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An integrated model for designing a distribution network of products under facility and transportation link disruptions

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Abstract

Due to occurrence of unexpected disruptions,a resilient supply chain design is important. In this paper, a bi-objective model is proposed for designing a resilient supply chain including suppliers, distribution centers (DCs), and retailers under disruption risks.The first objective function minimizes total costs. The second objective function maximizes satisfied demands. We use the augmented e-constraint method to solve the bi-objective problem. In the proposed model, the possibility of partial disruptions of DCs as well as complete disruptions of connection links between distribution centers and retailers is considered. In order to reduce risk, resilience strategies including, using multiple sourcing, direct shipment of products from suppliers to retailers, and lateral transshipment between distribution centers are used.We utilize a two-stage stochastic programming method to deal with disruption risks. The decisions of the first stage of the method consist selection of suppliers and location of DCs while the decisions of the second stage include integrated programs for supply and distribution of products**.** The validity of the proposed model is then evaluated by introducing a numerical example and performing different sensitivity analyses on it**.**

Keyword: resilient supply chain, supplier selection, two-stage stochastic programming, lateral transshipment, multiple sourcing.

1-Introduction

Risk management, as a vital element in literature of supply chain, is responsible for coordination and integration of different components of the chain. In other words, supply chain risk management can be defined as development of strategies to manage risks in a supply chain. It is mainly used to decrease the vulnerability of the chain and to assure business continuity (Wieland and Marcus Wallenburg, 2012, Zsidisin* et al., 2005).

Also, supply chains (SCs) complexity has arisen while the severity and frequency of disruptions seems to be increasing. The new report of World Economic Forum emphasizes on building resilient supply chains. The results indicate that huge disruptions in SCs decline the share price of affected companies by as much as seven percent averages, also it has determined that 80 percent of companies see better protection of SCs as priority(Risks, 2012).

Both of them threaten the ability of logistic providers, manufacturers, suppliers and other beneficiaries of SCs to maintain a state of business continuity which is the goal of logistic providers and related companies with no business tolerance for downtime(Snyder et al., 2006) .

There are several uncertainties in supply chain network including operational uncertainties and unexpected disruptions with low probabilities of occurrence. The first category is related to uncertainties in demand of customers, supply and procurement process and also uncertain quantities of raw material prices, etc. These uncertainties have significant impacts on the performance of supply chains and they occur frequently. There has been much work in literature of designing supply chain considering operational uncertainties only in demand-side (Shen and Daskin, 2005, Romeijn et al., 2007, Ko and Evans, 2007,You and Grossmann, 2008,Pan and Nagi, 2010,Park et al., 2010,Cardona-Valdés et al., 2011,Hsu and Li, 2011, Rezaee et al., 2015, Rezaee et al., 2015, Han et al., 2015, Yin et al., 2015, Cardoso et al., 2015). Also supply-side uncertainty management which affect operational uncertainty beside demand uncertainty has a rich literature (Santoso et al., 2005, Yu et al., 2009, Bode and Wagner, 2015, Giri and Bardhan, 2015,Jabbarzadeh et al., 2015). Difficulties with supply in one entity can disrupt the performance of all entities of the supply chain leading to lost sales and poor service level and long-term demand attenuation(Rezapour et al., 2015).

Second, disruption risks mainly refer to major disruptions, which influence the total chain significantly. The disruptions may happen as natural disasters such as earthquake and storm or as man-made disruptions and technological threats such as terrorist attacks, bombing, equipment failures, labor strikes etc (Marufuzzaman et al., 2014, Gedik et al., 2014, Khosrojerdi et al., 2016).The disruptions cause drastic social and economic damages (Sabouhi et al., 2016).

Disruption risks are divided into two categories: partial and complete. In partial disruptions, the events do not destroy all of the capacity of facilities so that disturbed facilities may use their remained capacity after disruption (Liberatore et al., 2012). On the other hand, in the complete disruption, all of the capacity of facilities is completely destroyed. Supply chains may tolerategreat lossesfor recovering from disruption in the case no appropriate responding strategies exist. In order to deal with it, designing and programming of supply chains are of great significance in order to perform resiliently in presence of disruptions (Dixit et al., 2016, Cardoso et al., 2014, Oke and Gopalakrishnan, 2009, Schütz and Tomasgard, 2011).

