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A New Model for Balancing between Asset Sharing Risk and Responsiveness: Developing the Augmented Ɛ-Constraint Method

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Abstract

In recent years, responsiveness in the Supply Chain Network (SCN) has been considered to improve competitiveness because customers are the most significant part of a supply chain, and promptly meeting customer demand is substantial. In this article, to deal with the technological risks, the Reinforcement Policy (RP) before the disruption and the Assets-Sharing (AS) policy before and after the disruption has been used as Resilience Policies for Disruption (RPD). Also, the responsiveness of the network, as well as the risks associated with AS, have been considered in mathematical modeling. In addition, Lateral Sending (LS), delivery time deviations, and penalties for lost sales for increasing customer satisfaction in the cost objective function are considered responsiveness policies. A solution method has been developed based on the augmented ε-constraint to solve the model. Finally, the results show an improvement in cost by up to 14% and responsiveness by up to 17% by using the proposed policies, as well as the effectiveness of the developed technique to cope with the Multi-Objective (MO) model.

Keywords: Aghezzaf's method, Supply chain, Augmented ε-constraint, Responsiveness policies, Delivery time.

1 | Introdction

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The vulnerability of the Supply Chain Network (SCN) due to risks has caused researchers to pay attention to this issue and introduce the 5th industrial revolution [1]. Some risks, such as uncertainties or disruption risks in SCN management, have been emphasized in the 5th industry [2]. These risks can sometimes severely affect the production and distribution system of products and lead to the loss of reputation or income of an organization. For this reason, organizations focus on strengthening their chain and try to fulfill the customer's demands on time [3].

The existence of risks and their impacts on the business environment and considering customer needs in supply chains caused organizations to pay attention to reducing product delivery time, increasing responsiveness, and focusing on meeting customers. Assets-Sharing (AS) between SCN members can play a significant role in achieving these goals [4]. Data sharing can lead to the reduction of lead time and obtaining accurate information and thus increase the level of

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responsiveness. Also, AS can adjust the inventory level, reduce costs, and prevent lost sales. So, AS, as a solution to minimize uncertainty risks, and to increase customer responsiveness, is used [5].

Also, various solutions have been presented to reduce the effect of disruption on the responsiveness of the SCN and timely satisfy customers' products. For example, researchers have provided solutions such as RP [6] or increasing responsiveness after disruption by using resource urgency to meet potential shortages [7]. One of the practical solutions to improve the responsiveness of the SCN is the use of AS [8].

AS in the SCN increases the speed of recovery and delivery of goods to customers after disruption and can increase customer service and responsiveness [8]. Nowadays, in competitive markets, the proper response to customers is essential; taking measures alone to increase response has less effect than when companies have AS [9]. For example, sharing knowledge and experience before the disruption, cooperating in supplying demand on time, and preventing the loss of customer demand after the disruption can effectively reduce the effects of risks in the SCN [8]. Therefore, instead of working alone, all supply chain members should work together to increase responsiveness [9]. Due to the increase in demand and the challenges that may arise from keeping inventory for the organization, the best way to reduce costs is AS because SCN members can AS such as warehouses, workforce, and transportation to reduce costs [9]. Also, the AS, such as data and knowledge between SCN members, will lead to a strong commitment to meet customer needs and increase responsiveness [9]. For this reason, researchers have presented different ways to use AS in reducing SCN risks [10], [11].

AS can create some risks; for example, the AS and information of the organization cause opportunistic risks, or AS leads to communication with partners with a lower level of capability [12]. So AS, in these cases, increases the delivery time and causes additional costs for the organization. The risks of joint work are also classified among SCN members [13].

In this article, the mathematical model has considered AS and Lateral Sending (LS) to increase responsiveness in the Steel Supply Chain (SSC). In addition, a new Multi-Objective (MO) model with responsiveness policies has been presented, in which the objective functions are cost, responsiveness, and AS risk. New stochastic optimization based on maximum deviation has been used to deal with uncertainty risks such as changing processing time and demand. Finally, a solution method based on the augmented ε-constraint way has been developed and applied to solve the MO model.

The rest of the study is as follows. In the next section, the related work is evaluated. Section 3 elaborates on the stochastic model and the augmented ε-constraint method for the MO model. In Section 4, related information is applied to the mathematical model, and the results are explained. Finally, the research findings are presented in the last section.

2 | Literature Review

There are many studies on the role of responsiveness in SCN and logistics. Richey et al. [3] reviewed the related works and concepts. One of the primary researches regarding the consideration of responsiveness in the design of the SCN is associated with the study of [14], in which the amount of responsiveness to the customer is maximized. Next, the authors defined the response rate as an objective function maximized in a MO mathematical model [15]. Martí et al. [16] presented a model balancing customer responsiveness and carbon dioxide output. Hamidieh et al. [17] proposed a model for designing a closed-loop SCN in which the speed of responding to customers in uncertainty is optimal. In the paper by [18], a responsiveness level for each customer is considered, and optimization of other variables is done according to these levels. Aboolian et al. [19] developed models in responsive SCN design and considered responsiveness in the network in two ways. First, they considered the responsiveness in the limitation. Second, for the delay in meeting the customer's demand, they determined the penalty, which is tried to be minimized in the mathematical model. Azaron et al. [20] presented a model in which the customers' travel to satisfy their demand is underrated as a responsiveness and objective cost function. In papers presented by Nayeri et al. [21] and Vali-Siar and Roghanian [22], the responsiveness rate is considered a limitation in the mathematical model, which should not be less than a particular value. Hamidieh and Johari [23] presented a method for reliable-responsive blood SCN. Ghasemi et al. [24] formulated a MO model and considered a time window for each customer so that reliability for delivering products timely to the customers is maximized.

Many works have been done regarding theoretical concepts and AS approaches in the SCN, and there are fewer studies on the quantitative modeling of AS in the SCN. Singh et al. [4] have explained the relevant concepts and future research in this context. Regarding quantitative studies, one of the primary research in AS is presented by [25], in which the role of AS in the SCN was investigated, and it was shown that AS decreases the SCN cost. Some authors have evaluated the role of AS in SCN transportation. For example, Ballot and Fontane [26], Pan et al. [27], and Sugiono et al. [28] investigated how to optimize capacity or vehicle sharing and routing in the transportation network. Some authors have also discussed the role of facility sharing in reducing costs and increasing sustainability in the SCN. For example, you can refer to [29]–[31], which evaluated positive economic, social, and environmental effects on the AS in SCN. Also, the problem of optimization of hub places in different SCNs under uncertainty in costs is addressed by Habibi et al. [32]. A model to optimize the strategic alliance network is presented by [33], in which the partners are determined to minimize the total cost of the entire network. A green model for the SCN design in the article by Foroozesh et al. [34] is presented to reduce the effects of disruption on the network in the mathematical model, and the LS of products in distribution centers is considered. Dorgham et al. [35] used collaboration to reduce transportation costs in the hospital SCN and developed a linear planning model considering fuzzy demand. In another research, by considering the scenarios of cooperation and non-cooperation in the design of the SCN, Mrabti et al. [36] presented a model to reduce the cost and amount of carbon dioxide gas and the performance of AS in a distribution network in France. Ghahremani Nahr and Zahedi [37] formulated a new information-sharing model in two levels of the SCN under uncertainty.

By reviewing the related works to AS, it is extracted that although some studies, such as [10], [11], considered AS in SCN risk mitigation, some authors, such as Mafini and Muposhi [12] and Tang [38], stated that due to the losing data and the inappropriate of colleagues, companies are often reluctant to AS. Also, they introduce data theft as the AS risk in the SCN.

Resilience in the SCN refers to the ability of the SCN to reach the desired level of disruption [39]. Resilience Policies for Disruption (RPD) in the SCN include policies before and after the disruption [7]. Xames et al. [40] investigated the impact of disruption on the SCN and the strategies for coping with the disruption risk. Mansory et al. [41] presented a model for evaluating suppliers and introduced some RPD criteria in the supply chain. Aliahmadi et al. [42] determined the impact factors on the intelligent and resilient SCN. In the field of designing SCN by RPD, each of the researchers has tried to design a resilient SCN by using policies. One of the primary studies in designing an SCN by RPD is related to the study of [43]. This study investigates the modeling approach for SCN design by RPD. In the following, researchers in the [44] developed the existing models and proposed a resilient network design model for the blood SCN. Rezapour et al. [45], Margolis et al. [46], and Hasani et al. [47] presented a model for SCN design by considering RPD, such as product holding, different suppliers, and raising capacity for factories. Hosseini-Motlagh et al. [48], Zahiri et al. [49], and Mohammed et al. [50] designed a resilient-sustainable SCN. Also, capacity planning for network design considering RPD and sustainability is addressed by Sazvar et al. [51]. Lotfi et al. [52] presented a two-stage mixed integer linear programming model for designing the closed-loop SCN of the machine assembly by RPD in Iran. In the paper published by Vali-Siar and Roghanian [22], the role of different RPD in reducing SCN costs is evaluated. Philsoophian et al. [53] categorized the proposed RPD models and presented a review article. Tordecilla et al. [54] reviewed the optimization and simulation methods for designing and evaluating the SCN under uncertainty. Also, other authors, such as Ivanov and Dolgui [55] and

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Hosseini et al. [56], have reviewed the related work in this field.

