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A resilient supply chain network for an online retailer: A three-phase robust framework and a case study

S.M.R. Hasani, M.M. Nasiri[*]**, S.A. Torabi, and Z. Mohtashami**

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran.

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Abstract. This paper proposes a three-phase robust approach to the problem of designing a supply chain in an e-tailing environment considering the resilience strategies such as fortification, backup suppliers, and transshipment. First, the scores of potential suppliers are obtained using several resilience criteria. Then, a scenario-based stochastic network design model is proposed which considers operational (demand and transfer cost) and disruption (a natural disaster) risks. Finally, an order transfer problem is solved. The results prove the effectiveness of the framework for a case study. A preferred Pareto optimal solution of the robust optimization model is selected such that its cost is only 0.15% worse than its neighbour while its score of suppliers is 2.46% greater than the mentioned point. In addition, the results of the sensitivity analysis show that although the suppliers with higher scores costs more, they have a smaller cost range.

1. Introduction

In the past two decades, the internet had a significant role in the evolution of selling methods, and now, e-tailing has added a new dimension to the competitive aspects of supply chains. E-tailing include those activities which are related to exchanging and selling products and services through the internet [1].

E-tailing and traditional retailing are different in various aspects such as types of customers, order fulfilment strategies, logistics methods, return policies, as well as cost and profit structure [2]. However, similar to a traditional supply chain, an e-tailing based supply chain encounters various risks and uncertainties. Operational and disruption risks are the main risks which can be happened in a supply chain [3]. Operational risks are internal uncertainties that inherently occur in supply chains with medium to high likelihood and low impact. They include supply risks, process risks, and demand risks. Examples of operational risks are key personnel absence, quality or delivery problems, and power outage [4,5]. On the other hand, disruption

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[*]. *Corresponding author. Tel./Fax: +98 21 8208 4485*
E-mail addresses: smr.hassani@ut.ac.ir (S.M.R. Hasani); mmnasiri@ut.ac.ir (M.M. Nasiri); satorabi@ut.ac.ir (S.A. Torabi); zahra.mohtashami@ut.ac.ir (Z. Mohtashami)

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risks are caused by natural or man-made disasters which rarely happen, but have significant effects on society, and the social as well as economic recovery after their occurrence is gradual. Examples are earthquakes, floods, and terrorist attacks [5].

The manager should take appropriate preventive actions before the occurrence of catastrophic disruptions or to add necessary redundancy to enhance the resilience of a supply chain [6]. In order to deal with supply chain risks more effectively, researchers have focused on its resilience features. Christopher and Peck [7] defined the resilience of a supply chain as “the ability to return to its original state or move to a new, more desirable state after being disturbed”. In addition, Krause et al. [8] state that supplier selection can considerably affect supply chain’s performance. Since one of the major sources of the supply chain risks is from the side of suppliers, selecting resilient suppliers can decrease supply chain’s vulnerability against supply risks [9].

Multi-Criteria Decision Making (MCDM) methods are commonly preferred for dealing with the supplier selection problem [4,10]. Obviously, for choosing resilient suppliers, the resilience criteria should also be used in addition to the general criteria (i.e., Quality, Cost, and Delivery (QCD) criteria).

The growth of online retailing sector on the one hand, and the increasing need for supply chains which can resist against disruptions and operational risks on the other hand, reveal that the researchers should pay attention to the problem of designing supply chain networks using the resilience strategies for e-tailing environment.

This article suggests a three-phase approach to deal with the above-mentioned problem. In the first phase, a suitable set of resilience criteria for the supplier selection topic is provided according to the literature and the opinions of field experts. After that, an AHP-TOPSIS technique is applied in order to calculate the final scores of potential suppliers. In the second phase, considering the scores obtained from the first phase, a robust bi-objective network design model is introduced with the aim of minimizing the total costs and maximizing the total score of the selected suppliers. Next, in the third phase, a mathematical model is proposed, in which a customer order delivery problem with lateral transshipment is addressed that concentrate on minimizing shipping cost as well as delay cost.

The rest of this paper is organized as follows: Section 2 reviews the related works. Section 3 describes the problem, and introduces a three-phase approach to deal with the proposed problem. Section 4 investigates a case study in Iran to evaluate the practicality of the proposed model in real world. Finally, conclusion remarks and directions for future studies are presented in Section 5.

2. Related works

In order to position the current research among the literature, four different but relevant research streams are investigated: (i) resilient supply chain network design (ii) resilient supplier selection, (iii) resilience strategies in supply chains, and (iv) resilient retailing. Then, the contributions of this research are summarized.

2.1. Resilient supply chain network design

Here, some of the recent researches focused on resilient supply chains are investigated. Kristianto et al. [11] made their efforts to solve the problem of designing a resilient supply chain network considering the inventory allocation and routing decisions. Sadghiani et al. [12] designed a resilient retail network which is capable of dealing with operational and disruption risks. They first proposed a deterministic multiple set covering model. Then, for designing a resilient and robust network, their basic model was extended to a robust counterpart by considering random scenarios. Hasani and Khosrojerdi [13] applied six resilience strategies to mitigate the disruption risks in a green supply chain. In addition, they developed a Taguchi-based memetic algorithm to solve the problem emanated from the case of an electro-medical device manufacturer. Aqlan and Lam [14] proposed a multi-objective model which investigates disruption risks and data uncertainty (i.e., operational risks) in a supply chain network. Backlog and lost sales are two factors which were assumed as threats for the resilience of the supply chain. For integrating resilience and sustainability concepts, Zahiri et al. [15] proposed an MILP model which considers different strategic and tactical decisions. They investigated the resilience measures, and tried to reveal a trade-off between resilience and sustainability. Fattahi et al. [16] presented a multi-stage stochastic model for designing a responsive and resilient supply chain regarding the operational and disruption risks. Unlike most of the related researches, they investigated demand issues in strategic planning and assumed that the customer demand depends on the delivery lead-time of the facilities. They also examined the impact of disruption risks on the capacity of facilities and the risk of responsiveness.

Ghavamifar et al. [17] address the problem of designing a resilient supply chain, which simultaneously considers the disruption and competition. Likewise, Jabbarzadeh et al. [18] studied the interactions between sustainability and resilience to disruption. Margolis et al. [19] helped decision makers to investigate the trade-off between cost and network connectivity by proposing a multi-objective optimization model. This model lets decision makers decide between the supply chain resiliency and its relevant costs. Namdar et al. [20] considered disruption and operational risks in their scenario-based model which employed single and multiple sourcing strategies for designing a resilient supply chain. Moreover, they determined the strategies which must be employed in single or multiple sourcing situations. Sabouhi et al. [21] proposed a resilient supply chain to overcome operational and disruption risks. They used proactive approaches such as multiple sourcing, fortification, and pre-positioning emergency inventory to increase the supply chain's resilience. Moreover, the case of Atra pharmaceutical company is studied for evaluating their proposed model. Yavari and Zaker [22] developed a green and resilient closed loop supply chain considering disruption caused by the electric power network. They examined the integration of a two-layer system to address the disruption of the dairy industry supply chain. Elluru et al. [23] used both proactive and reactive approaches for a location-routing problem. A proactive model was applied to address the inherent risks of the system before occurring a disruption while a proactive model was used after the disruption. Mohammed et al. [24] presented a multi-objective model which maximize the resilience of the supply chain, in addition to minimizing the cost and environmental impacts for reaching greenness and resiliency simultaneously. They solved the suggested model for a real case study using the epsilon constraint method. Fattahi et al. [25] developed a new metric for evaluating supply chain resilience by applying stochastic programming approach. In fact, this metric can measure the cost and time of the supply chain for recovery from a network disruption. Yavari and Ajalli [26] considered both coalition of suppliers and multi-sourcing strategies in designing a resilient supply chain network which concentrates on the cost and carbon emission minimization. The provided results confirm that both of the objectives of the proposed resilient supply chain network are lower than their counterparts in a non-resilient network. Esmizadeh and Mellat Parast [27] suggested some hybrid methods for a simultaneous consideration of the cost and resilience based on the comprehensive review on the network design.

