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Design of a reliable supply chain network with responsiveness considerations under uncertainty: case study of an Iranian tire manufacturer

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Abstract

This paper proposes a bi-objective reliable supply chain network design that immunizes the network against different sources of uncertainties. In this regard, scenario based stochastic programming method is applied to model different disruption scenarios affecting accurate performance of network stages. Also, reliable and unreliable facilities are suggested for lessening vulnerability of network against disruptions. To maximize responsiveness of the network, maximal covering concept is applied aside with a new facility reliability measuring method. To achieve to the noted aims, total expected costs of network design is minimized as well as maximizing responsiveness of facilities. Also, a possibilistic flexible programming method is suggested to cope with uncertainty of parameters and flexibility of constraints. The proposed method is capable of controlling risk-aversion of output decisions based on opinion company decision makers. Finally, the model is solved based on the derived from real case study of tire manufacturing and output results are analysed that show applicability and effectiveness of the extended network design model.

Keywords: Supply chain, reliable, responsiveness, uncertainty, maximal covering

1-Introduction

Nowadays, one the biggest challenges for company owners are satisfying customers. Noted matter could result in customer loyalty and market share increase that are very important for company stakeholders. Many factors can affect the customer's satisfaction. One the most important factors affecting customer satisfaction is on time delivery of products to customers (Mohammaddust et al. 2017) and (Fattahi et al. 2017). On time delivery is dependent on some issues in supply chain networks. First of all, supply chain echelons should operate accurately to deliver products with lowest production and transferring time. Disruptions could adversely affect processing activities of facilities and lower production capacity of facilities. Disruption is man-made or natural disasters that are unpredictable events for company owners (Cui et al. 2016) and (Poudel et al. 2016). Man-made disruptions are related to subversive activities done by people that could result in great losses for manufacturing networks. An example of noted disruptions is terroristic attacks. Natural disasters are the second kind of disruptions that are out of control of human beings and they also can destroy facilities and processing capability of network stages. The most known examples of disruptions are earthquake and flood (Fazli-Khalaf et al. 2017).

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Notably, disruption can lower responsiveness of network via late delivery of products or result in lost sales via destroying production facilities. Noted matters could lead to customer dissatisfaction, increasing delivery cost and time of products to customers that is a negative point in supply chain planning (Rezapour et al. 2017). Therefore, extending reliable networks for coping with adverse effects of disruptions and keeping on time delivery capability of networks is an important matter that should be regarded in supply chain planning procedure by company managers.

The other important issue is that most of the facilities have demand covering limitations. In other words, most of the companies define a district with predefined distance for distributing their manufactured products. Notably, markets farther than defined demand covering radius of facilities could not be covered owing to available demand responding policies (Zarandi et al. 2017). The most important issue is that disruptions strikes and covering limitations are closely dependent on each other and can basically affect responsiveness capabilities of manufacturing companies. In other words, while disruptions occur, operating capacity of facilities could be partially or completely destroyed. Therefore, customer should order their needs to the farther available nodes to satisfy their needs (Hatefi and Jolai, 2015) and (Behzadi et al. 2017). However, there are some disadvantages in this situation. Firstly, ordering demands to the farther facilities results in enhancement of delivery time of products. However, there is chance of violating covering radius of facilities. It results in incapability of facilities to meet the demand of customers that is a big deficiency for organizations. Also, using this method for demand satisfaction leads to increasing transportation costs of products. Based on the enumerated matters, concerning about covering limitations in design of reliable networks could result in increasing reliability of network in front of disruptions and opening facilities that are capable of satisfying maximum amount of customers needs while there are covering limitations.

The other important matter affecting responsiveness of supply chain networks is failure of machines uses in facilities for production aims. Machine failure is an unavoidable issue that could happen in manufacturing companies and results in halting production and transferring products to demand zones (Pasandideh et al. 2015) and (Rahmani, D., & Mahoodian , 2017). In this regard, using the most reliable technologies could lower failure rate of machines in facilities. Therefore, balancing cost efficiency and reliability of production technologies is an important issue that should be regarded in supply chain planning. Also, using reliable production technologies could help to maximizing processing capacity of companies that could lower processing capacity uncertainties. Therefore, using a new concept in supply chain planning scope for maximizing machines and network reliability could be regarded as an interesting issue in supply chain network design.