Table 1 shows the most critical works on this issue. The related works show that quantitative models related to AS require more attention. Considering the responsiveness time and RPD in the SCN and examining the role of each of these concepts in network design have been rarely addressed in the literature. The introduction of time, considering the methods of meeting the customer needs promptly, and evaluating the connection of AS require more attention from researchers in this field. Investigating the impact of each AS by asset type and AS levels on the delivery time has been less seen in related works. Appling responsiveness strategies such as responsiveness level, lead-time, and LS in the mathematical models are rarely addressed.

Table 1. The abstract of the literature.

	Input									Direction		Output						Type of AS			
References	**INR**	**BMR**	**OSR**	**Shipping Cost**	**Holding Cost**	**Processing Cost**	**Establishment Cost**	**AS Cost**	**Time**	**Forward**	**Backward**	**Amount of Product**	**Optimal Route**	**Cooperator Selection**	**Shipment Direction**	**Optimal Places**	**Production Methods**	**Horizontally**	**Vertically**	**Hybrid**	**RPD**
[25]				✓	✓	✓				✓		✓						✓			
[26]			✓	✓						✓		✓						✓			
[27]			✓	✓						✓		✓				✓		✓			
[15]	✓			✓		✓	✓		✓	✓	✓				✓	✓					
[27]			✓	✓	✓	✓						✓				✓		✓			
[38]				✓		✓				✓					✓	✓		✓			
[30]			✓	✓		✓	✓			✓		✓	✓		✓	✓		✓			
[32]				✓		✓	✓			✓					✓	✓		✓			
[33]				✓			✓	✓		✓				✓	✓	✓		✓			
[18]	✓		✓	✓		✓	✓		✓	✓					✓	✓					✓
[31]			✓	✓		✓	✓			✓	✓	✓	✓		✓	✓		✓			
[52]	✓		✓	✓			✓			✓	✓				✓	✓					✓
[47]	✓		✓	✓		✓	✓			✓					✓	✓					✓
[51]	✓		✓	✓	✓	✓	✓		✓	✓					✓	✓					✓
[22]	✓		✓	✓		✓	✓			✓	✓				✓	✓	✓				✓
[35]				✓	✓	✓				✓					✓			✓			
[36]			✓							✓		✓			✓	✓		✓			
[34]			✓	✓		✓	✓			✓					✓	✓		✓			✓
This study	✓	✓		✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓			✓

INR: Inside of SSC Risks BMR: Between Members of SSC Risks OSR: Outside SSC Risks

In this article, a model is presented that uses AS to deal with technological risks, as well as increase responsiveness in the SCN design. Responsiveness strategies such as responsiveness deviation and LS are addressed. Also, in this research, AS and RP are considered two policies to deal with the risk and to increase resiliency and responsiveness. In this study, the production time is uncertain due to technological risks and equipment failure, and an objective function has been presented for responsiveness. In addition, there is a penalty for unmeeting the demand for increasing customer satisfaction in the objective function. Due to uncertainty risks such as a change in capacity reduction and product production time, a new stochastic optimization method based on Aghezzaf et al. [57] has been used to deal with these risks. Due to the MO, an augmented ε-constraint way has been localized and developed. So, the novelty of the study can be described as follows:

- *Examining the role of AS in improving responsiveness in multi-echelon SSC.*
- *Appling responsiveness deviation and LS in the mathematical modeling under uncertainty.*
- *Applying new stochastic optimization based on scenarios to cope with uncertainty.*
- *Considering the time to deliver the product and penalty cost for unsatisfied customers in the mathematical model.*
- *Localization and development of an augmented ε-constraint method to solve the MO model.*

3 | Problem Definition and Model Formulations

The network used in this study is in the metal production industries. They engage in joint production by sharing their assets, such as equipment, repair capabilities, expert workforce, and other production assets. Next, the resulting product is sent to metal-producing factories. In these factories, the shape of the crude product must be altered, and the final product must be produced. Like steel factories, there will be a possibility of AS and joint production in these factories, and then the manufactured product will be available to the distributors. Due to the probability of losing the capacity of the distributors, it is possible that due to the AS, the required product will be shared and transferred from the Reliable Distributor (RD) to the Unreliable Distributor (UD), and the customer's demand will be met. These products can be collected again after distribution among the customers by Collection Centers (CC), for which a percentage has been predicted. Finally, these products are moved to steel factories and used to produce new products. *Fig. 1* depicts the provided explanation. Considered assumptions are as follows:

- *The possibility of disaster is considered with the help of different scenarios in the modeling.*
- *The possibility of AS between facilities has been seen in steel and metal-producing factories.*
- *LS and AS have been used to increase responsiveness in disruption on the SSC.*
- *It is assumed that AS is used to increase the speed of responsiveness after the occurrence of risks related to equipment failure.*
- *The maximum deviation allowed at the delivery time of products is already known.*
- *Due to the possibility of technological risk, the production time of the products is considered uncertain.*

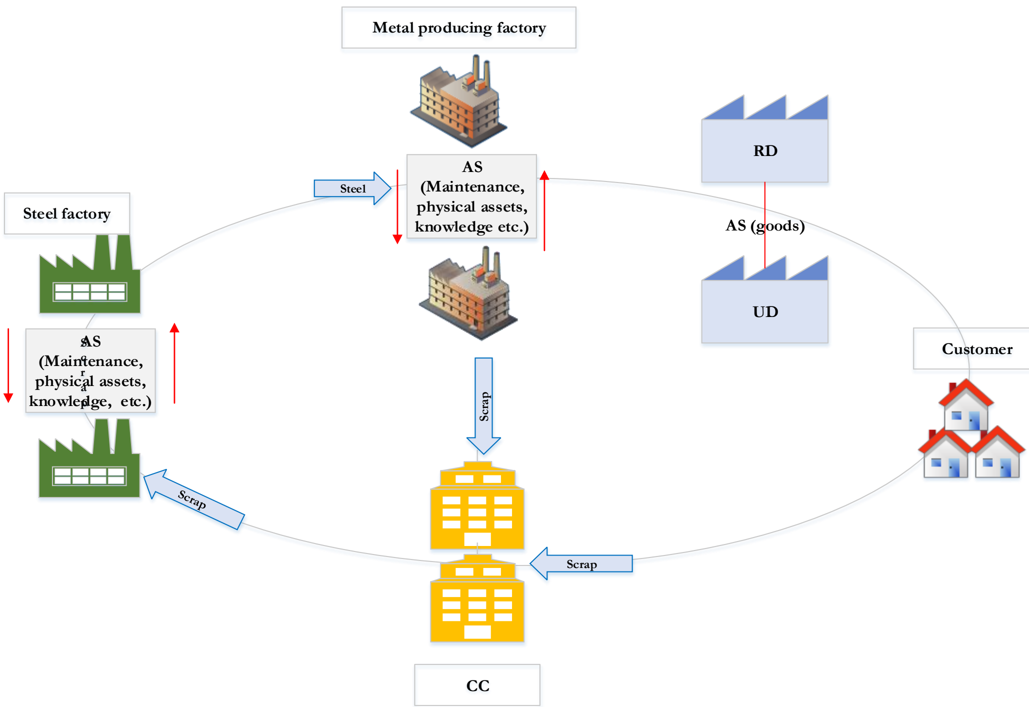

Fig. 1. Flow of product in the SSC.

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3.1 | Proposing Model under Uncertainty

Considering the uncertainty in some parameters, we used scenario building for uncertain parameters and the robust optimization method provided by Aghezzaf et al. [57]. This method takes into account the lost sales for different scenarios. Also, the maximum deviations are minimized in this model, providing better answers than the deterministic model. The notification considered in the model is as follows:

Indexes

o: Index for the steel factories.

p: Index for metal-producing factories.

c: Index for capacities in steel factories.

t: Index for CC.

q: Index for production method in steel factories.

m: Index for RD.

n: Index for UD.

r: Index for a customer.

f: Index for RP level.

g: Index for AS part in steel factories.

h: Index for AS part in metal-producing factories.

k: Index for the number of steel factories that have AS.

l: Index for the amount of metal-producing factories that have AS.

s: Index for scenarios.

Parameters

Eo_{of}^{cq}: Establishment cost of steel factory o, with production method q, RP part f, and capacity c.

Em_m: Establishment cost of RD m.

En_n: Establishment cost of UD n.

Et_t^f: Establishment cost of collection center t with RP part f.

Vo_{og}^{cq}: Allowable valency of factory o with production method q AS part g, and capacity c.

Vp_p: Allowable valency of factory p.

Vm_m: Allowable valency of RD m.