2.2. Resilient supplier selection

The operational as well as disruption risks should be noted for selecting suppliers while taking the resilience criteria of supply chains into account. Many authors only accounted for disruption risks [28–35], but few of them take both types of risks into account [4,10,36–38]. In the current contribution, both of the operational and disruption risks are considered.

2.3. Resilience strategies in supply chains

There are several strategies for enhancing the resilience of supply chains, among which three strategies, namely lateral transshipment, fortification, and backup suppliers, are used in this research; therefore, we review them as follows.

A traditional supply chain commonly includes a hierarchical inventory system, in which commodities flow from one echelon to the next (e.g., from suppliers to warehouses). More flexible systems also permit lateral transshipments within an echelon, (e.g., between warehouses). In this way, members of the same echelon share their inventories, which can permit them to reduce costs without sacrificing the desired service levels [39]. However, few researchers take the lateral transshipment into account as a strategy for enhancing the resilience of supply chains [40–44].

Fortification of suppliers or other facilities is another resilience strategy which is investigated in the literature of supply chain management. Several studies used fortification for encountering disruptions [18,45–49].

When a disruption is occurred, the backup suppliers can send the orders instead of the main suppliers. As a result, they are considered by some authors for enhancing the resilience of supply chains [50–55]. Tucker et al. [56] focused on examining resilience policies in a supply chain aimed at reducing drug shortages. They evaluated the effect of multiple resiliency policies on drug shortage as well as investigating the social-efficiency of those policies. Moreover, Keskin [57] employed both fortification of suppliers and backup suppliers as the resilience strategies for dealing with supply chain network disruptions. They proposed a two-stage approach which evaluates suppliers with fuzzy-AHP in the first stage. Then, a supply chain network with a fuzzy multi-objective model is designed in the second stage.

2.4. Resilient retailing

To our knowledge, as far as the resilience in the retailing from a supply chain viewpoint is concerned, there are not many related researches [12,58–60], and if online retailing is concerned, a far fewer number of studies are associated with the subject [61,62]. Alikhani et al. [63] considered disruption scenarios as well as various resilience strategies when developing a two-stage stochastic model for the problem of designing a retail supply chain. Employing their proposed approach for a real case study proves that simultaneous consideration of the resilience strategies will result in a lost sale reduction after the disruption occurrence.

2.5. Contribution of this paper

Considering operational and disruption risks while defining resilient criteria for supplier selection can increase the supply chain resilience, especially in the supply side. However, the literature review on supplier selection reveals that operational and disruption risks have been less discussed together in this context. The main contribution of this research, which distinguishes our efforts from the related studies is taking both types of supply chain risks into account simultaneously in an uncertain e-tailing environment while pursuing the resilience, by employing the related criteria for supplier selection, considering backup suppliers and fortified warehouses, and using lateral transshipment.

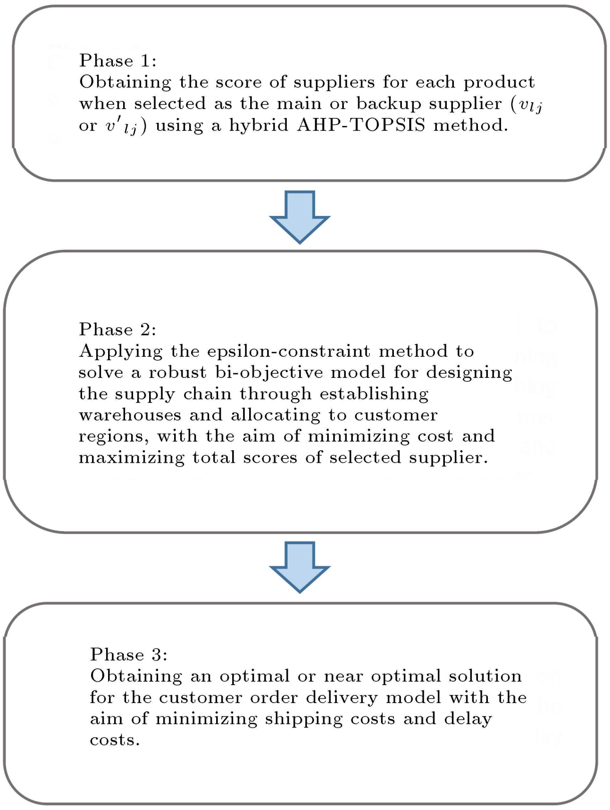
3. The three-phase approach

For solving the problem of designing a resilient supply chain in e-tailing environment, a three-phase approach is suggested. In the first phase, an AHP-TOPSIS approach obtains the scores of each supplier to be in the main or backup role for each particular product.

In the second phase, we focus on designing a three-echelon supply chain network, including multiple suppliers, retailers and customer zones, for an online retailer with respect to the resilience criteria. Based on the procurement policy of the retailer, most of the products which are available on the online store, are provided through the main suppliers and are stored in warehouses. The proposed problem is a single-period one and it is assumed that a replenishment optimization system is used for warehouses. In the network design problem, a supply chain network resilient to operational as well as disruption risk is designed. In this model, the main and backup suppliers are selected for each product and simultaneously, the location of new warehouses, the allocation of warehouses to customers, and fortification of high-risk warehouses will be considered. In the third phase, with the previous designed network, a customer order transfer problem is solved.

Like many other researches (see Ref. [64] for a list of them), in this paper, suppliers are selected through a combination of MCDM methods and mathematical programming. At first, the AHP method specifies suppliers' weights in the defined criteria and then the TOPSIS method rank suppliers by calculating the distance of alternatives from ideal solutions. In this approach, two scores are attributed to each supplier for being the main or backup supplier of a product, and these scores are used in the objective function of the network design model. Suppliers should be reliable in capacity in order to be able for providing the demand of customers and transferring products without delay. Moreover, suppliers should have a specific plan for encountering operational risks and disruptions. By reviewing the corresponding literature, criteria associated with resilient supplier selection are categorized in some main groups. Each of the groups consists of different criteria in their subsets. Since taking all of these criteria into account is complicated, the opinions of experts are used for extracting higher priority criteria for organizations. The second objective function of the network design mathematical model maximizes the total scores of the selected suppliers. For increasing the resilience of the network, inventory is distributed in several sites. Then, each customer region is allocated to one warehouse in order to fulfil the demand of its customers.