In the recent years, the number of research done about designing resilient supply chain has increased considerably and the development of mathematical models for optimization of supply chain under uncertainty and disruptions has attracted an increasing attention.Resiliency of the supply chain can be defined as the ability of the chain to return to its main state or a new state (a more appropriate situation) after disruption (Christopher and Peck, 2004, Pettit et al., 2010, Bhamra et al., 2011, Walker and Salt, 2012).

Although several works have been done on supply chain disruptions in recent years, there are only a few models for risk reduction strategies (Torabi et al., 2015, Snyder et al., 2016). Therefore, in this section, we have a review on published works in the field of resilient supply chain under disruption risks.

Using multiple sourcing is a common approach for reducing the risk of disruption. In fact, although in normal situations, single sourcing is much cheaper than multiple sourcing, it can lead to more losses when a disruption happens(Torabi et al., 2015, Shin et al., 2000).

To investigate it more, Peng et al. (2011)have proposed a network, consisting of suppliers and customers under disruption risks. They have used multiple sourcing strategies in order to decrease the risk. The objective of the proposed model is location of suppliers as well as determination of the flow of products from suppliers to customers, using P-robustness criterion. In the next work, a location-routing model for the network consisting of depots and customers have been presented by Zhang et al., 2015. Considering disruption risks in depots as well as using multiple sourcing, they have formulated their model as a two-stage stochastic problem.

In the same year, Sadghiani et al. (2015)have suggested a retailer supply chain under disruption risks and uncertainty. To decrease disruption risks in the suppliers, vehicles, products and transportation links, they have utilized multiple sourcing.The objective of the proposed model is location the suppliers, required vehicles in each mode of transportation, and the coverage methodof the retailers' demands. Later, a model to design closed-loop supply chain by considering partial and complete disruption of facilities has been presented by (Torabi et al., 2016).This network includes production-recovery centers,

distribution-collection centers, and disposal centers. Multiple sourcing strategies have been utilized to reduce disruption risks in facilities. Also, uncertainty in some of the input parameters is considered in their models. Hence, the possibility programming is applied to deal with it andP-robustness criterion is also used.

Fahimnia and Jabbarzadeh (2016) have worked on designing a sustainable supply chain, consisting of suppliers, factories, distributors, and market zones. A three-objective model has been proposed under suppliers' disruption and multiple sourcing strategies have been used for risk reduction.The objectives of the model are minimization of total costs and maximization of the environmental and social performance. Nooraie and Parast (2016)have worked on designing a supply chain, consisting of suppliers, producers, depots, distributors and customers. A stochastic multi-objective multi-products multi-period model is then proposed, taking the possibility of partial and complete disruptions into account. Note that, the authors have used multiple sourcing strategies to modify the resilience of the chain.The objectives of the model are minimization of the costs and maximization of value of the total revenue of opening facilities and selling products. Aqlan and Lam (2016)have presented a simulation and optimization model under disruption risks and uncertainty. The authors have considered their model as a multi-objective multi-product one. They have tried to maximize the profit, minimize lead timeand maximize risk reduction in factories through selecting a risk of mitigation strategies and allocating orders and inventory

Ivanov and Morozova (2016) have suggested a resilient multi-objective model consisting of suppliers, assembly plants, and customers under disruption. Their model is introduced as a dynamic structure and multi-period model. Minimization of returned products, inventory and transportation costs, and maximization of service level are included in the objectives of the proposed model. Proactive strategies used in this work to reduce disruption risks in facilities and transportation links are as follows: multiple sourcing strategies (facilities and alternative transportation channels), increasing capacity (facilities and transportation channels), backup facilities and extra inventory, recovery programming for lost capacity after disruption and bill of materials.