Vn_n: Allowable valency of UD n.

Vt_t: Allowable valency of collection center t.

π_{ab}: Distance of location a to b.

$o\rho_{og}^{cq}$: Operating cost in factory o with production method q, AS part g, and capacity c.

$p\rho_p^h$: Operating cost in factory p with AS part h.

$m\rho_m$: Processing cost in RD m.

$n\rho_n$: Processing cost in UD n.

$t\rho_t$: Processing cost in the CC t.

$\varnothing$: Transporting cost per distance per ton.

rw_p: Percentage of waste in factory p.

dr_r^s: Customer demand r in scenario s

sr_r^s: Percentage of returned scraps in customer r in scenario s.

β: Capacity of sending among factories or distributors.

ti: Shiping time per ton of metal product per distance.

to_{og}^{fs}: Production time each ton in factory o with RP part f and AS part g in scenario s.

tp_{ph}^s: Production time each ton in factory p with AS part h in scenario s.

tm_m^s: Handling time each ton in RD m in scenario s.

tn_n^s: Handling time each ton in UD n in scenario s.

tt_t^{fs}: Collecting and inspecting time each ton in CC t with RP part f in scenario s.

fo_{og}^{fs}: Rate of disrupted capacity in factory o with RP part f and AS part g in scenario s.

fp_{ph}^s: Rate of disrupted capacity in factory b with AS part h in scenario s.

fm_m^s: Rate of disrupted capacity in RD m in scenario s.

fn_n^s: Rate of disrupted capacity in UD n in scenario s.

ft_t^{fs}: Rate of disrupted capacity in CC t with RP part f in scenario s.

ro_{max}: The maximum adverse event in AS between steel factories.

ro_{min}: The minimum adverse event in AS between steel factories.

rp_{max}: The maximum adverse event in AS between metal-producing factories.

rp_{min}: The minimum adverse event in AS between metal-producing factories.

$Aeo_{oo'}$: The possible adverse event in AS between steel factories.

$Aep_{pp'}$: The possible adverse event in AS between metal-producing factories.

$lo\ (g)$: The minor acceptable limit for AS part g.

$lp\ (h)$: The minor acceptable limit for AS part h.

$uo\ (g)$: The high acceptable limit for AS part g.

$up\ (h)$: The high acceptable limit for AS part h.

co_o^k: Cost of AS between plants o and k other plants.

cp_p^l: Cost of AS between plants o and k other plants.

α: Maximum acceptable for deviation of responsiveness in SSC.

ph_s: Possibility of scenario s.

ω_1, ω_2: The average weight in the Aghezzaf method.

θ_1, θ_2: The deviations weight in the Aghezzaf method.

Ω_1, Ω_2: Penalty cost for unsatisfied customer demand.

$\gamma_{1s}^*, \gamma_{2s}^*$: Optimal value in goals for each scenario.

Decision variables

u_{ofg}^{qc}: Binary variable one if factory o with production method q, RP part f, AS part g, and capacity c is opened; zero otherwise.

v_m: Binary variable one if RD m is opened; zero otherwise.

z_n: Binary variable one if UD n is opened; zero otherwise.

y_t^f: Binary variable one if CC t with RP part f is opened; zero otherwise.

$ko_{oo'}$: Binary variable one if factory o has AS with factory o′; zero otherwise.

$kp_{pp'}$: Binary variable one if factory p has AS with factory p′; zero otherwise.

no_o^k: Binary variable one if the number of factories with AS with factory o is k; otherwise, zero.

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np_p^l: Binary variable one if the number of factories with AS with factory p is l; otherwise, zero.

ao_o^g: Binary variable one if factory o is given to part g; zero otherwise.

ap_p^h: Binary variable one if factory p is given to part h; zero otherwise.

$o\varphi_o^s$: The volume of returned products in the factories under scenario s.

$p\varphi_{ogp}^{qcs}$: The volume of steel sent from factory o with capacity c, production method q, and AS part g, to factory p under scenario s.

$m\varphi_{pm}^{hs}$: The volume sent from factory p with AS part h to the RD m in scenario s.

$n\varphi_{pn}^{hs}$: The volume sent from factory p with AS part h to UD n in scenario s.

$r\varphi_{mr}^s$: The volume sent from RD m to customer r in scenario s.

$b\varphi_{nr}^s$: The volume sent from UD n to customer r in scenario s.

$a\varphi_{mn}^s$: The volume sent from RD m to UD n in disruption in scenario s.

$d\varphi_{rt}^s$: The volume sent from the customer r to the CC t in scenario s.

$t\varphi_{to}^s$: The volume sent from the collection center t to the factory o in scenario s.

$c\varphi_{pt}^{hs}$: The volume sent from the factory p with AS part h to the collection center t in scenario s.

μ_1^{sr}, μ_2^{sr}: The volume of lost sales and not collecting scrap in customer r under scenario s.

The objective function and constraint in the robust optimization method provided by Aghezzaf et al. [57] are as follows:

$$\mathrm{w} = \omega \sum_{\mathrm{s}} \mathrm{ph}_{\mathrm{s}}(\gamma_{\mathrm{s}}) + \theta \mathrm{Max}(\gamma_{\mathrm{s}} - \gamma_{\mathrm{s}}^*), \tag{1}$$

$$\mathrm{Max}(\gamma_{\mathrm{s}} - \gamma_{\mathrm{s}}^*) \geq (\gamma_{\mathrm{s}} - \gamma_{\mathrm{s}}^*) \quad \text{for all s.} \tag{2}$$

In *Eq. (1)*, in the first part, the average and in the second part, the maximum deviation is minimized. *Eq. (2)* shows the deviation among the scenarios and is added in constraints. So, the final model is as follows:

$$
\begin{aligned}
\text{Min } w_1 = & \sum_{o}\sum_{f}\sum_{c}\sum_{q}\sum_{m} Eo_{of}^{cq} u_{ofg}^{qc} + \sum_{m} Em_m v_m + \sum_{n} En_n z_n \\
& + \sum_{t}\sum_{f} Et_t^f y_t^f + \sum_{k}\sum_{o} no_o^k co_o^k + \sum_{p}\sum_{l} np_p^l cp_p^l \\
& + \omega_1 \sum_{s} ph_s \Big(\sum_{o}\sum_{g}\sum_{p}\sum_{q}\sum_{c} p\varphi_{ogp}^{qcs} \left(\pi_{op}\emptyset + o\rho_{og}^{cq}\right) \\
& + \sum_{p}\sum_{m}\sum_{h} \left(\pi_{pm}\emptyset + p\rho_p^h\right) m\varphi_{pm}^{hs} \\
& + \sum_{p}\sum_{n}\sum_{h} \left(\pi_{pn}\emptyset + p\rho_p^h\right) n\varphi_{pn}^{hs} \\
& + \sum_{p}\sum_{t}\sum_{h} \left(\pi_{pt}\emptyset + p\rho_p^h\right) c\varphi_{pt}^{hs} + \sum_{m}\sum_{r} \left(\pi_{mr}\emptyset + m\rho_m\right) r\varphi_{mr}^{s} \\
& + \sum_{n}\sum_{r} \left(\pi_{nr}\emptyset + n\rho_n\right) b\varphi_{nr}^{s} + \sum_{m}\sum_{n} \left(\pi_{mn}\emptyset + m\rho_m\right) a\varphi_{mn}^{s} \\
& + \sum_{r}\sum_{t} \pi_{rt}\emptyset\, d\varphi_{rt}^{s} + \sum_{t}\sum_{o} \left(\pi_{to}\emptyset + t\rho_t\right) t\varphi_{to}^{s} \Big) \qquad (3) \\
& + \theta_1 \text{Max} \Bigg[\sum_{o}\sum_{g}\sum_{p}\sum_{q}\sum_{c} p\varphi_{ogp}^{qcs} \left(\pi_{op}\emptyset + o\rho_{og}^{cq}\right) \\
& + \sum_{p}\sum_{m}\sum_{h} \left(\pi_{pm}\emptyset + p\rho_p^h\right) m\varphi_{pm}^{hs} \\
& + \sum_{p}\sum_{n}\sum_{h} \left(\pi_{pn}\emptyset + p\rho_p^h\right) n\varphi_{pn}^{hs} \\
& + \sum_{p}\sum_{t}\sum_{h} \left(\pi_{pt}\emptyset + p\rho_p^h\right) c\varphi_{pt}^{hs} + \sum_{m}\sum_{r} \left(\pi_{mr}\emptyset + m\rho_m\right) r\varphi_{mr}^{s} \\
& + \sum_{n}\sum_{r} \left(\pi_{nr}\emptyset + n\rho_n\right) b\varphi_{nr}^{s} + \sum_{m}\sum_{n} \left(\pi_{mn}\emptyset + m\rho_m\right) a\varphi_{mn}^{s} \\
& + \sum_{r}\sum_{t} \pi_{rt}\emptyset\, d\varphi_{rt}^{s} + \sum_{t}\sum_{o} \left(\pi_{to}\emptyset + t\rho_t\right) t\varphi_{to}^{s} - \gamma_{1s}^{*} \Bigg] \\
& + \Omega_1 \sum_{s}\sum_{r} ph_s\, \mu_1^{sr} + \Omega_2 \sum_{s}\sum_{r} ph_s\, \mu_2^{sr},
\end{aligned}
$$