There are some uncertainties that could affect long-term plan of companies. Uncertainties in planning horizon could be led from two sources. First source is uncertainty of parameters that is a result of dynamic environment of supply chains. The second source of uncertainty is flexibility of constraints that is led from linguistic definition of constraints (Pishvaee and Khalaf, 2016) and (Mousazadeh et al. 2015). There are some methods that could be applied to model noted uncertainties. The first method is stochastic programming. It needs enough historical data for generation of uncertainty scenarios. Therefore, using this method in industries with low available historical data is difficult or somehow impossible (Lima et al. 2018), (Quddus et al. 2018) and (Badri et al. 2017). The second method that is applicable for modelling uncertainty of parameters and flexibility of constraints is fuzzy programming. Fuzzy programming uses opinion and experience of field experts and company managers for modelling noted uncertainties and their corresponding possibility distributions. In this regard, there is no need to historical data while using fuzzy programming approach (Hamidieh and Fazli-Khalaf , 2017) and (Pishvaee and Torabi , 2010). Fuzzy possibilitic programming could be employed for modelling uncertain parameters and fuzzy flexible programming method is applicable for modelling flexibility of constraint (Pishvaee et al. 2012). Therefore, hybridizing possibilistic and flexible programming methods could be suggested that results in extending a new hybridized fuzzy flexible programming method. It enables appropriate modelling and controlling of different sources of uncertainties, concurrently.

Based on the enumerated matters, the aim of this paper is presenting a bi-objective and multi-echelon reliable supply chain network design model based on case study of an Iranian tire manufacturing company. The extended model uses stochastic programming method to model different disruption scenarios. Also, reliable and unreliable facilities are employed in network design stage to protect network against disruptions and minimize total costs of network design while disruptions strikes. Also, a new reliability method is applied to model machine failures in facilities and accordingly the model is capable of choosing the most reliable facilities for processing activities. In this regard, the responsiveness of network would be maximized via on time delivery of products. Also, to cope with imprecision of parameters and flexibility of constraints, a fuzzy possibilistic flexible programming method is extended that enables company executives to control risk-aversion of output decisions. Notably, maximal covering concept is applied to model product delivery limitations. It helps to minimize transportation cost increase in disruption situations via opening the best facilities to respond to demand of customers via using an appropriate long-term plan. It should be noted that the extended model is extended based on case study of tire manufacturing. However, it is a general model and could be applied in other industries that are advantage of the proposed model.

The remainder of this paper is organized as follows. Detailed problem definition and model formulation is presented in section 2. The extended possibilitic flexible programming model is rendered in Section 3. The proposed model is implemented and evaluated based on case study of tire manufacturing industry in section 4. Conclusions and some future research guidelines are presented section 5.

2-Problem definition and model formulation

The extended resilient tire manufacturing supply chain network consists of three echelons. Tire production plants buy raw material from suppliers. Then, manufactured products are transferred to customer zones to satisfy demand of customers. Notably, suppliers and manufacturing plants have capacity restrictions. In other words, maximum supply and production capacity of each supplier and manufacturing plant is limited. Customers satisfy their demand via using single sourcing. Also, multi sourcing is permitted while factories buy raw materials from suppliers. Demand of customer zones could be satisfied and also could be dissatisfied by admitting penalty costs of customer dissatisfaction. Figure 1 represents the structure of proposed reliable supply chain network.

The notable matter is that the extended network is not safe against disruptions strikes. In this regard, a scenario based modelling method is applied that enables modelling different capacity disruption scenarios. In other words, in each defined scenario, a set of plants are in danger of disruptions and percent of capacity disruption of plants is determined in each defined scenario. Notably, each production plant could be opened as a reliable or unreliable facility. Reliable facilities are safe against disruptions via expending more money for protecting infrastructures in front of disruptions. Also, processing capacity of unreliable plants could be affected by disruptions that results in buying products from farther factories. Therefore, the model should choose to open reliable or unreliable plants based on transportation costs and amount of capacity failures. The other important matter is that plants have demand coverage restrictions. Customers that their distance from plant is more than coverage radius of plant, their demand could not be satisfied by the noted factory. When disruptions happen, demand should be satisfied by farther manufacturers that availability coverage radius restricts satisfaction of customers demand. In this regard, there is possibility of customer demand dissatisfaction. The model can create a balance between cost of opening reliable or unreliable facilities, and penalty cost of demand dissatisfaction.

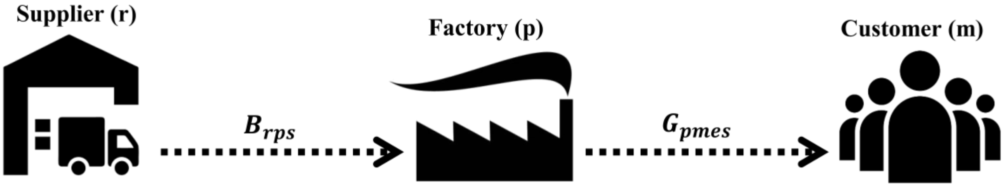

Fig. 1. Graphical representation of proposed reliable supply chain network

One of the most important points in the design of supply chain networks is reliability of machines used in different facilities of the network. In this regard, caring about reliability of machines in manufacturing plants as operational core of organization could be regarded as an important issue. Machine failures could affect long-term performance of the network. Also, it could lessen responsiveness of network and customer satisfaction owing to late delivery of products to customer zones. In this regard, a new reliability concept is applied in this section to assess reliability of facilities with regard to machine failures. It is assumed that different manufacturing technologies could be suggested for establishing manufacturing plants. Notably, manufacturing technologies that have higher reliability and lower failure rates are more expensive. It should be noted that machine failure have exponential probability distribution that is used to model failure of facilities and their corresponding responsiveness. In this regard, parameter $\tilde{\lambda}_{pe}$ is representative of average lifetime of machines of plant p that uses manufacturing technology e. also, operational time for each plant in planning period is presented via parameter ϕ. With regard to presented parameters, probability of reliable performance of a manufacturing plant that uses a special manufacturing technology e during planning period could be calculated as follows.