Based on e-tailing policies, products are supplied and transferred through two main approaches: (i) purchasing from the main supplier, storage and transferring, (ii) direct shipment from the main supplier to the customer. In the second approach for increasing profit and preventing the capital cost, products with high price and low order rate are not stored and if there is an order, they would be transferred directly from the main supplier to the customer. In order to consider resilience criteria, we used a two-stage scenario-based stochastic programming and for increasing the resilience of total supply chain, some of the fulfilment centres are fortified at a specific level against disruption. Warehouses are divided into two categories based on their location, warehouses which are located in high-risk sites or in low-risk sites. Obviously, the first kind of warehouses is more vulnerable and needs more fortification. The flow diagram of the proposed approach is shown in Figure 1. As shown in Figure 1, we used a three-phase robust approach for designing a resilient supply chain in an e-tailing environment. The first stage of this approach specifies the scores



Phase 1:
Obtaining the score of suppliers for each product when selected as the main or backup supplier (v_{lj} or v'_{lj}) using a hybrid AHP-TOPSIS method.

Phase 2:
Applying the epsilon-constraint method to solve a robust bi-objective model for designing the supply chain through establishing warehouses and allocating to customer regions, with the aim of minimizing cost and maximizing total scores of selected supplier.

Phase 3:
Obtaining an optimal or near optimal solution for the customer order delivery model with the aim of minimizing shipping costs and delay costs.

Figure 1. The framework of the proposed approach.

of potential suppliers as the backup or main supplier with AHP-TOPSIS method. Then, these calculated scores will be considered as the parameters of the presented mathematical model in the second stage. In fact, the bi-objective scenario-based stochastic network design model represented in the second stage focus on the cost minimization as well as the maximization of suppliers scores regarding to the evaluated scores in the first stage. Moreover, solving this bi-objective mathematical model will specify the strategic decisions of supply chain, including determining back-up and main suppliers, allocation of customer region to warehouse, location of warehouses, etc. Finally, in the third phase, operational decisions in an order transfer problem will be made based on the results of the network design model and the decisions made in the second phase.

3.1. Hybrid AHP-TOPSIS approach

In this article, AHP-TOPSIS method is employed for determining the weights of criteria and then ranking the suppliers. The reasons for selecting the AHP-TOPSIS approach are: (a) Rationality and comprehensibility of TOPSIS logic; (b) Straightforwardness of the computational processes; (c) Simplicity of the mathematical form; and (d) Incorporating the importance weights into the comparison procedures [65].

In the current contribution, based on the weights obtained from applying the AHP, the TOPSIS approach is used for giving scores to suppliers as the alternatives. In this research, employing the AHP-TOPSIS method results in calculating v_{lj} and v'_{lj}, which are the score of supplier j as the main supplier for product l and the score of supplier j as the backup supplier for product l, respectively. These scores are used in the mathematical model of the second phase.

3.2. Mathematical models for the second phase

3.2.1. Notations

Sets:

I	Set of candidate sites for building warehouses ($i \in I$)
H	Set of high-risk sites which are candidate for building warehouses ($H \subset I$)
T	Set of low-risk sites which are candidate for building warehouses ($T \subset I$)
K	Set of customer regions ($k \in K$)
J	Set of potential suppliers ($j \in J$)
L	Set of available products on the website of the e-tailer ($l \in L$)
S	Set of disruption scenarios ($s \in S = \{0, 1, 2, \ldots, \lvert S\rvert - 1\}$)
M	Set of possible capacities for building warehouses ($m \in M$)
N	Set of fortification levels for warehouses ($n \in N$)

Parameters:

C_{ikl}	Transferring cost of product l from warehouse i to customer region k
C_{jkl}	Transferring cost of product l from supplier j to customer region k
d_{kl}	Demand of customer region k for product l
F_{im}	Fixed cost of constructing warehouse i with capacity m
F_{jl}	Fixed cost for selecting supplier j as main supplier for product l
F'_{jl}	Fixed cost for selecting supplier j as a backup supplier for product l
FR_{in}	Fortification cost of warehouse in site i at level n
b_{ml}	Amount of available space for capacity of type m for storing product l
e_{jl}	Amount of available space for supplier j for storing product l
B	Maximum of available budget for building warehouses and fortifying them
W_{il}	Maintenance cost for product l in warehouse i
μ_m	Maximum number of customer regions which can be allocated to a fulfilment centre with capacity of type m
v_{lj}	Supplier j score as the main supplier for product l (captured from AHP-TOPSIS)
v'_{lj}	Supplier j score as a backup supplier for product l (captured from AHP-TOPSIS)
α	Desired aspiration level
τ_{ins}	Available capacity of warehouse i with fortification level n under disruption scenario s (%)
γ_{js}	Available capacity of supplier j under disruption scenario s (%)
π_{is}	Occurrence probability of disruption scenario s in site i (percentage)

Decision variables:

Here and now decision variables (independent from disruption scenarios)

θ_{im}	A binary variable which is equal to 1 if a warehouse is constructed in site i with capacity m

X_{ik}	A binary variable which is equal to 1 if customer region k is allocated to warehouse i
η_{jl}	A binary variable which is equal to 1 if supplier j is selected as the main supplier for product l
η'_{jl}	A binary variable which is equal to 1 if supplier j is selected as the backup supplier for product l
λ_{in}	A binary variable which is equal to 1 if warehouse i is fortified at level n

Wait and see decision variables (based on disruption scenarios)

a_{ikls}	A binary variable which is equal to 1 if product l is sent for customer region k from warehouse i under disruption scenario s
y_{jkls}	A binary variable which is equal to 1 if product l is sent directly from supplier j for customer region k under disruption scenario s
ω_{ils}	A binary variable which is equal to 1 if product l is available in warehouse i under disruption scenario s

3.2.2. Network design model

Objective functions:

$$\text{Min} \sum_{i,m} F_{im}\theta_{im} + \sum_{l,j} F_{jl}\eta_{jl} + \sum_{l,j} {F'}_{jl}\eta'_{jl} + \sum_{i,n} FR_{in}\lambda_{in} + \sum_{i,l,k} C_{ikl}a_{ikl0} + \sum_{kjl} C_{jkl}y_{jkl0} + \sum_{i,l} W_{il}\omega_{il0}. \qquad (1)$$

Objective function (1) minimizes the fixed cost of constructing warehouse, the fixed cost of main and backup supplier selection, the cost of transferring product from warehouse to customer regions, the cost of product direct transfer from supplier to customer regions, the cost of maintaining product in the warehouse, and fortification cost, just for scenario 0 while Constraint (17) ensures a limit for other scenarios (see Ref. [66] for a similar approach).

$$\text{Max} \sum_{l,j} \left(v_{lj}\eta_{jl} + v'_{lj}\eta'_{jl}\right). \qquad (2)$$

Objective function (2) maximizes the total score of the main and backup suppliers regarding to v_{lj} and v'_{lj}.