$$
\begin{aligned}
\text{Min } w_2 = \omega_2 & \sum_{s} ph_s \Big(\sum_{o}\sum_{g}\sum_{p}\sum_{q}\sum_{c}\sum_{f} \left(to_{og}^{fs} + \pi_{op} * \frac{ti}{\beta}\right) p\varphi_{ogp}^{qcs} \\
& + \sum_{p}\sum_{m}\sum_{h} \left(tp_{ph}^{s} + \pi_{pm} * \frac{ti}{\beta}\right) m\varphi_{pm}^{hs} \\
& + \sum_{p}\sum_{n}\sum_{h} \left(tp_{ph}^{s} + \pi_{pn} * \frac{ti}{\beta}\right) n\varphi_{pn}^{hs} \\
& + \sum_{p}\sum_{t}\sum_{h} \left(tp_{ph}^{s} + \pi_{pt} * \frac{ti}{\beta}\right) c\varphi_{pt}^{hs} + \sum_{n}\sum_{r} \left(tn_n^{s} + \pi_{nr} * \frac{ti}{\beta}\right) b\varphi_{nr}^{s} \qquad (4) \\
& + \sum_{m}\sum_{r} \left(tm_m^{s} + \pi_{mr} * \frac{ti}{\beta}\right) r\varphi_{mr}^{s} + \sum_{m}\sum_{n} \left(tm_m^{s} + \pi_{mn} * \frac{ti}{\beta}\right) a\varphi_{mn}^{s} \\
& + \sum_{r}\sum_{t} \left(\pi_{rt} * \frac{ti}{\beta}\right) d\varphi_{rt}^{s} + \sum_{t}\sum_{o}\sum_{f} \left(tt_t^{fs} + \pi_{to} * \frac{ti}{\beta}\right) t\varphi_{to}^{s} \Big) \\
& + \theta_2 \text{Max}\Big[\Big(\sum_{o}\sum_{g}\sum_{p}\sum_{q}\sum_{c}\sum_{f} \left(to_{og}^{fs} + \pi_{op} * \frac{ti}{\beta}\right) p\varphi_{ogp}^{qcs}
\end{aligned}
$$

$$+\sum_p\sum_m\sum_h(tp^s_{ph}+\pi_{pm}*\frac{ti}{\beta})m\varphi^{hs}_{pm}+\sum_p\sum_n\sum_h(tp^s_{ph}+\pi_{pn}*\frac{ti}{\beta})n\varphi^{hs}_{pn}$$
$$+\sum_p\sum_t\sum_h(tp^s_{ph}+\pi_{pt}*\frac{ti}{\beta})c\varphi^{hs}_{pt}+\sum_n\sum_r(tn^s_n+\pi_{nr}*\frac{ti}{\beta})b\varphi^s_{nr}$$
$$+\sum_m\sum_r(tm^s_m+\pi_{mr}*\frac{ti}{\beta})r\varphi^s_{mr}+\sum_m\sum_n(tm^s_m+\pi_{mn}*\frac{ti}{\beta})a\varphi^s_{mn}$$
$$+\sum_r\sum_t(\pi_{rt}*\frac{ti}{\beta})d\varphi^s_{rt}+\sum_t\sum_o\sum_f(tt^{fs}_t+\pi_{to}*\frac{ti}{\beta})t\varphi^s_{to})-\gamma^*_{2s}],$$

$$\text{Min } w_3=wo\left(\sum_{o\,(o\neq o')}\sum_{o'}Aeo_{oo'}\,ko_{oo'}-ro_{min}\right)\frac{1}{ro_{max}-ro_{min}}$$
$$+wp\left(\sum_{p\,(p\neq p')}\sum_{p'}Aep_{pp'}\,kp_{pp'}-rp_{min}\right)\frac{1}{rp_{max}-rp_{min}}, \quad (5)$$

$$\sum_{o'\,(o\neq o')}ko_{oo'}=\sum_k k*no^k_o \quad \text{for all } o, \quad (6)$$
$$\sum_{p'\,(p\neq p')}kp_{pp'}=\sum_l l*np^l_p \quad \text{for all } p, \quad (7)$$
$$\sum_g ao^g_o\leq 1 \quad \text{for all } o, \quad (8)$$
$$\sum_h ap^h_p\leq 1 \quad \text{for all } p, \quad (9)$$
$$\sum_g ao^g_o\leq\sum_l no^k_o \quad \text{for all } o, \quad (10)$$
$$\sum_h ap^h_p\leq\sum_l np^l_p \quad \text{for all } p, \quad (11)$$
$$\sum_g lo(g)ao^g_o\leq\sum_k k*no^k_o \quad \text{for all } o, \quad (12)$$
$$\sum_k k*no^k_o\leq\sum_g uo(g)ao^g_o \quad \text{for all } o, \quad (13)$$
$$\sum_h lp(h)ap^h_p\leq\sum_l l*np^l_p \quad \text{for all } p, \quad (14)$$
$$\sum_l l*np^l_p\leq\sum_h up(h)ap^h_p \quad \text{for all } p, \quad (15)$$
$$ko_{oo'}+ko_{o'o''}-ko_{oo''}\leq 1 \quad \text{for all } o, \quad (16)$$
$$ko_{pp'}+ko_{p'p''}-ko_{pp''}\leq 1 \quad \text{for all } p, \quad (17)$$
$$\sum_f\sum_q\sum_c\sum_g u^{qc}_{ofg}\geq\sum_g ao^g_o \quad \text{for all } o, \quad (18)$$
$$u^{qc}_{ofg}\leq ao^g_o \quad \text{for all } o,f,g,q,c, \quad (19)$$
$$\sum_p p\varphi^{qcs}_{ogp}\leq Vo^{cq}_{og}\sum_f u^{qc}_{ofg}\left(1-fo^{fs}_{og}\right) \quad \text{for all } o,g,c,q,s, \quad (20)$$
$$\sum_p\sum_h m\varphi^{hs}_{pm}\leq Vm_m v_m(1-fm^s_m) \quad \text{for all } m,s, \quad (21)$$
$$\sum_p\sum_h n\varphi^{hs}_{pn}\leq Vn_n z_n(1-fn^s_n) \quad \text{for all } n,s, \quad (22)$$

$$\sum_{m} a\varphi^{s}_{mn} \le Vn_n z_n fn^{s}_{n} \quad \text{for all } n, s, \tag{23}$$

$$\sum_{o} t\varphi^{s}_{to} \le Vt_t \sum_{f} y^{f}_{t}\left(1 - ft^{fs}_{t}\right) \quad \text{for all } t, s, \tag{24}$$

$$\sum_{m} m\varphi^{hs}_{pm} + \sum_{n} n\varphi^{hs}_{pn} + \sum_{t} c\varphi^{hs}_{pt} \le ap^{h}_{p} Vp_p \left(1 - fp^{s}_{ph}\right) \quad \text{for all } p, h, s, \tag{25}$$

$$\sum_{m} v_m \ge 1 \quad \text{for all } m, \tag{26}$$

$$\sum_{f}\sum_{q}\sum_{c}\sum_{g} u^{qc}_{ofg} = 1 \quad \text{for all } o, \tag{27}$$

$$\sum_{p}\sum_{h} m\varphi^{hs}_{pm} = \sum_{r} r\varphi^{s}_{mr} + \sum_{n} a\varphi^{s}_{mn} \quad \text{for all } m, s, \tag{28}$$

$$\sum_{p}\sum_{h} n\varphi^{hs}_{pn} + \sum_{m} a\varphi^{s}_{mn} = \sum_{r} b\varphi^{s}_{nr} \quad \text{for all } n, s, \tag{29}$$

$$rw_p \sum_{o}\sum_{g}\sum_{q}\sum_{c} p\varphi^{qcs}_{ogp} = \sum_{h}\sum_{t} c\varphi^{hs}_{pt} \quad \text{for all } p, s, \tag{30}$$

$$\left(1 - rw_p\right) \sum_{o}\sum_{g}\sum_{q}\sum_{c} p\varphi^{qcs}_{ogp} = \sum_{h}\sum_{m} m\varphi^{hs}_{pm} + \sum_{h}\sum_{n} n\varphi^{hs}_{pn} \quad \text{for all } p, s, \tag{31}$$

$$\sum_{o} t\varphi^{s}_{to} + o\varphi^{s}_{o} = \sum_{g}\sum_{q}\sum_{c}\sum_{p} p\varphi^{qcs}_{ogp} \quad \text{for all } o, s, \tag{32}$$