Makui and Ghavamifar (2016) proposed a bi-level model for designing a competitive supply chain under risk of disruptions. They have assumed disruptions impact on the DCs and connection links. They developed a two stage stochastic programming approach for handling uncertainty in demand. Finally, benders decomposition algorithm is developed for solving the bi-level model.

In addition to, the lateral transshipment has been applied as a policy to improve the performance of systems(Ahmadi et al., 2016). This means that if demand at one facility cannot be met, it will be satisfied from the other facility by a transshipment flow.

In this field, Torabi and Moghaddam (2012)have considered the lateral transshipments policy in a production–distribution system with fuzzy parameters. Alvarez et al. (2014) have applied lateral transshipment between two warehouses in a multi-product model, including multiple warehouses and two customer classes.Ahmadi et al. (2016)have proposed a bi-objective location-inventory model with multi-product and transshipment between depots. To deal with uncertainty of some parameters, they have used the possibilistic programming approach.

1-1-Gap analysis

The recent studies reviewed in this paper are analyzed according to different factors including objective functions, model formulation, decision level, network components and the disrupted components. Then, our study is analyzed in the last row of the Table 1.

Considering earlier researches, the gaps in the literature can be summarized as follows:

- The majority of previous works have considered a two-echelon network and only under disruption of one single facility. In fact, disruptions of transportation links are rarely discussed in published works.
- Using direct shipment of products and lateral transshipment is less applied to reduce disruption risks while a number of papers consider using multiple sourcing.
- Little attention has been paid to such features as the probability of partial disruptions of facilities, the possibility of lack of inventory as lost sales, and capacity limitation for facilities.
- Most papers are single-objective, and their aim is to minimize the total costs.

The contributions of this paper include:

- Designing a resilient supply chain, consisting of suppliers, DCs, and retailers, under simultaneous disruptions of DCs and connection links between distribution centers and retailers.
- Using proactive resilient strategies including using multiple sourcing, direct shipment of products from suppliers to retailers, and lateral transshipment between distribution centers.
- Considering real assumptions such as the probability of partial and complete disruptions DCs and connection links between distribution centers and retailers respectively, the possibility of lack of inventory as lost sales, and capacity limitation for suppliers and DCs.
- Presenting a multi-objective model and solving it with the augmented e-constraint method.

Table 1. Review table of supply chain network design under disruption

Authors	Objective functions		Model		Decision level			Network components					Disrupted components				
	Single Objective	Multi-Objective	Linear Programming	Nonlinear Programming	Strategic	Tactical	Operational	Supplier	Manufacturer	Warehouse	Distribution centers	Customer	Suppliers	Manufacturers	Warehouses	Distribution centers	Communication links
Hasani&khosrojerdi (2016)	*			*	*	*		*	*		*	*	*	*		*	
Zhang et al. (2015)	*		*		*		*			*		*			*		
Fahimnia&Jabbarzadeh (2016)		*	*		*	*		*	*		*	*	*				
Nooraie&MellatParast (2016)		*	*		*	*		*	*	*	*	*		*		*	*
Torabi et al. (2015)		*		*		*		*	*				*				
Torabi et al. (2016)	*		*		*	*			*		*	*		*		*	
Aqlan and Lam (2015)		*	*		*	*			*					*			
Jabbarzadeh et al. (2016)	*		*		*	*			*		*		*				
Peng et al. (2011)	*		*		*	*		*			*	*	*				
SalehiSadghiani et al (2015)	*		*		*	*		*				*					*
Dmitry Ivanov et al. (2016)		*		*	*	*		*	*			*		*			*
Our Study	*	*			*	*		*		*	*	*			*	*	*

The rest of paper is organized as follows. Problem description is explained in Section 2. Section 3 presents the proposed mathematical modeling. The model is executed on a numerical example in Section 4. Then, the results of different sensitivity analyses are provided in Section 5. Finally the paper is concluded in Section 6 and suggestions are proposed for future works.