$$\mathrm{P}(t \geq \phi) = \int_{\phi}^{+\infty} \tilde{\lambda}_{pe}.\, e^{-\tilde{\lambda}_{pe}.t} = e^{-\tilde{\lambda}_{pe}.\phi} \tag{1}$$

It is notable that multiplying number of products manufactured in each plant in the reliability probability shows expected number of products that could be delivered to customer zones on time. It could be used as a measure for assessing responsiveness of the network and customer satisfaction level. Finally, it should be noted that the model seeks to opening facilities with manufacturing technologies that are costs efficient and reliable considering machine failures.

Based on the enumerated matters, the aim of this paper is presenting a bi-objective resilient maximal covering supply chain network design model for the case study of tire manufacturing industry. The extended model minimizes total costs of network design aside with maximizing responsiveness of plants. To achieve the noted aims, flow of products in the proposed network is optimized.

2-1- Model formulation

With regard to presented problem definition, following nomenclatures are rendered to formulate the proposed supply chain network. In the extended model, imprecise parameters and flexible constraints are presented with a tilde on.

Sets:

r	Set of fixed locations of suppliers ($r = 1,2,\dots,R$)
p	Set of potential locations of tire production plants ($p = 1,2,\dots,P$)
m	Set of fixed locations of customer zones ($m = 1,2,\dots,M$)
e	Set of production technologies of plants ($e = 1,2,\dots,E$)
s	Set of scenarios ($s = 1,2,\dots,S$)

Parameters:

$\tilde{D}_m$	Demand of customer zone *m*
$\tilde{Q}_r$	Maximum capacity of supplier *r* for selling raw materials to plants
$\tilde{A}_{ep}$	Maximum capacity of tire production plant *p* opened with production technology *e*
U_{ps}	Percent of disrupted capacity of tire production plant *p* regarding uncertainty scenario *s*
$\tilde{O}_{pe}$	Fixed cost of opening a reliable plant at potential location *p* with production technology *e*
$\tilde{L}_{pe}$	Fixed cost of opening an unreliable plant at potential location *p* with production technology *e*
V_s	Probability of uncertainty scenario *s*
$\tilde{T}_r$	Cost of buying each unit of raw material from supplier *r*
$\tilde{I}_{pe}$	Cost of producing each unit of raw material at tire production plant *p* with manufacturing technology *e*
$\tilde{H}_{rp}$	Transportation cost of each unit of raw material between supplier *r* and production plant *p*
$\tilde{J}_{pm}$	Transportation cost of each unit of tire between production plant *p* and customer zone *m*
$\tilde{\pi}_{ms}$	Penalty cost of not satisfying demand of customer zone *m* regarding uncertainty scenario *s*
cov_p	Coverage radius of tire production plant *p*
DIS_{pm}	Distance between tire production plant *p* and customer zone *m*
$\emptyset$	Duration of planning period
$\tilde{\lambda}_{pe}$	Average lifetime of machines of plant *p* using manufacturing technology *e*

Decision variable:

$$N_{pe} \quad = \begin{cases} 1:\ if\ a\ reliable\ plant\ is\ opened\ at\ potential\ location\ p\ with\ manufacturing\ technology\ e \\ 0:\ otherwise \end{cases}$$

$$C_{pe} = \begin{cases} 1: \ if \ an \ unreliable \ plant \ is \ opened \ at \ potential \ location \ p \ with \ manufacturing \ technology \ e \\ 0: \ otherwise \end{cases}$$

$$\theta_{ms} = \begin{cases} 1: \ if \ demand \ of \ customer \ zone \ m \ is \ not \ staisfied \ regarding \ scenario \ s \\ 0: \ otherwise \end{cases}$$

$$Y_{pmes} = \begin{cases} 1: \ if \ demand \ of \ customer \ zone \ p \ is \ assigned \ to \ tire \ production \ plant \ p \ that \ is \ opened \ with \ production \ technology \ m \ at \ scenario \ s \\ 0: \ otherwise \end{cases}$$

B_{rps}	Amount of transported raw materials between supplier *r* and tire manufacturing plant *p* regarding uncertainty scenario *s*
G_{pmes}	Amount of transported tires between tire manufacturing plant *p* and customer zone *m* manufactured with production technology *m* regarding uncertainty scenario *s*
$\mathfrak{I}_{ms}$	Amount of lost sales at customer zone *s* regarding uncertainty scenario *s*