$$\sum_{o} t\varphi^{s}_{to} = \sum_{p}\sum_{h} c\varphi^{hs}_{pt} + \sum_{r} d\varphi^{s}_{rt} \quad \text{for all } t, s, \tag{33}$$

$$\sum_{m} r\varphi^{s}_{mr} + \sum_{n} b\varphi^{s}_{nr} + \mu^{sr}_{1} = dr^{s}_{r} \quad \text{for all } r, s, \tag{34}$$

$$\sum_{t} d\varphi^{s}_{rt} + \mu^{sr}_{2} = \left(\sum_{m} r\varphi^{s}_{mr} + \sum_{n} b\varphi^{s}_{nr}\right) * sr^{s}_{r} \quad \text{for all } r, s, \tag{35}$$

$$\begin{aligned}
&\mathrm{Max}\Big[\textstyle\sum_o \sum_g \sum_p \sum_q \sum_c p\varphi^{qcs}_{ogp}\left(\pi_{op}\emptyset + o\rho^{cq}_{og}\right) + \sum_p \sum_m \sum_h\left(\pi_{pm}\emptyset + p\rho^{h}_{p}\right) m\varphi^{hs}_{pm} + \\
&\textstyle\sum_p \sum_n \sum_h\left(\pi_{pn}\emptyset + p\rho^{h}_{p}\right) n\varphi^{hs}_{pn} + \sum_p \sum_t \sum_h\left(\pi_{pt}\emptyset + p\rho^{h}_{p}\right) c\varphi^{hs}_{pt} + \sum_m \sum_r(\pi_{mr}\emptyset + \\
&m\rho_m)r\varphi^{s}_{mr} + \textstyle\sum_n \sum_r(\pi_{nr}\emptyset + n\rho_n)b\varphi^{s}_{nr} + \sum_m \sum_n(\pi_{mn}\emptyset + m\rho_m)a\varphi^{s}_{mn} + \\
&\textstyle\sum_r \sum_t \pi_{rt}\emptyset\, d\varphi^{s}_{rt} + \sum_t \sum_o(\pi_{to}\emptyset + t\rho_t)t\varphi^{s}_{to}) - \gamma^{*}_{1s}\Big] \ge \Big[\sum_o \sum_g \sum_p \sum_q \sum_c p\varphi^{qcs}_{ogp}\left(\pi_{op}\emptyset + \right. \\
&\left. o\rho^{cq}_{og}\right) + \textstyle\sum_p \sum_m \sum_h\left(\pi_{pm}\emptyset + p\rho^{h}_{p}\right) m\varphi^{hs}_{pm} + \sum_p \sum_n \sum_h\left(\pi_{pn}\emptyset + p\rho^{h}_{p}\right) n\varphi^{hs}_{pn} + \\
&\textstyle\sum_p \sum_t \sum_h\left(\pi_{pt}\emptyset + p\rho^{h}_{p}\right) c\varphi^{hs}_{pt} + \sum_m \sum_r(\pi_{mr}\emptyset + m\rho_m)r\varphi^{s}_{mr} + \sum_n \sum_r(\pi_{nr}\emptyset + n\rho_n)b\varphi^{s}_{nr} + \\
&\textstyle\sum_m \sum_n(\pi_{mn}\emptyset + m\rho_m)a\varphi^{s}_{mn} + \sum_r \sum_t \pi_{rt}\emptyset\, d\varphi^{s}_{rt} + \sum_t \sum_o(\pi_{to}\emptyset + t\rho_t)t\varphi^{s}_{to}) - \gamma^{*}_{1s}\Big]
\end{aligned} \tag{36}$$

$$\begin{aligned}
&\mathrm{Max}[(\textstyle\sum_o \sum_g \sum_p \sum_q \sum_c \sum_f(to^{fs}_{og} + \pi_{op} * \frac{ti}{\beta})p\varphi^{qcs}_{ogp} + \sum_p \sum_m \sum_h(tp^{s}_{ph} + \pi_{pm} * \\
&\tfrac{ti}{\beta})m\varphi^{hs}_{pm} + \textstyle\sum_p \sum_n \sum_h(tp^{s}_{ph} + \pi_{pn} * \frac{ti}{\beta})n\varphi^{hs}_{pn} + \sum_p \sum_t \sum_h(tp^{s}_{ph} + \pi_{pt} * \frac{ti}{\beta})c\varphi^{hs}_{pt} + \\
&\textstyle\sum_n \sum_r(tn^{s}_{n} + \pi_{nr} * \frac{ti}{\beta})b\varphi^{s}_{nr} + \sum_m \sum_r(tm^{s}_{m} + \pi_{mr} * \frac{ti}{\beta})r\varphi^{s}_{mr} + \sum_m \sum_n(tm^{s}_{m} + \pi_{mn} * \\
&\tfrac{ti}{\beta})a\varphi^{s}_{mn} + \textstyle\sum_r \sum_t(\pi_{rt} * \frac{ti}{\beta})d\varphi^{s}_{rt} + \sum_t \sum_o \sum_f(tt^{fs}_{t} + \pi_{to} * \frac{ti}{\beta})t\varphi^{s}_{to}) - \gamma^{*}_{2s}] \ \ge \\
&[(\textstyle\sum_o \sum_g \sum_p \sum_q \sum_c \sum_f(to^{fs}_{og} + \pi_{op} * \frac{ti}{\beta})p\varphi^{qcs}_{ogp} + \sum_p \sum_m \sum_h(tp^{s}_{ph} + \pi_{pm} * \frac{ti}{\beta})m\varphi^{hs}_{pm} + \\
&\textstyle\sum_p \sum_n \sum_h(tp^{s}_{ph} + \pi_{pn} * \frac{ti}{\beta})n\varphi^{hs}_{pn} + \sum_p \sum_t \sum_h(tp^{s}_{ph} + \pi_{pt} * \frac{ti}{\beta})c\varphi^{hs}_{pt} + \sum_n \sum_r(tn^{s}_{n} + \pi_{nr} * \\
&\tfrac{ti}{\beta})b\varphi^{s}_{nr} + \textstyle\sum_m \sum_r(tm^{s}_{m} + \pi_{mr} * \frac{ti}{\beta})r\varphi^{s}_{mr} + \sum_m \sum_n(tm^{s}_{m} + \pi_{mn} * \frac{ti}{\beta})a\varphi^{s}_{mn} + \sum_r \sum_t(\pi_{rt} * \\
&\tfrac{ti}{\beta})d\varphi^{s}_{rt} + \textstyle\sum_t \sum_o \sum_f(tt^{fs}_{t} + \pi_{to} * \frac{ti}{\beta})t\varphi^{s}_{to}) - \gamma^{*}_{2s}],
\end{aligned} \tag{37}$$

$$\text{Max}[(\sum_{o}\sum_{g}\sum_{p}\sum_{q}\sum_{c}\sum_{f}(to^{fs}_{og} + \pi_{op} * \frac{ti}{\beta})p\varphi^{qcs}_{ogp}$$
$$+ \sum_{p}\sum_{m}\sum_{h}(tp^{s}_{ph} + \pi_{pm} * \frac{ti}{\beta})m\varphi^{hs}_{pm}$$
$$+ \sum_{p}\sum_{n}\sum_{h}(tp^{s}_{ph} + \pi_{pn} * \frac{ti}{\beta})n\varphi^{hs}_{pn}$$
$$+ \sum_{p}\sum_{t}\sum_{h}(tp^{s}_{ph} + \pi_{pt} * \frac{ti}{\beta})c\varphi^{hs}_{pt} + \sum_{n}\sum_{r}(tn^{s}_{n} + \pi_{nr} * \frac{ti}{\beta})b\varphi^{s}_{nr} \quad (38)$$
$$+ \sum_{m}\sum_{r}(tm^{s}_{m} + \pi_{mr} * \frac{ti}{\beta})r\varphi^{s}_{mr} + \sum_{m}\sum_{n}(tm^{s}_{m} + \pi_{mn} * \frac{ti}{\beta})a\varphi^{s}_{mn}$$
$$+ \sum_{r}\sum_{t}(\pi_{rt} * \frac{ti}{\beta})d\varphi^{s}_{rt} + \sum_{t}\sum_{o}\sum_{f}(tt^{fs}_{t} + \pi_{to} * \frac{ti}{\beta})t\varphi^{s}_{to}) - \gamma^{*}_{2s}],$$
$$\leq \alpha.$$

$$u^{qc}_{ofg}, v_m, z_n, y^{f}_{t}, ko_{oo'}, kp_{pp'}, ap^{h}_{p}, ao^{g}_{o}, no^{k}_{o}, np^{l}_{p} \in \{0,1\}, \quad (39)$$

$$p\varphi^{qcs}_{ogp}, m\varphi^{hs}_{pm}, n\varphi^{hs}_{pn}, c\varphi^{hs}_{pt}, t\varphi^{s}_{to} \geq 0. \quad (40)$$

In *Eq. (3)*, expressions in brackets are related to maximum cost deviations, and the other remaining expressions are related to opening AS, lost sales, and average variable costs. In *Eq. (4)*, the expressions in brackets are the maximum time deviation, and the rest of the expressions are related to the average time of the network. In *Eq. (5)*, the number of undesirable events caused by AS in factories is minimized.

