of a unit of product for distance (kilometer) in the distance between two centers is used in order to calculate cost of transportation between two centers. Capacity of production centers of Khuzestan Steel, Mobarakeh Steel and Esfahan Steel have been respectively considered 250, 700 and 800 thousands ton.

The maximum capacity of producing slab, bloom and billet have been respectively considered 100, 150 and 200 thousands ton in Khuzestan Steel. These values have been respectively considered 230, 200 and 250 thousands ton for Mobarakeh Steel and 12, 80 and 100 thousands ton for Esfahan Steel. Costs of producing slab, bloom and billet are respectively 2024, 2052 and 2064 thousands Toman in the producing centers. Costs of imports or exports of a thousand ton of slab, bloom and billet have been respectively considered 2833.8, 2872.8 and 2889.6 milion Toman.

The environmental effect of shipping a ton of product in one kilometer has been considered 17.3 and the environmental effect of producing a kilogram of product of billet, bloom or slab have been considered equal to 32.2 based on Eco-indicator. The following table shows values of other parameters of the supply chain network. In the following table, the cost parameters are based on thousand Toman and parameters related to capacity and value of production are based on thousand ton.

Table 1: values of parameters of steel supply chain network

Parameter	Random distribution function	Parameter	Random distribution function
$c\overline{m}_i$	~ Uniform (200, 400)	G_{kp}^{D}	~ Uniform (5, 10)
$\overline{D}_{k1}$	~ Uniform (10, 50)	G_i^{cm}	~ Uniform (10, 20)
$\overline{D}_{k2}$	~ Uniform (15, 40)	G_j^{cp}	~ Uniform (20, 30)
$\overline{D}_{k3}$	~ Uniform (10, 70)	G_{jp}^{CR}	~ Uniform (5, 15)

The purposes of this paper are designing and solving the related model to Iran's steel supply chain, planning in order to realization of imports and exports purposes, programming in order to develop producers, providing the required budget to develop producers, selecting stationary and non-stationary suppliers and long-term contracting in order to supply the required iron ore from domestic and foreign mines. Determination of value of sending each type of product of node belonging to a level to node belonging to the next level and determination of production levels are tactical purposes.

Results

To solve the robust counterpart problem by using the mentioned combined solution in different levels of uncertainty first the positive ideal solution and negative ideal solution should be obtained for each one of objective functions in each level of uncertainty to do this; we use tables of payoff and relations (24) to (27). We change all levels of uncertainty equally for easiness. Therefore $\rho_* = 0, 0.25, 0.5, 0.75, 1$ are considered. In following tables the positive and negative ideal solutions have been reported for sample problem 1 in different levels of uncertainty.

Table 2: payoff table and positive and negative ideal solutions in the uncertainty level

	f_1	f_2
f_1	72535570.34*	53140203.08
f_2	72815077.92	53080656.48*
f_h^{PIS}	72535570.34*	53080656.48*
f_h^{NIS}	72815077.92	53140203.08

After obtaining positive and negative ideal solutions, the membership function of each one of objective functions should be calculated based relation (28) and (29) in each level of uncertainty. After calculating the membership functions by using the presented aggregation function of TH in relation (30), the final results can be calculated. The following table shows the obtained results which have been calculated by sing GAMS software.

This table shows optimal values of objective functions and membership degree of each one of objective functions in the uncertain and certain modes. It should be noted that when the level of uncertainty is considered equal to zero in the robust counterpart model, the robust counterpart model is changed to the certain model. $\phi_1 = \phi_2 = \frac{1}{2}$ and $\psi = 0.5$ have been used to obtain the following table.