2- Problem description

According to figure 1, a resilient supply chain is designed under disruption risks. Existing supply chain includes suppliers, distribution centers and retailers. Due to occurrence of unexpected disruptions in the recent years, the managers of supply chain have been decided to strengthen the supply chain

against disruptions. In light of this, some resilience strategies are suggested for diminishing the effect of disruptions on the performance of supply chain. The possibility of partial disruptions of DCs as well as complete disruptions of connection links between distribution centers and retailers is considered. The resilience strategies suggested are as follows:

Using multiple sourcing for distribution: This strategy can reduce losses when some DCs are disrupted.

- **Direct shipment of products from suppliers to retailers**: This strategy is used to diminish the effect of disrupted DC and unavailability of link between DCs and retailers.
- **Lateral transshipment between distribution centers**: For compensation of missed capacity, the lateral transshipment of products between DCs is utilized.

The assumed problem is formulated based on the following assumptions:

- In the present, the supply chain is working and the model aims to determine the location of DCs as well asselection of suppliers to designresilient supply chain.
- Disruption is considered partially in DCs.
- The connection links between DCs and retailers are considered fully disrupted.
- A fixed contract cost is assumed for supplying product from each supplier.
- Suppliers have a limited capacity for supplying products.

The model is formulated by using a two stages stochastic programming approach under a set of scenarios. In this approach, decision variables are categorized in scenario-dependent and scenario-independent variables (Birge and Louveaux, 2011). Scenario-independent variables are first-stage decisions do not depend on scenario realization while scenario-dependent variables (second-stage decisions) are taken after scenario realization. As explained above, capacity of DCs as well as communication links are subject to disruptions. Therefore, a set of scenarios is developed for considering this situation in which DCs' capacity and connection links are disrupted.In our model, the following decisions are determined under disruption risks:

- The number of supplier which is needed for supplying products.
- The number, location, and capacity level of established DCs.
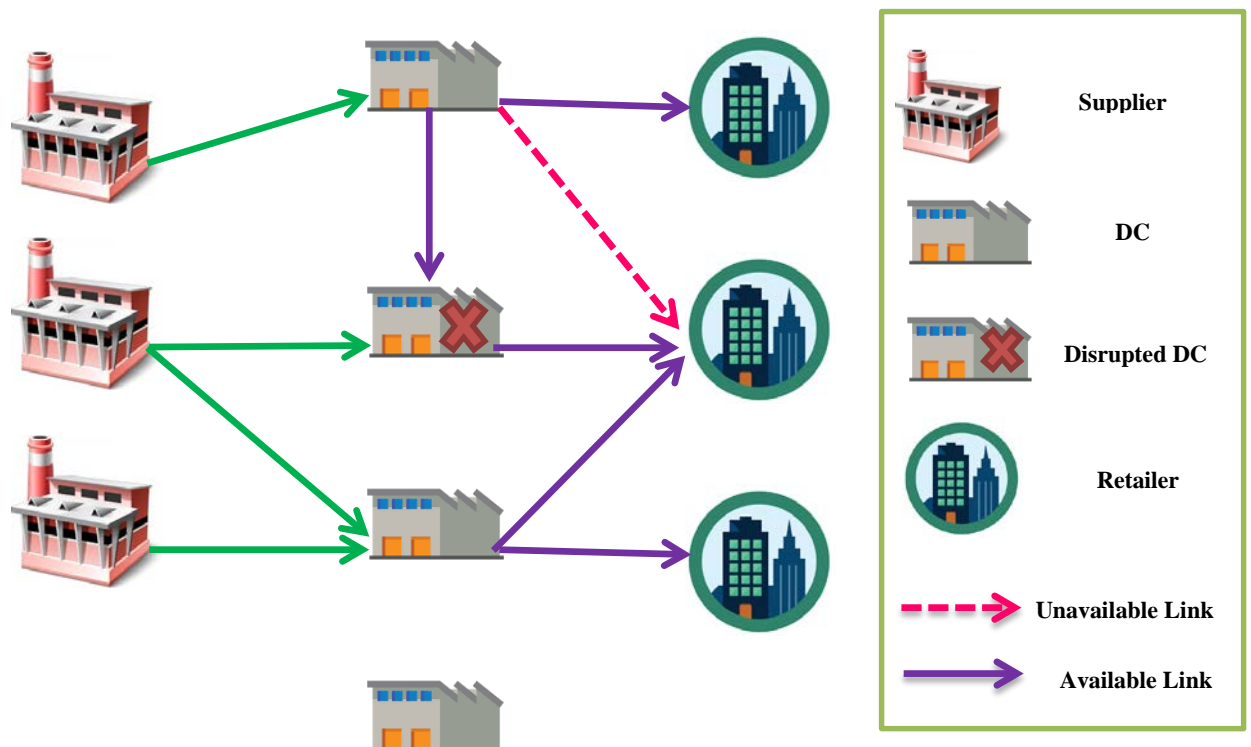- The tentative distribution plan of product under different scenarios.