Constraints:

$$\sum_{i} X_{ik} = 1 \qquad \forall k. \qquad (3)$$

Eq. (3) illustrates that each customer region is allocated to one warehouse:

$$\sum_{k} X_{ik} \leq \sum_{m} \mu_m\theta_{im} \qquad \forall i \in I. \qquad (4)$$

A customer region is allocated to a warehouse if that warehouse is constructed with one of the specified capacities.

$$\sum_{m} \theta_{im} \leq 1 \qquad \forall i \in I. \qquad (5)$$

Each warehouse can be constructed with only one type of capacity:

$$a_{ikls} \leq X_{ik} \qquad \forall i \in I, k, l, s. \qquad (6)$$

Warehouse i can provide product l for customer region k, only if customer region is allocated to that warehouse:

$$\sum_{k} y_{jkls} \leq \eta_{jl} + \eta'_{jl} \qquad \forall s, j, l. \qquad (7)$$

Supplier j can transfer product l to customer region k, when it is selected as main supplier for product l.

$$\sum_{j} y_{jkls} + \sum_{i \in I} a_{ikls} = 1 \qquad \forall k, l, s. \qquad (8)$$

Demand of each customer region is provided only through one way:

$$a_{ikls} \leq M\omega_{ils} \qquad \forall i \in I, k, l, s. \qquad (9)$$

Providing demand from fulfilment centre is possible if product is available in warehouse k:

$$\sum_{i,j} d_{kl}\left(a_{ikls} + y_{jkls}\right) \leq \sum_{i,m,n} b_{ml}\theta_{im}\pi_{is}\tau_{ins} + \sum_{j} e_{jl}\gamma_{js}\left(\eta_{jl} + {\eta'}_{jl}\right) \qquad \forall k, l, s. \qquad (10)$$

Demand of each customer region under disruption scenario s must be less than the available capacity of warehouse, main and backup suppliers:

$$\left(\eta_{jl} + \eta'_{jl}\right) \leq 1 \qquad \forall l, j. \qquad (11)$$

A selected supplier can only be main or backup supplier for a product:

$$\sum_{j} \eta_{jl} = 1 \qquad \forall l. \qquad (12)$$

For each product a main supplier must be selected:

$$\sum_{j} \eta'_{jl} = 1 \qquad \forall l. \qquad (13)$$

For each product a backup supplier must be selected:

$$\sum_n \lambda_{in} = \sum_m \theta_{im} \qquad \forall i \in H. \tag{14}$$

Each warehouse which is constructed in a high-risk site should be fortified in a specific level:

$$\sum_n \lambda_{in} \leq \sum_m \theta_{im} \qquad \forall i \in I. \tag{15}$$

Each warehouse which is constructed in a low-risk site can be fortified at a specific level:

$$\sum_{i \in I} F_{im}\theta_{im} + \sum_{i \in H} FR_{in}\lambda_{in} \leq B \qquad \forall m, n. \tag{16}$$

Available budget constraint for warehouses fortification and construction:

$$\sum_{i,m} F_{im}\theta_{im} + \sum_{l,j} F_{jl}\eta_{jl} + \sum_{l,j} F'_{jl}\eta'_{jl} + \sum_{i,n} FR_{in}\lambda_{in} + \sum_{i,l,k} C_{ikl}a_{ikls} + \sum_{k,j,l} C_{jkl}y_{jkls} + \sum_{i,l} W_{il}\omega_{ils} \leq (1+\alpha)\,\Delta_s^* \qquad \forall s \in S/0. \tag{17}$$

This constraint emphasizes on the robust criterion α. It means that the cost of each disruption scenario should not be more than $100(1+\alpha)\%$ of the optimal cost as if we know that which disruption scenario will be occurred:

$$\theta_{im}, X_{ik}, \eta_{jl}, \eta'_{jl}, \lambda_{in}, a_{ikls}, y_{jkls}, \omega_{ils} \in \{0,1\}. \tag{18}$$

At the following, a complementary mathematical model is presented for determining the optimal solution of each disruption scenario. The difference between the main and the complementary model is that in the complementary model, Constraint (17) is omitted and in that model, optimal solutions for each disruption scenario is obtained as if we know with certainty that this scenario will be occurred. Before solving the model, which includes all scenarios, the complementary mathematical model should be solved for each S:

$$\Delta_s^* = \text{Minimize} \sum_{i,m} F_{im}\theta_{im} + \sum_{l,j} F_{jl}\eta_{jl} + \sum_{l,j} F'_{jl}\eta'_{jl} + \sum_{i,n} FR_{in}\lambda_{in} + \sum_{i,l,k} C_{ikl}a_{ikls} + \sum_{kjl} C_{jkl}y_{jkls} + \sum_{i,l} W_{il}\omega_{ils}, \tag{19}$$

subject to:

Constraints (3)–(5), (11)–(16), (18), and:

$$a_{ikls} \leq X_{ik} \qquad \forall i \in I, k, l, \tag{20}$$

$$\sum_k y_{jkls} \leq \eta_{jl} + \eta'_{jl} \qquad \forall j, l, \tag{21}$$

$$\sum_j y_{jkls} + \sum_{i \in I} a_{ikls} = 1 \qquad \forall k, l, \tag{22}$$

$$a_{ikls} \leq M\omega_{ils} \qquad \forall i \in I, k, l, \tag{23}$$

$$\sum_{i,j} d_{kl}\left(a_{ikls} + y_{jkls}\right) \leq \sum_{i,m,n} b_{ml}\theta_{im}\pi_{is}\tau_{ins} + \sum_k e_{jl}\gamma_{js}\left(\eta_{jl} + \eta'_{jl}\right) \qquad \forall k, l. \tag{24}$$

Constraints (20)–(24) are mentioned in the network design model, but here they are rewritten only for one scenario s.

3.2.3. Robust counterpart of the network design model

In the phase of designing the network of an online retailer, the demand is obviously uncertain. In addition, the transfer cost can be subject to uncertainty due to the fluctuations of the transport factors, like the fuel price. Therefore, the demand and transfer costs are considered as uncertain parameters to cope with.

Robust optimization is one of the popular approaches in optimization concept and for dealing with uncertainty. In this paper, the linear version of scenario-based robust optimization approach of Mulvey et al. [67] which is introduced by Yu and Li [68] as follows:

$$\text{Min } Z = \sum\nolimits_{\tilde{\mathrm{h}} \in \Omega} p_{\tilde{\mathrm{h}}}\xi_{\tilde{\mathrm{h}}} + \lambda \sum\nolimits_{\tilde{\mathrm{h}} \in \Omega} p_{\tilde{\mathrm{h}}}\left[\left(\xi_{\tilde{\mathrm{h}}} - \sum\nolimits_{\tilde{\mathrm{h}} \in \Omega} p_{\tilde{\mathrm{h}}}\xi_{\tilde{\mathrm{h}}}\right) + 2\theta_{\tilde{\mathrm{h}}}\right], \tag{25}$$

subject to:

$$\xi_{\tilde{\mathrm{h}}} - \sum\nolimits_{\tilde{\mathrm{h}} \in \Omega} p_{\tilde{\mathrm{h}}}\xi_{\tilde{\mathrm{h}}} + \theta_{\tilde{\mathrm{h}}} \geq 0, \tag{26}$$

$$\theta_{\tilde{\mathrm{h}}} \geq 0. \tag{27}$$

Based on the above equations, new parameters and variables are presented as follows in order to present the robust counterpart of the disruption model considering the demand and transfer cost uncertainty.