Eqs. (6) and *(7)* indicate the number of AS factories. *Eqs. (8)* and *(9)* state that a single AS part can be assigned to each factory. *Eqs. (10)* and *(11)* show the connection between the factories that have AS and their AS parts. In *Eqs. (12)* to *(15)*, the AS part in factories is determined based on the limits. *Eqs. (16)* and *(17)* show AS relation in producing factory. In *Eqs. (18)* and *(19)*, the link between the binary variable of factory creation and the variable of AS part is displayed. *Eqs. (20)* to *(25)* are the capacity controls. *Eq. (26)* specifies that the minimum number of the RD is one. *Eq. (27)* states that a steel factory with a single capacity, RP AS part, and production method can be opened in each place. *Eqs. (28)* to *(33)* exhibit the link between location and shipping variables. *Eqs. (34)* and *(35)* state the volume of steel conveyed to the customers and the amount of product to CC. *Eqs. (36)* and *(37)* determine the maximum deviation among all scenarios. *Eq. (38)* guarantees the maximum acceptable deviation of responsiveness in the SSC. *Eqs. (39)* and *(40)* show the applied variables in the models.

3.2 | Developing an Augmented Ɛ-Constraint Method

A new method is developed to solve the MO model. The way is based on Mavrotas [58], but some modifications have been made. This proposed method has some benefits; 1) this method does not change the dimensions of the model, 2) it will be easier to decide regarding the partial restriction amount, and 3) this method can be combined with other methods.

The solution stages in this method are as follows:

Step 1. Computing the best answers (w^{be}_{j}) for goal j, so other goals are ignored, and the proposed model with one objective considering the constraints of the mathematical model is resolved.

Step 2. Computing the worst answer (w^{wo}_{j}) for goal j in this stage. The worst answer is computed in the cost objective as follows:

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$$y_1^{wo} = \max\left(w_1\left(y_2^{be}\right), w_1\left(y_3^{be}\right)\right). \tag{41}$$

Step 3. To create an interval of zero and one for the easier choice of the decision maker, the desirability function is commuting for goals based on [59], which is as follows:

$$\xi_j(y) = \begin{cases} 1, & \text{if} \quad w_j < w_j^{be}, \\ \dfrac{w_j^{wo} - w_j}{w_j^{wo} - w_j^{be}}, & \text{if} \quad w_j^{be} \le w_j \le w_j^{wo}, \\ 0, & \text{if} \quad w_j > w_j^{wo}. \end{cases} \tag{42}$$

Step 4. Solving the MO model proposed by Mavrotas [58].

$$\begin{aligned} &\text{Max } \xi_j(y) + \varepsilon \sum_j \frac{su_j}{re_j}, \\ &\text{s.t.} \\ &\xi_j(y) - su_j = ep_j \quad \text{for all } j, \\ &ep_j \epsilon \{0,1\}, su_j \ge 0. \end{aligned} \tag{43}$$

ep_j represents the minimum acceptable part of the objective function and is specified by the decision maker. The small number ε is between 10^{-3} and 10^{-6}, and re_j is the range of objective function j and is used for de-scaling [58].

According to [58], the presented model provides strong solutions. If the answer provided in the answer model is not strong, then there is another strong answer, which is as follows:

$$\begin{aligned} &ep_2 + su_2 \le ep_2 + su_2', \\ &ep_3 + su_3 \le ep_3 + su_3', \\ &ep_j + su_j \le ep_j + su_j'. \end{aligned} \tag{44}$$

It results that $\sum_j \frac{su_j}{re_j} \le \sum_j \frac{su_j'}{re_j}$ And Max $\xi_1(y) + \varepsilon \sum_j \frac{su_j}{re_j} \le$ Max $\xi_1(y) + \varepsilon \sum_j \frac{su_j'}{re_j}$.

This conflicts with the assumption of the maximum of the objective *Function (44)*, so the solution provided by the model is the dominant solution [58].

Step 5. Solve the model in stage four; if the result is acceptable, the algorithm is finished; otherwise, change the desired values and present a new answer to the decision maker.

4 | Case Study and Analysis of Results

Steel sectors and the production of metal products have a large share of the total industries in Iran. Since other sectors in the country, such as construction, railway sectors, production of auto spare parts, etc., are dependent on this industry, any increasing time in the production and distribution network of this product will cause damage to various producing sectors. Due to the dependence of other sectors on the SSC, the part of responsiveness and meeting customer demand is also high. To increase the productivity and efficiency of the SSC, AS in the maintenance field, the expert workforce, as well as production abilities and suitable production methods, can be an efficient solution. Therefore, we used data from an SSC in Iran as a case study in this study. *Fig. 2* shows the existing and potential places for opening the facilities. Also, *Table 2* displays the range of data used to implement the proposed model.

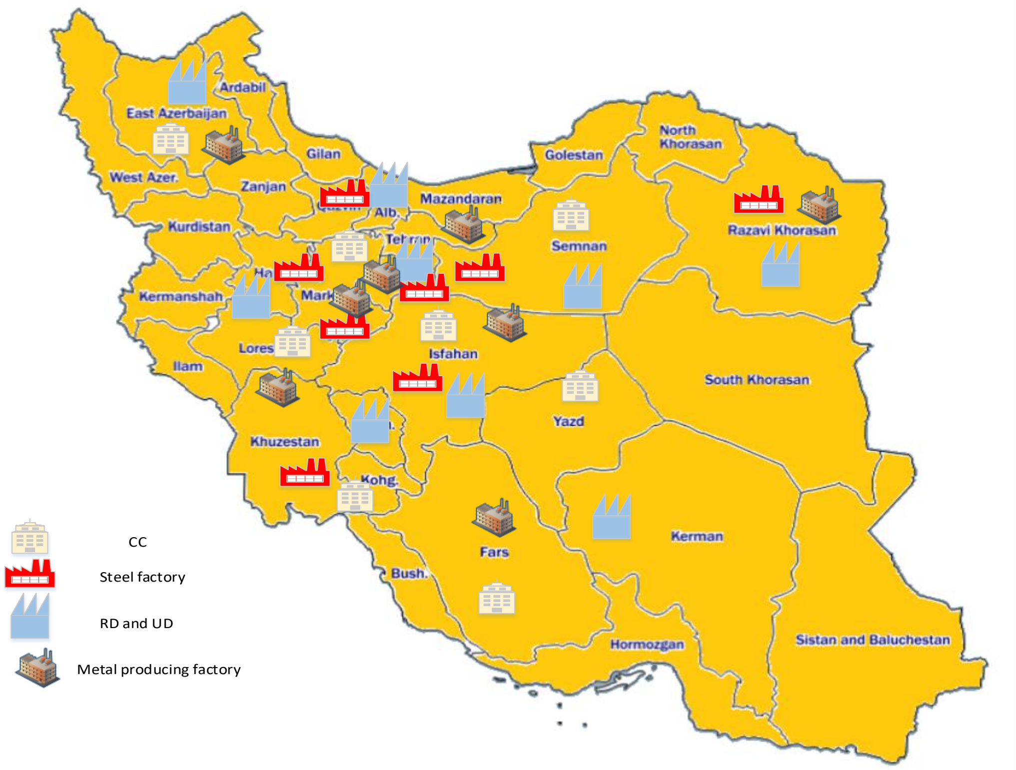

Fig. 2. Existing and potential places for opening the facilities.

Table 2. The data range used in the case study.

Factor	Bound	Factor	Bound
Eo_{of}^{1q}	U(295000،935000)	$do_{og}^{fs}, dp_{ph}^{s}, dt_{t}^{fs}, dn_{n}^{s}$	U(0،0.7)
Eo_{of}^{2q}	$\Upsilon \times Fo_{of}^{1q}$	$p\rho_{p}^{h}$	U(19،43)
Υ	U(0.55،0.75)	$m\rho_{m}$	U(1.5،4.5)
Em_m	U(5500،11500)	$n\rho_{n}$	U(3.5،8.5)
En_n	U(4100،8600)	$t\rho_{t}$	U(1.5،4.5)
Et_t^f	U(4100،8600)	sr_r^s	U(0.83،0.96)
Vo_{og}^{1q}	U(1300،3500)	ti	U(0.9،1.6)
Vo_{og}^{2q}	U(600،1850)	to_{og}^{fs}	U(0.55،0.95)
Vp_p	U(1280،3450)	tp_{ph}^{s}	U(0.4،0.85)
Vm_m, Vn_n, Vt_t	U(600،1850)	tm_m^s	U(0.05،0.27)
π_{ab}	U(8،1150)	tn_n^s	U(0.1،0.32)
op_{og}^{cq}	U(52،136)	tt_t^{fs}	U(0.05،0.27)

For implementing the model, GAMS and a computer with 6GB RAM and Intel(R) cori3-7100 specifications were used to run the model. In this article, the value of wo, wp= 0.5, is measured. Also, the ε value is considered to be 0.0001, according to Mavrotas [58]. In *Table 3*, the results for running the model with the augmented ε-constraint method are exhibited for different ep_j.