Based on the rendered nomenclatures, the proposed supply chain network could be formulated as follows.

$$\boldsymbol{Min\ W_1} = \sum_{\boldsymbol{p}}\sum_{\boldsymbol{e}} \tilde{O}_{pe}.N_{pe} + \sum_{\boldsymbol{p}}\sum_{\boldsymbol{e}} \tilde{L}_{pe}.C_{pe} + \sum_{\boldsymbol{s}} V_s \Bigg[\sum_{\boldsymbol{r}}\sum_{\boldsymbol{p}} \big(\tilde{T}_r + \widetilde{H}_{rp}\big) B_{rps} + \sum_{\boldsymbol{p}}\sum_{m}\sum_{e} \big(\tilde{I}_{pe} + \tilde{J}_{pm}\big) G_{pmes} + \sum_{\boldsymbol{m}} \tilde{\pi}_{ms} \,.\, \mathfrak{I}_{ms}\Bigg] \tag{2}$$

$$\boldsymbol{Min\ W_2} = \sum_{p}\sum_{m}\sum_{e}\sum_{s} \mathrm{V}_s.\big(1 - e^{-\tilde{\lambda}_{pe}.\emptyset}\big) \,.\, G_{pmes} \tag{3}$$

$$\textbf{\textit{S.t.}} \qquad \sum_{\boldsymbol{r}} B_{rps} = \sum_{\boldsymbol{m}}\sum_{\boldsymbol{e}} G_{pmes} \qquad \forall p, s \tag{4}$$

$$\sum_{\boldsymbol{p}} B_{rps} \mathrel{\widetilde{\leqq}} \tilde{Q}_r \qquad \forall r, s \tag{5}$$

$$\sum_{\boldsymbol{m}}\sum_{\boldsymbol{e}} G_{pmes} \mathrel{\widetilde{\leqq}} \sum_{\boldsymbol{e}} \tilde{A}_{ep}.\big(N_{pe} + \big(1 - U_{ps}\big)C_{pe}\big) \qquad \forall p, s \tag{6}$$

$$\sum_{\boldsymbol{e}} \big(N_{pe} + C_{pe}\big) \leq \mathbf{1} \qquad \forall p \tag{7}$$

$$\sum_{\boldsymbol{e}} DIS_{pm} \,.\, Y_{pmes} \leq \sum_{\boldsymbol{e}} \big(N_{pe} + C_{pe}\big) \,.\, cov_p \qquad \forall p, m, s \tag{8}$$

$$\sum_{\boldsymbol{p}}\sum_{e} Y_{pmes} + \theta_{ms} = 1 \qquad \forall m, s \tag{9}$$

$$Y_{pmes}.\widetilde{D}_m \leq G_{pmes} \qquad \forall p, m, e, s \tag{10}$$

$$\widetilde{D}_m.\theta_{ms} \leq \mathfrak{I}_{ms} \qquad \forall m, s \tag{11}$$

$$N_{pe}, C_{pe}, \theta_{ms}, Y_{pmes} \in \{0,1\} \qquad \forall p, m, e, s \tag{12}$$

$$G_{pmes}, B_{rps} \geq 0 \qquad \forall p, m, e, s, r \tag{13}$$

Objective function (2) minimizes total costs of network design. It includes fixed costs of opening costs of reliable or unreliable plants at potential locations. Also, it minimizes total weighted costs of buying raw materials from suppliers, manufacturing tires at plants, transferring products between consecutive echelons of the network and penalty cost of not satisfying demand of customers. Objective function (3) minimizes total late delivery of products to customer zones regarding unreliability of plants. In other words, it maximizes total reliability and responsiveness of production plants. Constraint (4) assures flow balance at tire production plants. Constraint (5) assures that total raw material sent from each supplier to different tire manufacturing plants could not exceed its maximum supply capacity. Constraint (6) ensures that total tire sent from each manufacturing plant should be less than or equal to its maximum processing capacity. Notably, each plant could be opened as a reliable or unreliable facility. Processing capacity of opened unreliable plants could be lessen by disruptions strikes. Constraint (7) assures that only a reliable or unreliable manufacturing plant with one of its manufacturing technologies could be opened at each potential location of plants. Constraint (8) guarantees that each production plant can satisfy demand of each customer zone, if distance between opened plant and customer is less than covering radius of manufacturing plant. Constraint (9) assures that demand of each customer zone could be assigned to one of manufacturing plants or could be penalized as dissatisfied demand. Constraint (10) is an auxiliary constraint that calculates total tires transferred between each tire manufacturing plant and customer zone. Also, constraint (11) is an auxiliary constraint that calculates amount of lost sales at each customer zones regarding different uncertainty scenarios. Constraints (12) and (13) are representative of non-negative and binary variables, respectively.