Fig 1.Resilient supply chain network design

3-Mathematical model

Let us start with a description of the sets, the parameters, decision variables, and the proposed mathematical model.

Sets and indices

I Set of suppliers indexed by $i \in \{1, 2, 3, ..., I\}$

J Set of locations of distribution centers indexed by $j \in \{1, 2, 3, ..., J\}$

K Set of retailers indexed by $k \in \{1, 2, 3, ..., K\}$

P Set of products indexed by $p \in \{1, 2, 3, ..., P\}$

N Set of capacity level indexed by $n \in \{1, 2, 3, ..., N\}$

S Set of probable scenarios indexed by $s \in \{1, 2, 3, ..., S\}$

Parameters

f_j^n Establishment costs of DC j at capacity level of n

c_i Fixed cost of setting a contract by supplier i

sd_{ijp}^s Unit operational and transportation cost of delivering product p from supplier i to DC j under scenario s

sr_{ikp}^s Unit operational and transportation cost of delivering product p from supplier i to retailer k under scenario s

$dd_{jj'p}^s$ Unit transportation cost of delivering product p from DC j to DC j' under scenario s

dr_{jkp}^s Unit transportation cost of delivering product p from DC j to retailer k under scenario s

dc_j^n Handling capacity of DC j at capacity level n

sc_{ip} Supply capacity of supplier i for product p

d_{kp}^s Demand of retailer k for product p under scenario s

λ_j^s Usable ratio of holding capacity of DC j under scenario s

η_{jk}^s Equal to 1 if the rout between DC j and retailer k is accessible under scenario s; otherwise equal to 0.

π_s Probability of occurring scenario s

Decision variables

X_j^n Equal to 1 if DC j is established at capacity level n; otherwise equal to 0.

W_i Equal to 1if a contract is set by supplier ifor supplying products; otherwise equal to 0.

Y_{ijp}^s Quantity of product p delivered from supplier i to DC j under scenario s

Z_{jkp}^s Quantity of product p delivered from DC j to retailer k under scenario s

$L_{jj'p}^s$ Quantity of product p delivered from DC j to DC j' under scenario s

R_{ikp}^s Quantity of product p delivered from supplier i toretailer k under scenario s

3-1- Model formulation

The explained mathematical programming model is as follows:

$$MinF_1 = \sum_i c_i W_i + \sum_j \sum_n f_j^n X_j^n + \sum_s \pi_s (\sum_i \sum_j \sum_p sd_{ijp}^s Y_{ijp}^s + \sum_i \sum_k \sum_p sr_{ikp}^s R_{ikp}^s$$

$$+ \sum_j \sum_{m \neq j} \sum_p dd_{jmp}^s L_{jj'p}^s + \sum_j \sum_k \sum_p dr_{jkp}^s Z_{jkp}^s) \tag{1}$$

$$Max\, F_2 = \sum_s \pi_s \frac{\sum_j \sum_k \sum_p Z_{jkp}^s + \sum_i \sum_k \sum_p R_{ikp}^s}{\sum_k \sum_p d_{kp}^s} \tag{2}$$

$$\sum_j Y_{ijp}^s + \sum_k R_{ikp}^s \leq sc_{ip} W_i \qquad \forall i \in I, \forall p \in P, \forall s \in S \tag{3}$$