Table 3. Result of applying the MO solution method.

Row	Ep1	Ep2	Responsiveness Desirability	AS Risk Desirability	Cost Desirability	Total Cost
1	0.2	0	0.2	0	0.99	3175425
2	0.2	0.2	0.2	0.23	0.983	3174822
3	0.2	0.4	0.2	0.417	0.969	3196644
4	0.2	0.6	0.2	0.667	0.835	3304562
5	0.2	0.8	0.2	0.833	0.814	3321746

Table 3. Continued.

Row	Ep1	Ep2	Responsiveness Desirability	AS Risk Desirability	Cost Desirability	Total Cost
6	0.2	1	0.2	1	0.701	3412993
7	0.4	0	0.4	0	0.976	3190656
8	0.4	0.2	0.4	0.25	0.967	3194674
9	0.4	0.4	0.4	0.427	0.957	3205608
10	0.4	0.6	0.4	0.607	0.836	3304155
11	0.4	0.8	0.4	0.812	0.807	3327603
12	0.4	1	0.4	1	0.697	3416307
13	0.6	0	0.6	0	0.945	3215358
14	0.6	0	0.6	0.22	0.95	3211393
15	0.6	0.2	0.6	0.412	0.926	3230834
16	0.6	0.4	0.6	0.607	0.828	3310474
17	0.6	0.6	0.6	0.81	0.798	3334371
18	0.6	0.8	0.6	1	0.695	3417853
19	0.8	0	0.8	0	0.94	3219620
20	0.8	0.2	0.8	0.2	0.92	3235671
21	0.8	0.4	0.8	0.428	0.905	3247754
22	0.8	0.6	0.8	0.637	0.804	3329595
23	0.8	0.8	0.8	0.829	0.789	3341748
24	0.8	1	0.8	1	0.678	3441668

To analyze the performance of the model under uncertainty, the correlation between the cost of lost sales and the volume of lost sales, and the cost of the network is shown in *Fig. 3*. On the left, the network cost, on the right, total lost sales, on the horizontal axis, the penalty for lost sales is displayed, as shown in *Fig. 3* by rising the penalty of lost sales, the SCN costs rise and the amount of lost sales reductions. Also, *Fig. 3* shows that if the amount of lost sales has high costs, the SCN costs will also grow.

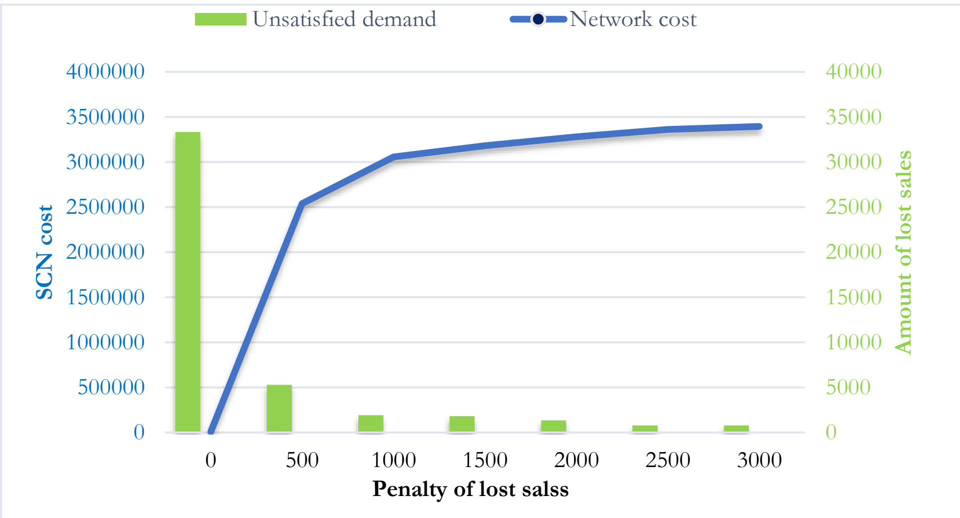

Fig. 3. Evaluation of costs and amount of lost sales with the penalty of lost sales.

In *Fig. 4*, the role of using RP, AS, and Ls in reducing the network cost has been calculated; as can be seen in *Fig. 4*, the RP, AS, and LS mitigate the SCN costs (11% for AS and 5% for RP and 4% for LS), and this reduction is higher in the AS and by using RP, AS, and LS, the SCN costs will decrease by 14%.

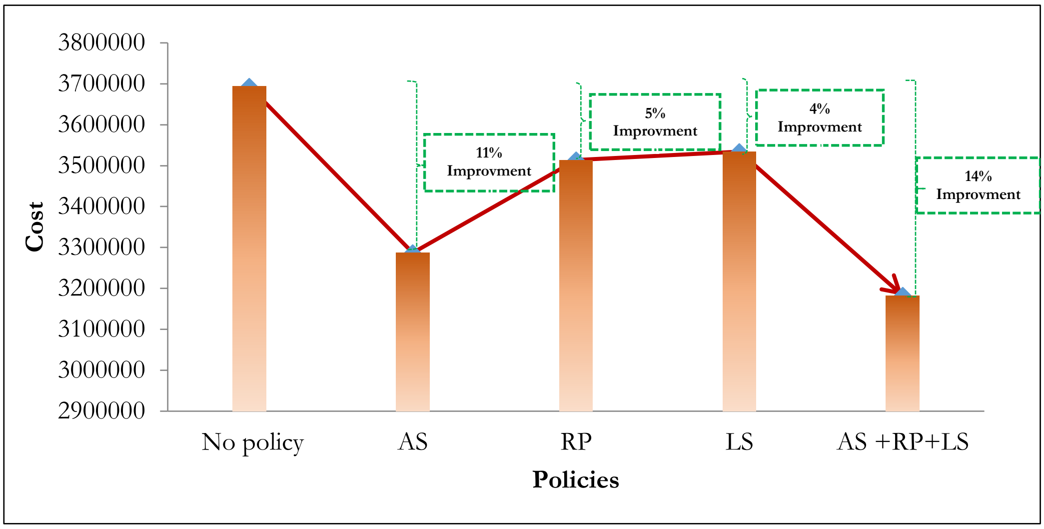

Fig. 4. The role of policies in cost reduction.

Also, for the responsiveness rate, the results show an increase in the desirability of the objective function by using an RP, AS, and LS. For example, this amount is 13% for AS, 7% for RP, and 4% for LS, and using RP, AS, and Ls simultaneously will bring up to 17% improvement in responsiveness (*Fig. 5*).

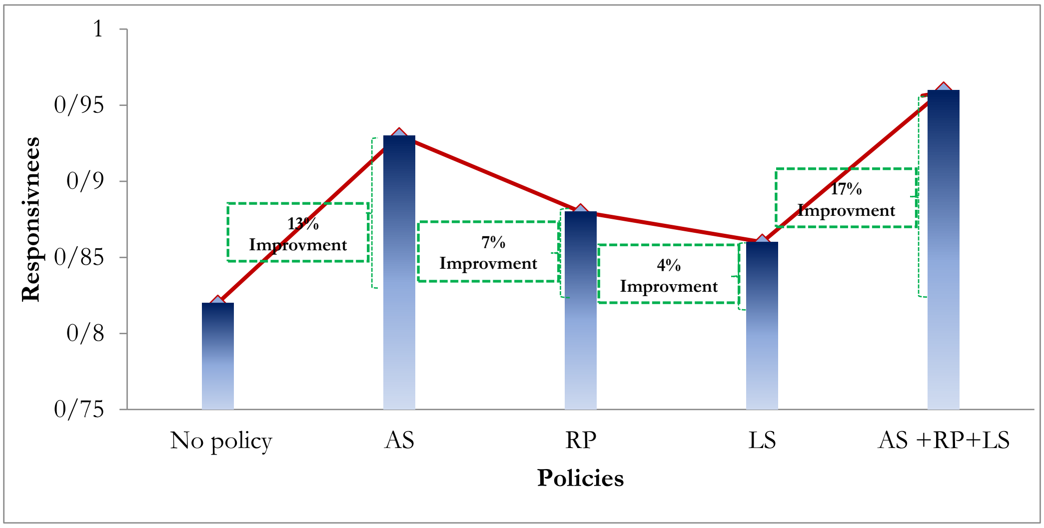

Fig. 5. The role of policies in decreasing time.

In *Fig. 6*, the relationship between the SCN cost and the AS risks is drawn, considering the responsiveness desirability of 0.5. As it is clear from *Fig. 6,* by reducing AS in the network, the risk part will decrease, and risk-desirability will increase, leading to a rise in SCN costs. In addition, the slope of the graph increases on the right side, which indicates a further height in SCN, costs to reach the part of desirability close to 1.