3-Proposed fuzzy flexible stochastic programming model

In the proposed model, some of the parameters of the model are uncertain. Also, some of the constraints are flexible because they are defined linguistically and their satisfaction is related to the risk-aversion level of company planners. Therefore, to model imprecise parameters and soft constraints, a fuzzy flexible programming model is extended in this section. To this aim, compact form of the presented model is formulated as follows.

$$Min\ W = \tilde{\mu}.\aleph + \sum_{s} V_s\,.\,\tilde{\gamma}.\delta_s$$

$$\begin{aligned}
\textbf{s.t.}\quad & \varepsilon.\delta_s = 0 && \forall s\\
& \alpha.\delta_s \widetilde{\leqq} \tilde{\vartheta}.\aleph && \forall s\\
& \tilde{\varphi}.\rho_s \leq \delta_s && \forall s\\
& \aleph, \rho_s \in \{0,1\}, \quad \delta_s \geq 0 && \forall s
\end{aligned} \tag{14}$$

In the model (14), parameters $\tilde{\mu}$ and $\tilde{\gamma}$ are uncertain parameters of objective function. Presented parameters are related to fixed opening costs of facilities and variable processing costs at different echelons of the network, respectively. Parameters $\tilde{\vartheta}$ and $\tilde{\varphi}$ are uncertain parameters of the constraints. They correspond to capacity of facilities and demand of customer zones. Also, second constraint of the proposed model is regarded as flexible. The rendered constraint is representative of capacity restriction constraints. Notably, in the following sub sections, the equivalent crisp model is formulated to control uncertainty of presented parameters and flexibility of constraints.

3-1-The extended possibilistic chance constrained programming model

In the extended model, objective function and constraints include uncertain parameters. In this regard, possibilistic chance constrained programming model rendered by Inuiguchi and Ramik (2000) and Liu and Iwamura (1998) is employed to control uncertainty of parameters. The noted approach uses opinion of company decision makers to model imprecise parameters. The extended fuzzy possibilistic programming model could be formulated as follows. Notably, triangular possibility distribution is used to form membership function of imprecise parameters ($\tilde{\Psi} = \left(\Psi^{(p)}, \Psi^{(m)}, \Psi^{(o)}\right)$).

$$Min\ W = \left(\frac{\mu^{(p)} + \mu^{(m)} + \mu^{(o)}}{3}\right).\aleph + \sum_{s} V_s\,.\left(\frac{\gamma^{(p)} + \gamma^{(m)} + \gamma^{(o)}}{3}\right).\delta_s$$

$$\begin{aligned}
\textbf{s.t.}\quad & \varepsilon.\delta_s = 0 && \forall s\\
& \alpha.\delta_s \widetilde{\leqq} \left[\Omega.\vartheta^{(p)} + (1-\Omega).\vartheta^{(m)}\right].\aleph && \forall s\\
& \left[\zeta.\varphi^{(o)} + (1-\zeta).\varphi^{(m)}\right]\tilde{\varphi}.\rho_s \leq \delta_s && \forall s\\
& \aleph, \rho_s \in \{0,1\}, \quad \delta_s \geq 0 && \forall s
\end{aligned} \tag{15}$$

In the proposed model (15), the objective function is modelled based on expected value of the imprecise parameters. Also, constraints including imprecise parameters are modelled on the basis of satisfaction level of uncertain parameters (i.e., ζ and Ω). In other words, increasing the value of satisfaction levels leads to maximizing risk-aversion of model outputs (i.e., $0.5 < \zeta, \Omega \leq 1$). The value of satisfaction levels should be defined based on risk-aversion level of company managers and their preferences in long-term planning. Notably, the value of satisfaction levels should be changed to find the best value of decision variables and objective function value based on comment of company planners.

3-2-The extended flexible possibilistic chance constrained programming model

In the proposed model, some of the constraints are flexible. In this regard, their satisfaction is related to adjustment of output decisions by company managers. To present equivalent crisp form of soft constraints, flexible programming method proposed by Peidro et al. (2009), Yager (1981) and Cadenas and Verdegay (1997) is used in this section. The flexible possibilistic programming model is presented as follows.

$$Min\ W = \left(\frac{\mu^{(p)} + \mu^{(m)} + \mu^{(o)}}{3}\right).\aleph + \sum_{s} V_s.\left(\frac{\gamma^{(p)} + \gamma^{(m)} + \gamma^{(o)}}{3}\right).\delta_s$$

$$\begin{aligned} \textit{\textbf{s.t.}} \quad & \varepsilon.\delta_s = 0 \qquad \forall s \\ & \alpha.\delta_s \le \left[\Omega.\vartheta^{(p)} + (1-\Omega).\vartheta^{(m)}\right].\aleph + \left[\left(\varrho^{(m)} + \frac{\varrho^{(p)} + \varrho^{(o)}}{3}\right)(1-\eta)\right]\aleph \qquad \forall s \\ & \left[\zeta.\varphi^{(o)} + (1-\zeta).\varphi^{(m)}\right]\tilde{\varphi}.\rho_s \le \delta_s \qquad \forall s \\ & \aleph, \rho_s \in \{0,1\}, \quad \delta_s \ge 0 \qquad \forall s \end{aligned} \tag{16}$$