Sets:

Ω	Set of uncertain scenarios ($h \in \Omega$)

Parameters:

C_{iklh}	Cost of transferring product l from warehouse i for customer region under uncertain scenario h

C_{jklh}	Cost of transferring product l from supplier j for customer region under uncertain scenario h
d_{klh}	Physical demand of customer region k for product l under uncertain scenario h
P_h	Probability of occurring uncertain scenario h
ψ	Specified weight for solution variance

Decision variables:

Wait and see decision variables (based on uncertain scenarios)

a_{iklsh}	A binary variable which is equal to 1 if product l transferred from warehouse i to customer region k under disruption scenario s and uncertain scenario h
y_{jklsh}	A binary variable which is equal to 1 if product l transferred from supplier j for customer region k under disruption scenario s and uncertain scenario h
ω_{ilsh}	A binary variable which is equal to 1 if product l is available in fulfilment centre i under disruption scenario s and uncertain scenario h
φ_h	Robust approach variable
ξ_h	An auxiliary variable for the uncertain terms of the objective function, which is calculated in Constraint (37)

$$\text{Min } Z=\sum\nolimits_h P_h.\xi_h+\psi\sum\nolimits_h P_h \cdot\left[\left(\xi_h-\sum\nolimits_{h'}P_{h'}.\xi_{h'}\right)+2\varphi_h\right] +\sum_{i,m}F_{im}\theta_{im}+\sum_{l,j}F_{jl}\eta_{jl}+\sum_{l,j}F'_{jl}\eta'_{jl} +\sum_{i,n}FR_{in}\lambda_{in}, \tag{28}$$

$$\text{Max}\sum_{l,j}\left(v_{lj}\eta_{jl}+v'_{lj}\eta'_{jl}\right), \tag{29}$$

subject to:
Constraints (3)–(5), (11)–(16), and:

$$\xi_h-\sum\nolimits_h P_h.\xi_h+\varphi_h\geq 0 \qquad \forall h\in\Omega, \tag{30}$$

$$a_{iklsh}\leq X_{ik} \qquad \forall i\in I,k,l,s,h, \tag{31}$$

$$\sum_k y_{jklsh}\leq \eta_{jl}+\eta'_{jl} \qquad \forall s,j,l,h, \tag{32}$$

$$\sum_j y_{jklsh}+\sum_{i\in I}a_{iklsh}=1 \qquad \forall k,l,s,h, \tag{33}$$

$$a_{iklsh}\leq M\omega_{ilsh} \qquad \forall i\in I,k,l,s,h, \tag{34}$$

$$\sum_{i,j}d_{klh}\left(a_{iklsh}+y_{jklsh}\right)\leq\sum_{i,m,n}b_{ml}\theta_{im}\pi_{is}\tau_{ins} +\sum_k e_{jl}\gamma_{js}\left(\eta_{jl}+\eta'_{jl}\right) \qquad \forall k,l,s,h, \tag{35}$$

$$\sum_{i,m}F_{im}\theta_{im}+\sum_{l,j}F_{jl}\eta_{jl}+\sum_{l,j}F'_{jl}\eta'_{jl} +\sum_{i,n}FR_{in}\lambda_{in}+\sum_{i,l,k,h}C_{ikl}a_{iklsh} +\sum_{k,j,l,h}C_{jkl}y_{jklsh}+\sum_{i,l,h}W_{il}\omega_{ilsh} \leq(1+\alpha)\Delta_s^* \qquad \forall s\in S/0, \tag{36}$$

$$\xi_h=\sum_{i,l,k}C_{iklh}a_{ikl0h}+\sum_{k,j,l}C_{jklh}y_{jkl0h} +\sum_{i,l}W_{il}\omega_{il0h}, \tag{37}$$

$$\theta_{im},X_{ik},\eta_{jl},\eta'_{jl},\lambda_{in},a_{iklsh},y_{jklsh},\omega_{ilsh}\in\{0,1\}, \quad \varphi_h\geq 0 \text{ and } \textit{integer}. \tag{38}$$

Moreover, a complement of the above model is presented below, as if we know with certainty that disruption scenario s will be occurred. The optimal solution of the complementary model is indicated by Δ_s^*. In this article, we want to solve the presented model considering all the scenarios together, and each disruption scenario should not be significantly worse than its optimal condition, which is guaranteed by $(1+\alpha)\Delta_s^*$ in Constraint (36). Therefore, the complementary mathematical model should be solved for each S:

$$\text{Min}\Delta_s^*=\sum\nolimits_h P_h.\left(\xi_h\right)'+\psi\sum\nolimits_h P_h \cdot\left[\left(\left(\xi_h\right)'-\sum\nolimits_{h'}P_{h'}.\left(\xi_{h'}\right)'\right)+2\varphi_h\right] +\sum_{i,m}F_{im}\theta_{im}+\sum_{l,j}F_{jl}\eta_{jl}+\sum_{l,j}F'_{jl}\eta'_{jl} +\sum_{i,n}FR_{in}\lambda_{in}, \tag{39}$$

$$\text{Max}\sum_{l,j}\left(v_{lj}\eta_{jl}+v'_{lj}\eta'_{jl}\right), \tag{40}$$

subject to:
Constraints (3)–(5), (11)–(16), and:

$$(\xi_h)' - \sum\nolimits_h P_h.(\xi_h)' + \varphi_h \geq 0 \qquad \forall h \in \Omega, \tag{41}$$

$$a_{iklsh} \leq X_{ik} \qquad \forall i \in I, k, l, h, \tag{42}$$

$$\sum_k y_{jklsh} \leq \eta_{jl} + \eta'_{jl} \qquad \forall j, l, h, \tag{43}$$

$$\sum_j y_{jklsh} + \sum_{i \in I} a_{iklsh} = 1 \qquad \forall k, l, h, \tag{44}$$

$$a_{iklsh} \leq M\omega_{ilsh} \qquad \forall i \in I, k, l, h, \tag{45}$$

$$\sum_{i,j} d_{klh}\left(a_{iklsh} + y_{jklsh}\right) \leq \sum_{i,m,n} b_{ml}\theta_{im}\pi_{is}\tau_{ins} + \sum_k e_{jl}\gamma_{js}\left(\eta_{jl} + \eta'_{jl}\right) \qquad \forall k, l, h, \tag{46}$$

$$(\xi_h)' = \sum_{i,l,k} C_{iklh}a_{iklsh} + \sum_{k,j,l} C_{jklh}y_{jklsh} + \sum_{i,l} W_{il}\omega_{ilsh}, \tag{47}$$

$$\theta_{im}, X_{ik}, \eta_{jl}, \eta'_{jl}, \lambda_{in}, a_{iklsh}, y_{jklsh}, \omega_{ilsh} \in \{0, 1\},$$

$$\varphi_h \geq 0 \text{ and } \textit{integer}. \tag{48}$$

3.3. Mathematical model for the third phase

In this phase, we concentrate on operational decisions in an order transfer problem based on the results of the network design model of the second phase, in which a main and a backup supplier for each product are determined.

In e-tailing, the orders of customers are specified at the end of each day (8:00 p.m.), and a 12-hour time will exist for planning until tomorrow (8:00 a.m.) that the orders should be delivered. Usually, there are various shipping options, each of which has its specified cost, and each customer is able to choose a shipping option when s/he purchases from the e-tailer's website.

Under normal circumstances, customer orders are shipped as follows. Orders which all their items are available in the warehouse allocated to their related customer will be shipped to the customer in one package. If some order items are not available in the warehouse assigned to the customer, either they are transhipped from another warehouse and the customer's order is shipped upon completion in a package; or some items from another warehouse are sent directly to the customer. In the latter case, the shipment will be shipped in two packages. Also, if the customer's order includes items that are not available in any of the warehouses, the items in the warehouse will be shipped to the customer in one package and unavailable items will be shipped directly to the customer from the main supplier.