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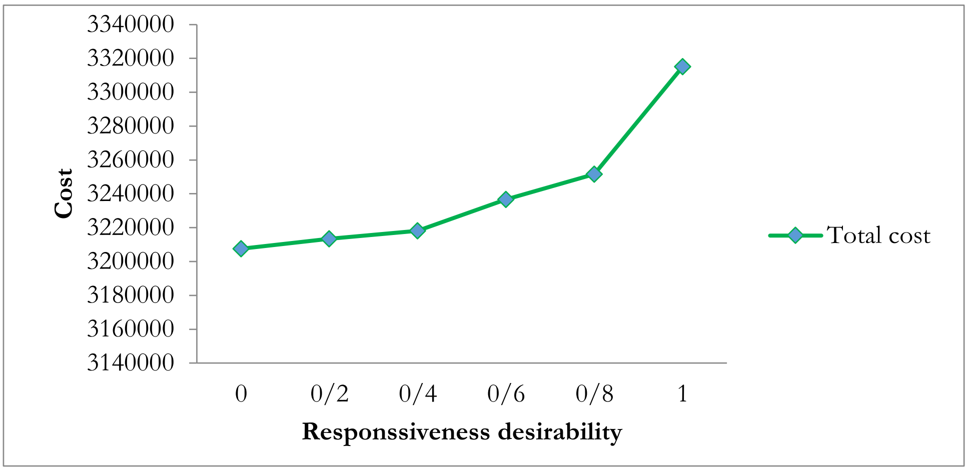

Fig. 6. Performance of cost vs. AS risk.

The relationship between responsiveness and total costs is also depicted in *Fig. 7*. As can be seen, increasing the desirability of responsiveness will increase the SCN cost, and the decision-makers, according to the degree of their desirability, can decide in this regard.

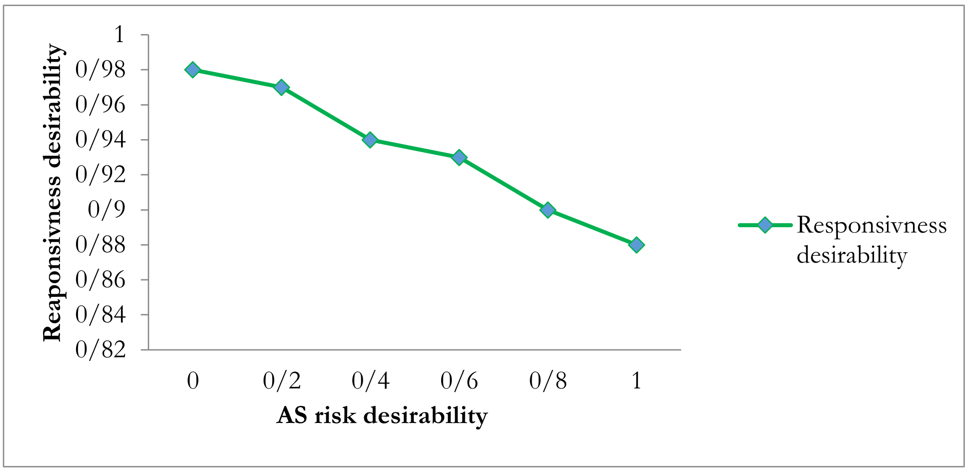

Fig. 7. Performance of cost vs. time.

Finally, the relationship between the second and third objective functions is shown in *Fig. 8*. As seen with the increase in the desirability of AS risks, the desirability of the responsiveness objective function decreases, indicating that the existence of the AS increases the level of responsiveness.

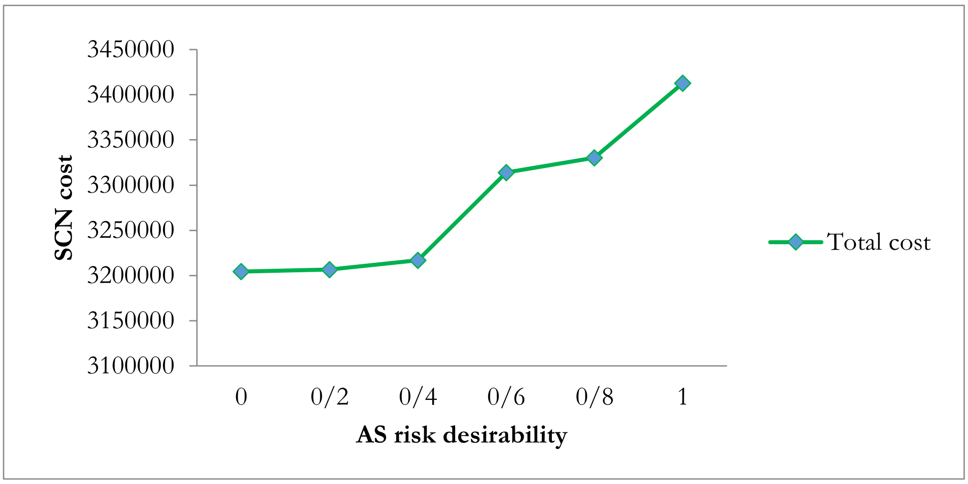

Fig. 8. Performance of time vs. AS risk.

4.1 | Practical Implications

I. Because using RP, AS, and Ls simultaneously will be beneficial in reducing SCN costs. Since the AS is more influential in reducing SCN costs than the RP, senior managers can focus on AS to decrease the total SSC cost.

II. Because in the presented model, the maximum amount allowed for the deviation of the delivery time can be changed if the delivery time of the products to the customers is essential. This case was considered in the model by allocating a smaller amount.

III. Since the simultaneous application of RP, AS, and LS can improve the response rate by up to 17% in cases where the part of competitiveness between different supply chains is high, the use of the mentioned policies has a valuable role in increasing customer satisfaction and company fame because increasing the response rate will increase customer loyalty and, as a result, increase the profit of the chain.

IV. In this article, LS was evaluated. If LS is possible, this strategy can play an influential role in increasing responsiveness in the SCN.

V. Due to the uncertainty in the various input parameters to the mathematical model, the presented model can play an influential role in reducing the SCN costs because, in this model, there is the ability to observe the maximum deviation of the costs in the future. For this reason, senior managers can reduce their investment risk in the future by using the model under uncertainty.

VI. Metal production is done with the help of collected scraps, and the greater availability of these scraps plays an influential role in reducing SCN costs. System managers can allocate more penalties for the non-collection product. So, collecting returned products will increase the amount of scrap entering the network and help the profitability of the SCN.

VII. Creating scenarios and predicting the probability of each scenario more accurately can reduce the cost deviation in the future. For this purpose, using software, data available in the industry, such as data extracted from physics asset management software, play a constructive role in this case.

VIII. Since the research results show the increase in network efficiency with AS and this AS will also bring risks, steel SCN senior managers can use solutions with less risk, for example, equipment sharing, to monitor the condition of the equipment that improves network performance with less risk.

5 | Concluding Remarks and Future Suggestions

In recent decades, senior managers have paid particular attention to the customers' needs and increased the responsiveness of the SCN to increase profitability. In this article, in the presented mathematical model, in addition to the optimal place, capacity, amount of scrap purchased and collected for production in a period, and the amount of conveyed products between factories that existed in the customary supply chain, the selection of factories for AS was made according to the relationship between the risks and benefits of AS in the SCN and the parts of AS for each of the factories were carried out. In the SCN as well as the strategy of AS and RP, a responsive model for the design of the SCN was presented, and LS, delivery time deviations, and penalties for lost sales for increasing customer satisfaction in the cost objective function were considered responsiveness policies. Also, due to uncertainty parameters in the mathematical model, optimization methods under uncertainty based on Aghezzaf et al. [57] were used to increase the model's efficiency. Finally, to solve the MO problem, a solution centered on the augmented ε-constraint was developed.

The consequences of solving the mathematical model show the model's efficiency in creating a Pareto space and a supporter for senior managers in the supply chain. Using data from the steel industry showed that using RP, AS, and LS simultaneously could improve the total cost by 14% and the responsiveness of the SCN by 17%. On the other hand, the calculation results of the presented algorithm based on the augmented ε-constraint method prove the effectiveness of this algorithm. So, using the finding of this article, senior managers in the field of steel can make more productive decisions on the SCN design, using RP, AS, and Ls and increasing responsiveness in the SCN.

According to the consideration of the model under uncertainty in this study, the use of other methods,

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such as fuzzy [60] or different ways of solving models [61], maybe a path for future research. Authors can combine the aspect of industry 5.0 (for example, human-centric) in the article. On the other hand, since the steel industry is one of the most vital sectors in the field of sustainability, presenting a mathematical model based on sustainability [62], [63] is essential for future studies.

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Conflicts of Interest

The researchers certify that the submission is not under review at any other publication and is original work.

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