In the extended Model (16), parameter $\tilde{\varrho} = \left(\varrho^{(p)}, \varrho^{(m)}, \varrho^{(o)}\right)$ is representative of possible violation of soft constraints. Also, the term $\left[\left(\varrho^{(m)} + \frac{\varrho^{(p)}+\varrho^{(o)}}{3}\right)(1-\eta)\right]$ is equivalent crisp value of presented violation's uncertain parameter. The notable matter is that the violation of constraint should be determined by field experts. They change the value of satisfaction levels to find the best value of objective function. Increasing the satisfaction levels enhances the possible violations of soft constraints and risk-aversion level of model outputs ($0 \le \eta \le 1$).

4-Implementation and evaluation

To solve the extended model, the data is extracted from an Iranian tire manufacturing supply chain. Company has an active manufacturing plant in Semnan city and seven potential locations are determined by company executives for opening new factories. Raw materials of company could be bought from four available suppliers. Also, twelve customer zones are defined for distributing produced tires. Figure 2 shows potential locations of plants and fixed locations of suppliers in different regions of Iran. The notable matter is that there are two different production technologies that can affect reliability of supply chain network. All needed data is gathered via available historical data. Also, opinion and experience of company managers is employed to form possibility distribution of uncertain parameters. Therefore, based on the determined nominal value of parameters, the model is solved to analyze its effectiveness and applicability in real world situations. In the first step, the cost minimization objective is regarded as the main objective function and the model is solved by different uncertainty satisfaction levels. Outputs of the cost minimization objective with regard to different uncertainty satisfaction levels are presented in figure 3. Notably, different cases of satisfaction levels used for solving the model is presented in table 1.

Table 1. Different cases of satisfaction levels

Uncertainty case	**Case No. 1**	**Case No. 2**	**Case No. 3**	**Case No. 4**	**Case No. 5**
Satisfaction levels	$\Omega, \zeta = 0.6$ $\varrho = 0.2$	$\Omega, \zeta = 0.7$ $\varrho = 0.4$	$\Omega, \zeta = 0.8$ $\varrho = 0.6$	$\Omega, \zeta = 0.9$ $\varrho = 0.8$	$\Omega, \zeta = 1$ $\varrho = 1$