In the case of disruption, if the assigned warehouse is damaged, orders will be shipped from the fortified warehouse to the customer. Also, if the main supplier of a product has been damaged, it will be sent to the customer through a backup supplier.

If the products are sent to the customer from the backup supplier, fortified warehouse, or through transshipment, the associated delay is calculated in the second objective function. The order transfer model should be solved separately for each disruption scenario. The following decisions are made in the third phase:

- Amount of the transferred items from each warehouse to customer;
- Amount of the transferred items from supplier to customer directly;
- Amount of the transferred items between fulfilment centres;
- Amount of the transferred items from backup fulfilment centres for each customer;
- Decision about product displacement between warehouse.

Furthermore, the assumptions made in formulating the third phase's model are as follows:

- Warehouses are specified and each customer is allocated to a warehouse;
- Specified warehouses are fortified;
- The lateral transshipment is possible between warehouses;
- When the lateral transshipment is used, there is only one shipping option to transfer the product to the customer;
- It is possible to transfer products from supplier to customer directly;
- Backup suppliers are more reliable and simultaneous damage of backup and main supplier, is not possible;
- Damage caused by occurring a disruption scenario is specified with a percentage of products in the warehouse;
- There is no probability of selecting more than one unavailable product in the form of an order by a customer;
- There is not product shortage in the system;
- The replenishment of warehouses is not considered, because the model is not multi-period;

- The location of warehouses, make direct shipment possible from an unassigned warehouse to a customer. Moreover, in the case of transferring products from one warehouse to others, delays must be considered;
- Each warehouse is independent from the others.

3.3.1. Notations

Sets:

I	Set of e-tailer's warehouses ($i \in I$)
H	Set of fortified warehouses ($H \subset I$)
T	Set of unfortified warehouses ($T \subset I$)
K	Set of customers of the e-tailer ($k \in K$)
J	Set of suppliers of the e-tailer ($j, j' \in J$)
L_1	Set of available products in the e-tailer's warehouses ($l \in L_1$)
L_2	Set of unavailable products in the e-tailer's warehouses, which are transferred directly from suppliers ($l \in L_2$)
R	Set of shipping option ($r \in R$)

Parameters:

K_i	Set of assigned customers to warehouse i
C^r_{ikl}	Shipping cost for product l from warehouse i to customer k using shipping option r
${C'}^r_{jkl}$	Shipping cost for product l from supplier j to customer k using shipping option r
$\hat{C}^r_{ikl}$	Shipping cost for product l from fortified warehouse i to customer k using shipping option r
$VCT_{i'ikl}$	Variable cost for lateral transshipment of product l, which is ordered by customer $k \in K_i$ from warehouse i' to i
$FCT_{i'ikl}$	Fixed cost for lateral transshipment of product l which is ordered by customer $k \in K_i$ from warehouse i' to i
LT^r_{jkl}	Delay cost in transferring one unit of product l from backup supplier j to customer k using shipping option r
${LT'}^r_{ikl}$	Delay cost in transferring one unit of product l from fortified warehouse i to customer k using shipping option r
$\widehat{LT}_{ii'l}$	Delay cost in transshipment of one unit of product l from warehouse i to i'
I_{il}	Inventory level of product l in warehouse i
${I'}_{jl}$	Inventory level of product l in supplier j
d^r_{kl}	Demand for product l realized by customer k supplied by option r
τ_{is}	Percentage of the capacity of warehouse i which is available under disruption scenario s
γ_{js}	Available capacity of supplier j under disruption scenario s
η_{jl}	Binary parameter for selection of supplier j as the main supplier for product l
η'_{jl}	Binary parameter for selection of supplier j as the backup supplier for product l

Decisions variables:

x^r_{ikls}	Shipment quantity of product l from allocated warehouse i to customer k using shipping option r under disruption scenario s
${x'}^r_{ikls}$	Shipment quantity of product l from fortified warehouse i to customer k using shipping option r under disruption scenario s
$q_{i'ikls}$	Lateral transshipment quantity of product l which is ordered by customer $k \in K_i$ from warehouse i' to i under disruption scenario s
y^r_{jkls}	Shipment quantity of product l from supplier j to customer k using shipping option r under disruption scenario s
$z_{i'ikls}$	Binary variable for lateral transshipment which is equal to 1 if product l which is ordered by customer $k \in K_i$ is shipped from warehouse $i' \neq i$ under disruption scenario s

3.3.2. Order transfer model

The third phase solves the following mathematical model for each disruption scenario.

Objective function:

$$\text{Min} \sum_{i,k,l,r} C^r_{ikl} x^r_{ikls} + \sum_{i,i' \neq i,k,l} VCT_{i'ikl} q_{i'ikls}$$

$$+ \sum_{j,l,k,r} {C'}^r_{jkl} y^r_{jkls} + \sum_{i \in H,k,l,r} \hat{C_{ikl}}^r {x'}^r_{ikls}$$

$$+ \sum_{i,i' \neq i,k,l} FCT_{i'ikl} z_{i'ikls}$$

$$+ \sum_{j,j' \neq j,k,l,r} LT^r_{j'kl} y^r_{j'kls}$$

$$+ \sum_{i\in H,k,l,r} {LT'}^{r}_{ikl} {x'}^{r}_{ikls}$$

$$+ \sum_{i,i'\neq i,k\in K_i,l} \widehat{LT}_{ii'l}\, q_{ii'kls}. \tag{49}$$

Objective function (49) aims to minimize the shipping costs, fixed and variable costs of lateral transshipment, and the total cost of delay in satisfying the customers that their orders are not shipped from their assigned warehouses.

Constraints:

$$x^{r}_{ikls} + \sum_{i'\neq i} {x'}^{r}_{i'kls} + \sum_{i'\neq i} q_{i'ikls} \geq d^{r}_{kl}$$

$$\forall i, k\in K_i, l\in L_1, r. \tag{50}$$

For products available in a warehouse, there are three approaches for fulfilling the orders of customers. Transferring from allocated warehouse, lateral transshipment, or transferring from fortified warehouse using the shipping option specified by the customer:

$$\sum_{k,r} x^{r}_{ikls} + \sum_{k,r} {x'}^{r}_{ikls} + \sum_{i'\neq i,k} \left(q_{ii'kls} - q_{i'ikls}\right)$$

$$\leq I_{il}\tau_{is} \qquad \forall i, l. \tag{51}$$

Quantity of output products from each warehouse must be less than warehouse's capacity for that product (under disruption scenario s):

$${x'}^{r}_{ikls} = 0 \qquad \forall l, k, r, i\in T. \tag{52}$$

After the occurrence of a disruption scenario, just fortified warehouses can transfer products to customers.

$$q_{i'ikls} \leq I_{il}\tau_{is} z_{i'ikls} \qquad \forall i, i'\neq i, k\in K_i, r, l. \tag{53}$$

The lateral transshipment of products from a warehouse to another one is possible when that warehouse is selected and the shipment quantity is less than the warehouse capacity which is available under disruption:

$$\sum_{i'\neq i} z_{i'ikls} \leq 1 \qquad \forall l, i, k\in K_i. \tag{54}$$

When there is not enough products in the allocated warehouse there will be just one alternative warehouse:

$$\sum_{r,j} y^{r}_{jkls}\eta_{jl} + \sum_{r,j'} y^{r}_{j'kls}\eta'_{j'l} \geq d^{r}_{kl} \qquad \forall k, l\in L_2. \tag{55}$$