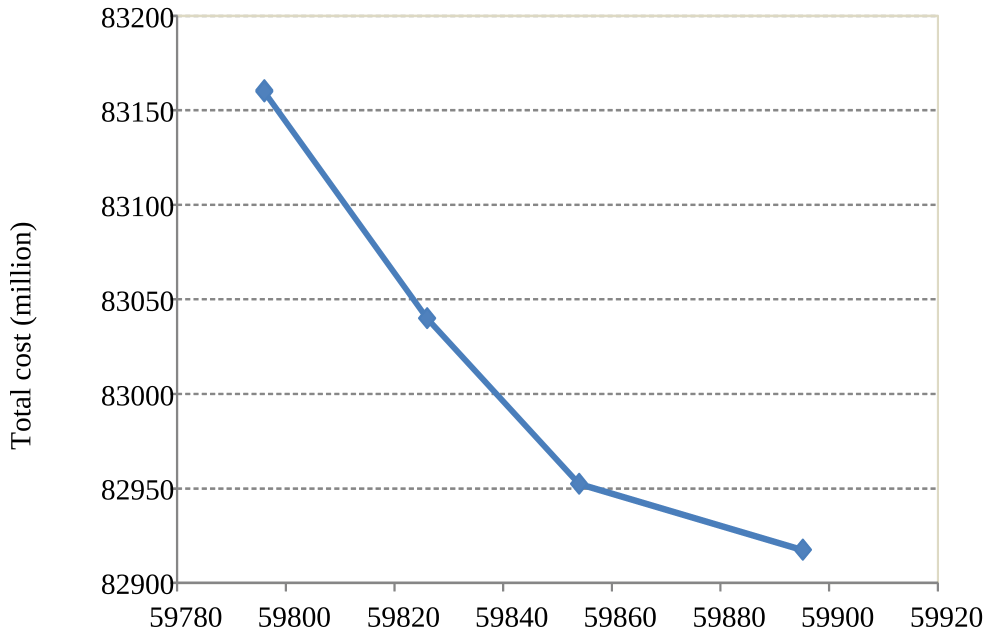
As the results show by comparing objective functions in the robust and certain modes it can be concluded that the first and second objective functions have become worse in the robust mode that shows support of the model against uncertainty of parameters. In another word, the robust counterpart problem which supports the supply chain network against uncertainty imposes more cost (first objective function) than the certain mode to the network and also the total of environmental effects becomes more.

By comparing the optimal value of objective functions (total of costs and environmental effects of the network) it can be concluded that whole costs and the environmental effects of the supply chain network have become more by increase of the uncertainty level. It means that when it supports the network model against more uncertainties, total of costs and environmental effects of whole network are increased.

Table 3: operation of robust counterpart problem model to the certain model

Certain model		Level	Robust counterpart problem	
(f_1, μ_{f_1})	(f_2, μ_{f_2})		(f_1, μ_{f_1})	(f_2, μ_{f_2})
$f_1 = 72624450.34$ $\mu_{f_1} = 0.682$	$f_2 = 53111831.08$ $\mu_{f_2} = 0.476$	0.25	$f_1 = 77534788.55$ $\mu_{f_1} = 0.626$	$f_2 = 56390860.15$ $\mu_{f_2} = 0.714$
		0.5	$f_1 = 83039894.63$ $\mu_{f_1} = 0.458$	$f_2 = 59826033.60$ $\mu_{f_2} = 0.697$
		0.75	$f_1 = 88485310.61$ $\mu_{f_1} = 0.496$	$f_2 = 63297664.68$ $\mu_{f_2} = 0.696$
		1	$f_1 = 88594302.24$ $\mu_{f_1} = 0.512$	$f_2 = 63367118.33$ $\mu_{f_2} = 0.645$

The following figure shows the mutual operation of the two objective functions of total cost and environmental effects that have been obtained for value of $\phi_1 = 1, 0.8, 0.6, 0.4, 0.2, 0$, $\phi_2 = 1 - \phi_1$. The provided results in this figure show that the two objective functions are in conflict with each other. It means that movement of an objective function to desirable side (more satisfaction of the objective function) needs movement of another objective function to undesirable side (lower satisfaction). From another hand, improvement of an objective function will lead to deterioration of another objective function. In another word, reduction of the objective function of environmental effects will lead to increase of total costs of the network and vice versa.



The environmental effect (thousand pt)

Figure 2: the mutual effect of two objective functions of environmental effects and total cost of the network

Conclusion

The purpose of this paper is designing green supply chain network of steel according to uncertainty of parameters and random disturbances of suppliers. In the under evaluated problem the two objective functions of total cost of networks and environmental effects were optimized. The uncertain parameters in the supply chain network of customers' demands are maximum capacity of suppliers' supply, the maximum capacity of production and casting in the production centers. The robust optimization approach was used for modeling uncertainties.

In addition to this, in the under evaluated problem it was assumed that suppliers face random disturbances. To deal with this issue, two types of stationary and non-stationary suppliers were considered in the problem modeling. The stationary suppliers that their price of supplying iron ore is more than non-stationary suppliers are not affected by disturbances.

In another word, these suppliers have supported themselves against random disturbances by spending infrastructural costs. The proposed model was implemented in the steel supply chain and the operation of robust counterpart model was confirmed against the certain model. Finally the operation of objective functions of total cost of network was evaluated against function of environmental effects.

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