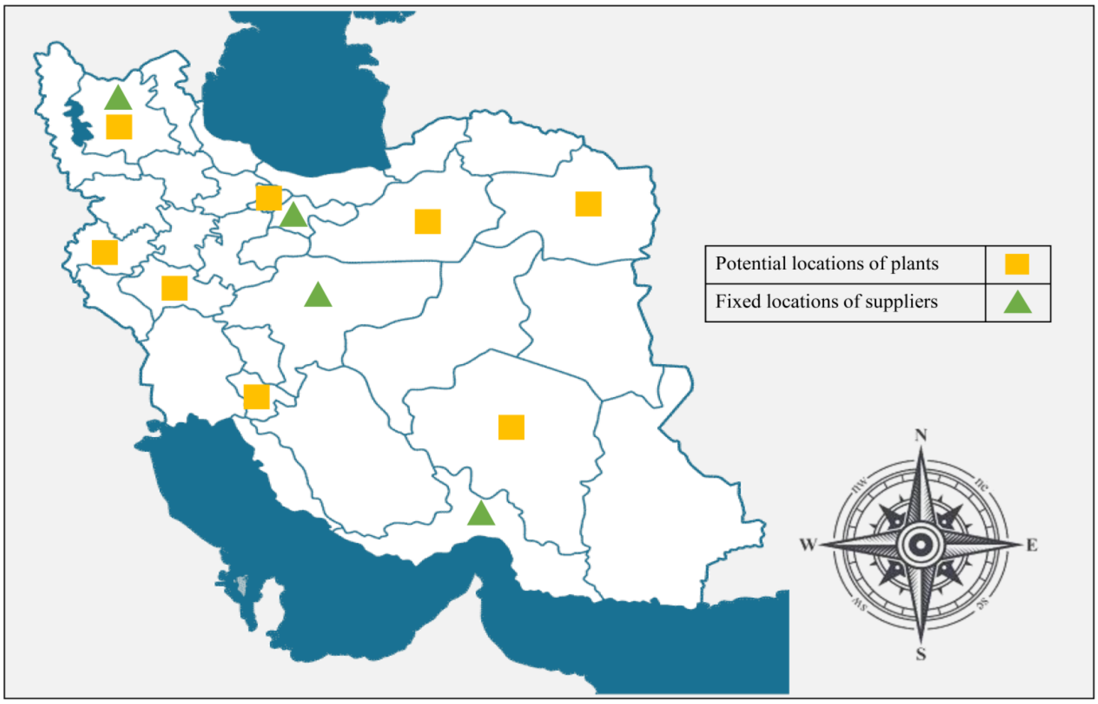

Fig. 2. Structure of tire manufacturing supply chain

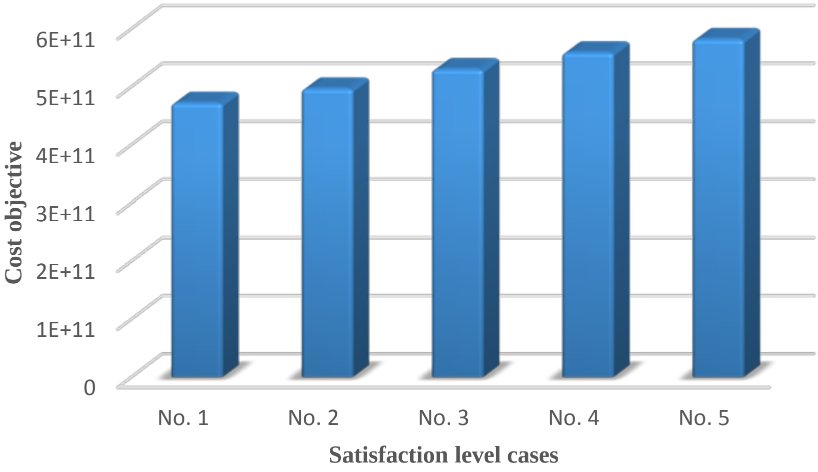

Fig. 3. Outputs of cost minimization objective

As it could be understood from presented results in figure 3, increasing satisfaction levels has led to increasing the value of cost objective function. In other words, enhancement of satisfaction levels leads to growing the value of flow of products in supply chain network. The other notable matter is that cost minimization objective tends to designing centralized network and opening minimum number of facilities to minimize total costs of network design. Notably, regarding case No. 5 of satisfaction levels, three plants are opened in addition to available production plant. Opened plants are located in Semnan, Kerman, Khoramabad and Kermanshah cities. Available plant is unreliable and opened plants are chosen to be reliable. Structure supply chain regarding the opened plants is rendered in figure 4.

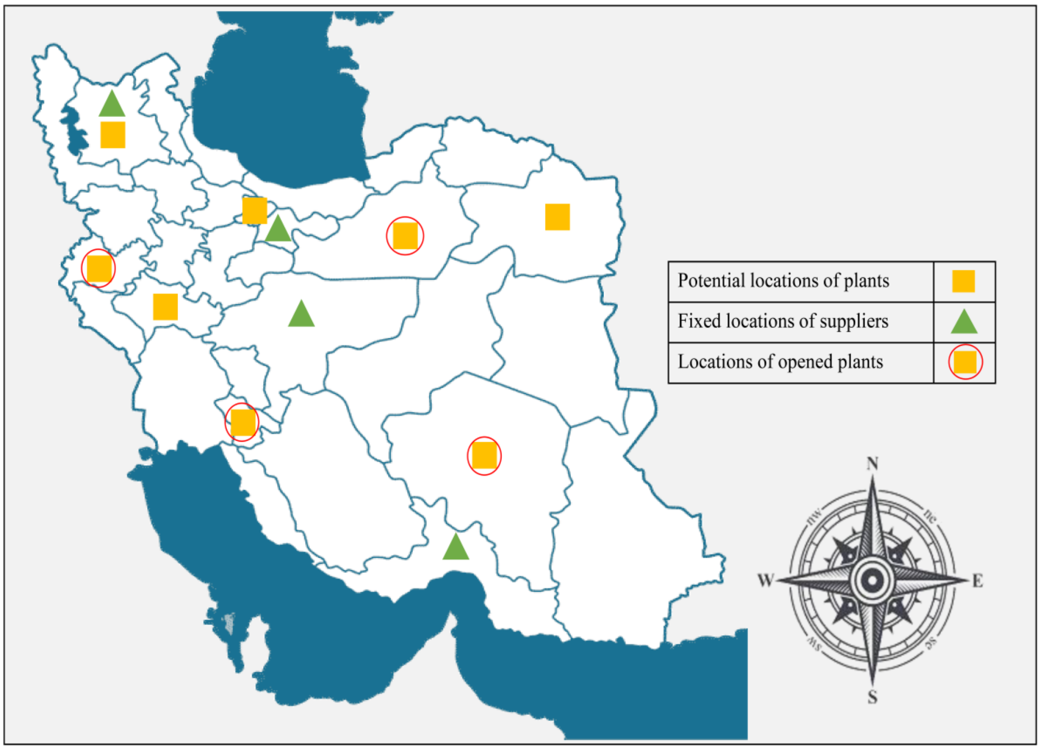

Fig. 4. Graphical representation of reliable supply chain network

Output results of the model regarding the second objective function as the main objective is presented in figure 5. The notable matter is that increasing the value of satisfaction levels leads to enhancement of flow of products. Accordingly, total responsiveness of products would be decreased because more products should be transferred in the network and total delivery times would be increased.