The demand which cannot be fulfilled through warehouses should be provided by the main and backup suppliers using the shipping option specified by the customer:

$$\sum_{r,k} y^{r}_{jkls} \leq I'_{jl}\gamma_{js} \qquad \forall j, l. \tag{56}$$

Shipment quantity from supplier for each product, must be less than the supplier's inventory level for that product:

$$x^{r}_{ikls}, {x'}^{r}_{ikls}, q_{ii'ls}, y^{r}_{jkls} \geq 0;$$

$$\forall i, i'\neq i, k\in K_i, r, l, \tag{57}$$

$$z_{i'ikls}\in\{0,1\}.$$

4. Computational results

The proposed models are coded in GAMS software, and solved by using a computer with these specifications: Intel Core i5 CPU 2.67 GHz using 4 GB of RAM. Then, a small-sized problem is utilized to verify the proposed models (see Appendix A of the supplementary material). After the verification of the model, in order to investigate the practical application of the proposed framework in real world, a case study about an e-tailing company is considered. With the designed scenarios, the resilience of the system is investigated when dealing with disruptions. Moreover, the system is considered strategic and practical levels.

4.1. Data for case study

Dobisell is a new online retailer in Iran and works in the field of sport equipment which are related to nature (e.g., for mountaineering). Its target market is the whole country, but at the first years of its work the most of the demands were from Tehran (capital of Iran). Gradually by growing the number of customer orders from all over the country, warehouses were not sufficient to meet the demand. Moreover, the variety of products was also increased by the expansion of the work, and a precise plan for transferring orders to customers was required. So, Dobisell tried to construct warehouses in other cities in order to reduce the transfer costs and deliver products on time. Therefore, the need for designing a supply chain in the national scale was formed. In addition, Iran is prone to natural disasters and therefore, it is necessary to consider the disruptions when designing a nationwide supply chain. Consequently, Dobisell decided to incorporate resilience and reliability into its business. First of all, 30 potential suppliers were evaluated and 15 of them were selected. Resilient and general supplier selection criteria extracted from the literature are shown in Table 1.

Figures 2 and 3 demonstrate the customer region and the candidate sites for establishing the warehouses. In the next step, demand in the two last years is specified and by clustering algorithm, the country is divided into four demand regions. Then, target sites for constructing new warehouses were selected. By

Table 1. Suppliers' criteria.

General supplier selection criteria	Resilient supplier selection criteria
Inventory level	Speed
Convenient communication with company	Collaboration-supply chain continuity management
Rate of transferring products	Speed-observation capability
Collaboration (%)	Price
Paid terms	Price-flexibility
Type of agency	Quality
Capability of company in supply	Observation capability-flexibility
Plan of company for dealing with disasters	Supply chain continuity management
Price of products	Price
Products originality	Quality
Safety	Vulnerability-risk awareness
Guaranty	Quality
Infrastructure availability based on information technology	Technological capability
Stay up to date	R&D

Figure 2. Customer regions.

using the opinions of the experts and regarding to the access of the city to the national transportation system, the cost of land, climate, labor force and dispersion of selected cities, five cities were selected as candidate sites for building warehouses. In this research, earthquake, as an important natural disaster in the case of Iran is used for developing disruption scenarios. Sites 1, 3, and 5 are considered as high-risk sites while sites 2 and 4 are low-risk ones based on earthquake hazard. If a warehouse is built in a high-risk site it should be fortified against earthquake. Each warehouse can be established in five levels of capacity. The occurrence probabilities of the three uncertain scenarios for demand and transfer costs are indicated in Table 2. In each uncertain scenario, 20% is added to or subtracted from the nominal demand. Moreover, there are four disruption scenarios, the data of which are indicated in Table 3. In addition, the aspiration level of Constraint (17) is considered to be $\alpha = 0.15$, and the weight for solution variance is assumed to be $\psi = 0.1$.

4.2. Results for the network design model

According to subsection 3.2.2, before solving the bi-objective model, Δ_s^* are obtained by solving four models corresponding to four scenarios as $\Delta_1^* = 1.3068E{+}8$,

Figure 3. Candidate sites for building warehouses.

Table 2. Uncertain scenarios for demand and transfer costs with their probability.

Uncertain scenarios	**Probability**	**The percentage of deviation from the nominal value**
1	0.1	–20%
2	0.8	0%
3	0.1	+20%

Table 3. The probability of disruption scenarios in each candidate site (in percent).

	Scenarios			
	1	**2**	**3**	**4**
Regions	**Lower than 4 Richter**	**4-6 Richter**	**6-8 Richter**	**Greater than 8 Richter**
Site 1	50	5	1	0.1
Site 2	20	1	0.1	0.001
Site 3	50	5	1	0.1
Site 4	20	1	0.1	0.001
Site 5	60	10	1	0.1

$\Delta_2^* = 1.3089E+8$, $\Delta_3^* = 1.3068E+8$, and $\Delta_4^* = 1.3144E+8$. After that, the bi-objective model is solved using GAMS software, and the ε-constraint method obtained nine Pareto solutions, which are demonstrated in Figure 4. The preferred solution (distinguished by a red square) is selected because its cost is only 0.15% worse than its neighbour while its score of suppliers is 2.46% greater than the mentioned point. The objective value of the point which maximizes the scores of suppliers is 23.75, and the value of one which concentrate on cost minimization is 129,020,436.

Table 4 shows the values of the decision variables in the preferred solution. Warehouses 1 and 3 are selected to be fortified in the first level of fortification. It is reasonable because they are located in high-risk sites. For each product, a main and a backup supplier is chosen. Table 4 illustrates that supplier 8 is not selected for any product, neither as a main supplier nor as a backup one.

According to Figure 5, as the value of parameter ψ changes from 0.05 to 0.3, the best cost changes from 1.2882E+8 to 1.2907E+8, and the best total score does not change. In the middle of the curves, changes in the solutions leads to a fluctuation in the trend. Moreover, it can be seen that when the total score is low, the cost range is larger, and vice versa.

Table 4. The values of decision variables in the optimal solution of network design problem.

Values of decision variables								
θ_{im}		X_{ik}		η'_{jl}, η_{jl}			λ_{in}	
Established warehouses	**Type of capacity**	**Established warehouses**	**Allocated customer regions**	**Product #**	**Main supplier**	**Backup supplier**	**Fortification level**	**Fortified warehouses**
1	1	1	1	1	1	9	1	1
2	1	2	2	2	1	9	1	3
3	1	3	3	3	1	9		
4	1	4	4	4	9	1		
				5	2	11		
				6	3	7		
				7	3	7		
				8	4	7		
				9	6	5		
				10	6	5		
				11	9	12		
				12	12	9		
				13	13	9		
				14	9	14		
				15	9	12		

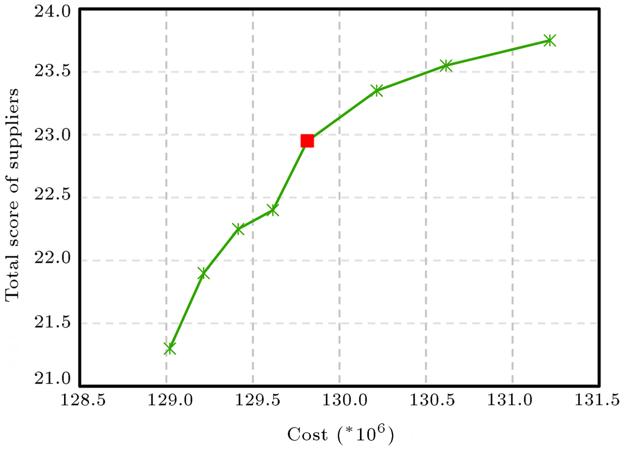


Figure 4. Pareto optimal solutions.