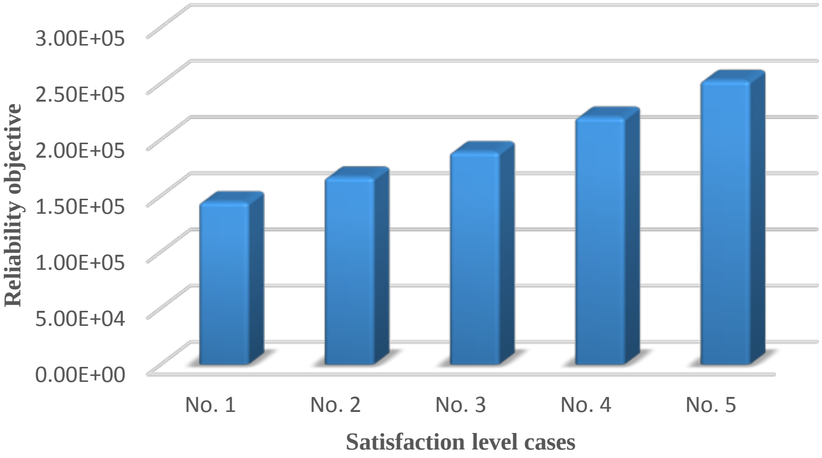

Fig. 5. Outputs of reliability maximization objective

To analyze the effect of each objective function on the value of other objective, epsilon constraint method is applied. In this regard, the best value each objective function is found by solving the extended model as a single-objective optimization problem. Then, optimum value of decision variables is put in the second objective function to find the worst value of reliability objective. Then, the second objective would be added to constraints. Then, the value of the second objective would be changed between its worst and best values to assess the effect of changing reliability on cost minimization objective. Figure 6 presents output results of epsilon constraint method and effect of changing the value of each objective functions on the other objective function of the model.

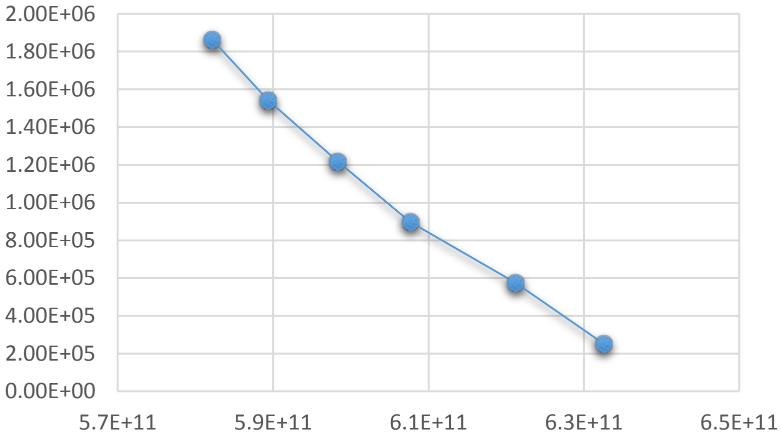

Fig. 6. Graphical representation of outputs of epsilon constraint method

As it could be understood from presented results in Fig. 6, objective functions are conflicting. In other words, increasing reliability of plants would result in enhancement of costs. Also, decreasing the value of cost minimization would increase delivery time of products to customer zone. Noted matters affirm accurate performance of the extended model. It should be noted that decreasing the value of cost objective function results in network centralization and decreasing delivery time of products to customer zones as the second objective would result in network decentralization. Opening more plants would improve delivery speed of products to customer zones owing to availability of more choices for ordering products by customers.

Finally, it should be noted that the extended model could be regarded as a reliable decision making tool because it can help to manage adverse effects of disruptions aside with controlling satisfaction levels of output results by company decision makers. Therefore, it could be concluded that the proposed model could be applied in real world situations that is the greatest advantage of the extended network design model.

5-Conclusions

Supply chain networks are vulnerable in front of disruptions and different uncertainties. In this regard, a reliable supply chain network design model is proposed in this paper that maximizes network design costs aside with maximizing total reliability of facilities and responsiveness of the network. To control adverse effects of disruptions strikes, a bi-level scenario based model is extended that uses reliable or unreliable facilities to safeguard network against disruptions. Also, a new concept is extended to model reliability of facilities and their corresponding responsiveness to demand of customers. Maximal covering method is applied to assess the performance of network in responding to customers demand while disruptions occur. Finally, a fuzzy flexible programming model is extended that enables decision makers to cope with uncertainty of parameters and flexibility of constraints, concurrently. Output results of the extended model based on case study of tire manufacturing shows effective performance of the model against uncertainties and its applicability in real world situation.

As a future research guideline, design of a multi-echelon supply chain network that considers reliability of facilities and transportation modes could be suggested. Also, caring about environmental concern aside with maximizing reliability of the network could be suggested as an interesting research line.

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