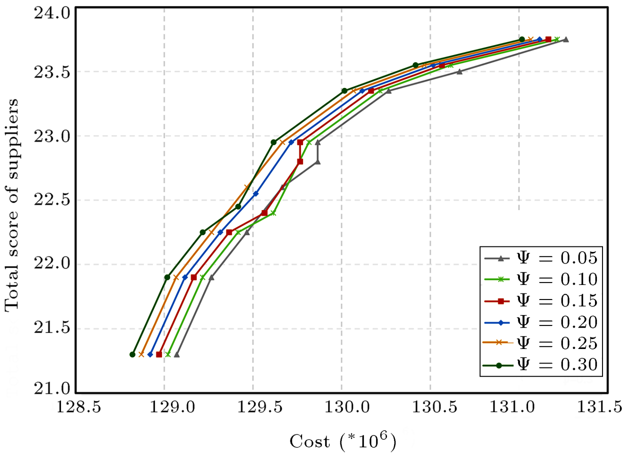


Figure 5. Pareto optimal solutions for the sensitivity analysis in ψ.

Table 5. The allocation of customers to warehouses.

Allocated warehouse	Customers	Customer region
1	1–5	1
2	6–10	2
3	11–17	3
4	18–20	4

4.3. Results of the order transfer model

Based on the solution of the network design problem, an order transfer problem is solved with delay consideration for Dobisell. The list of orders is accumulated until 8 p.m. and the delivery process will start from tomorrow 8 a.m.. In a specific day, 20 orders from 20 customers has been registered. Customers' allocation to warehouses is shown in the Table 5.

Products 1-7 and 9-15 are available in the warehouses and product 8 should be provided from suppliers. Two kinds of shipping options are considered named fast and slow. Slow approach will have less cost with longer delay. In the case of disruption, if the main supplier or the allocated warehouse is unable to meet the demand, the customer's demand will be provided through a backup supplier or a fortified warehouse with a two days delay for slow shipping option and one day for the fast one. Each customer's order is deterministic and inventory level is specified. Available capacities

Table 6. The definition of disruption scenarios.

Scenarios	Disruption definition	Objective value
1	7 Richter earthquake in region 1	1437204
2	7 Richter earthquake in region 2	5702407
3	7 Richter earthquake in region 3	1405407
4	7 Richter earthquake in region 4	0

of warehouses in each disruption scenario, and the supplier's available capacity in each disruption scenario are given in Appendix B of the supplementary material.

The order transfer problem is solved with GAMS software for each scenario. The objective values for the four kinds of disruption scenarios are indicated in Table 6.

By evaluating the results of the four scenarios and the model capability in managing the disruption circumstances with minimum delay, it can be concluded that the designed supply chain is resilient.

5. Conclusion and future research

In this research, we focus on designing a resilient supply chain by employing a three-phase approach. In the first phase of this approach, resilient criteria beside general ones are defined for supplier selection. Then, weights of criteria are specified by AHP method and after that, the TOPSIS method then allocates a specific score to each supplier as the main or backup one. In the second phase, a scenario-based mathematical model is presented. In addition, a robust approach is employed in this phase to deal with model's uncertainty which is investigated on demand uncertainty. Different disruption scenarios are defined in this phase. Moreover, the main and backup suppliers for each product, location and capacity of new warehouses, allocation of customers' regions to warehouses and fortification in high-risk sites are considered as strategic decisions in the second phase of the proposed approach. Then by using the designed supply chain in the second phase, a customers' orders delivery problem is solved and different disruption scenarios and delays are considered as criteria for resilience evaluation in the third phase of the approach. A numerical example was then proposed for model's verification and a case study in Iran is then presented for investigating the model's capability in real world conditions. By solving the mathematical model in the third phase, it is concluded that although the disruption was a major one (7 Richter earthquake), supply have not been disrupted.

Disruption scenarios which were considered in this research were natural disasters (earthquake). So, in national scale, it cannot affect all over the country. But economic and social disruptions such as exchange rate fluctuation, worker strikes and so on can affect the whole country. In future researches, economic and social disruptions can be investigated. In this article, all items of an order are transferred to customers from one warehouse. Therefore, split delivery can be suggested for future works. Furthermore, return of products from customers is another possible extension. The method which was used for solving the model in this article obtains optimal solutions for small and moderate businesses. For larger businesses in global scale, metaheuristic methods can be used.

6. Managerial insights

In the occurrence of disruption and operational risks, organizations which are not resilient will not be able to recover their supply chains in a rational time and will face the loss of performance. Therefore, in this research we focused on designing a resilient supply chain through a proposed three-phase approach. Based on the results of our paper, we have provided some managerial implications for managers of e-tailing companies. Therefore, the first step toward providing a resilient supply chain is selecting the main and back-up suppliers regarding the resilience criteria. In this case, managers are suggested to select main and back-up suppliers for each product which have the largest value of resiliency score based on the represented objective function of the mathematical model of the second phase. Furthermore, by following the presented approach in the first phase, they can minimize supply chain's costs as well as making supply chain's strategic decisions. Finally, based on the results of the two last steps, operational decisions in an order transfer problem can be made in the third phase. Moreover, selecting the optimum solution is relevant to the attitude of managers toward the importance of supply chain's costs or resiliency and they can decide about the value of objective functions of the first phase by changing the value of specified weight for the solution variance. Accordingly, using the suggestions of this research, the managers can guarantee the resiliency of the supply chain even in the occurrence of major disruptions.

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Biographies

Seyed Mohammad Reza Hasani earned BSc in Industrial Engineering from K. N. Toosi University of Technology. He received his MSc in Industrial Engineering from University of Tehran. His research interests are supply chain management, operations research, and integer programming.

Mohammad Mahdi Nasiri is an Associate Professor at the University of Tehran. He received his BSc, MSc, and PhD in Industrial Engineering from the Sharif University of Technology, Iran in 2004, 2006, and 2011. His research interests are in scheduling, cross-dock optimization, supply chain management, transportation, and integer programming. His works appear in Computers & Operations Research, Expert systems with applications, Applied Mathematical Modelling, International Journal of Production Research, Computers & Industrial Engineering, Applied Soft Computing, Transportation, and other reputed journals.

Seyed Ali Torabi is a Professor of Operations and Supply Chain Management at the School of Industrial Engineering, University of Tehran, Tehran, Iran. His main research interests include: Supply Chain Resilience, Supply Chain Sustainability & Circular Economy, Supply Chain 4.0 and Humanitarian Logistics. Professor Torabi has published several papers in peer-reviewed high quality international journals such as EJOR, IJPE, TRE, IJPR, JORS, COR, and CIE.

Zahra Mohtashami is a PhD student in Industrial Engineering at Sharif University of Technology. She received her MSc and BSc degree in Industrial Engineering from University of Tehran and Iran University of Science and Technology, respectively. Her research interests are supply chain management, operations research, integer programming, energy systems and healthcare optimization. Her papers are relevant to the aforementioned research interests and have appeared in reputed journals.