$$\sum_i \sum_p Y_{ijp}^s + \sum_{m \neq j} \sum_p L_{mjp}^s \leq \sum_n \lambda_j^s dc_j^n X_j^n \qquad \forall j \in J, \forall s \in S \tag{4}$$

$$\sum_n X_j^n \leq 1 \qquad \forall j \in J \tag{5}$$

$$\sum_m L_{jmp}^s \leq \sum_i Y_{ijp}^s \qquad \forall j \in J, \forall p \in P, \forall s \in S \tag{6}$$

$$\sum_k Z_{jkp}^s \leq \sum_i Y_{ijp}^s + \sum_{m \neq j} L_{mjp}^s - \sum_{m \neq j} L_{jmp}^s \qquad \forall j \in J, \forall p \in P, \forall s \in S \tag{7}$$

$$Z_{jkp}^s \leq \eta_{jk}^s \sum_n dc_j^n X_j^n \qquad \forall j \in J, \forall p \in P, \forall s \in S \tag{8}$$

$$\sum_j Z_{jkp}^s + \sum_i R_{ikp}^s \leq d_{kp}^s \qquad \forall k \in K, \forall p \in P, \forall s \in S \tag{9}$$

$$X_j^n, W_i \in \{0,1\} \qquad \forall i \in I, \forall j \in J, \forall n \in N \tag{10}$$

$$Y_{ijp}^s, Z_{jkp}^s, L_{jj'p}^s, R_{ikp}^s \geq 0 \qquad \forall i \in I, \forall j \in J, \forall k \in K, \forall p \in P, \forall s \in S \tag{11}$$

The first objective function is formulated in equation (1) minimizing total costs, including contract costs, establishment costs, and transportation costs between different nodes of supply chain. The second objective aims to maximize the fraction of demand satisfied by the suppliers and DCs, directly or indirectly.

Constraint (3) enforces that flow of products to DCs and retailers is possible from suppliers which have been contracted by them. Constraint (4) considers the handling capacity of established DC. Constraint (5) enforces that each DC can be established at most one capacity level. Constraint (6) and (7) balance the flow of products between DCs and retailers. Constraint (8) ensures that products can be delivered form DCs to retailers if the connecting rout between them is not be disrupted. Constraint (9) indicates that demand of each retailer is fully satisfied by suppliers and DCs. Finally, constraints (10) and(11) determine the eligible domain of variables.

4-Solution method

Multi-objective programming is a part of mathematical programming in which decision variables are determined with notice to multiple objective functions that should be optimized over a feasible set of decisions. Such problems are commonly used in the areas of human activities including engineering, management and healthcare(Ehrgott and Ruzika, 2008), and etc.

Several number of solution methods have been proposed for multi-objective programming which can be classified to five main categories, including scalar methods, interactive methods, fuzzy methods, metaheuristic methods, and decision aided methods. The common methods are e-constraint method, weighted sum and weighted metric method, goal programming and lexicographic method. Here, we apply augmented e-constraint (Mavrotas, 2009). In most of multi objective programming, e-constraint method is used for transforming the problem to a single objective model, some advantages of using e-constraint method mentioned as follow:

1. In comparison with weighting method, using e-constraint poses to obtain non-extreme solution by changing the feasible regions, decreases running time and obtaining more rich efficient results.
2. In weighting method, scaling of objective function has a great impacts on obtaining results while in e-constraint method it is not necessary.
3. We can control number of efficient solutions by using e-constraint while it is not easy to reach in the other methods(Mavrotas, 2009; Fahimnia et al., 2015).

In this section, we will have a brief review on the augmented e-constraint method for converting two-objective model, presented in section 3.1to a single objective model. In this method, we choose one of the objective functions as the primary objective function and then convert remained objective functions to constraints. Finally, we consider a bound for each of the constraints. Assume a multi-objective model, having K objective as the following one:

$$Min_{x \in \chi} \{F(x) = (F_1(x), F_2(x), ... F_k(x))\} \tag{12}$$

In the above equation, X and $F(x)$ are vector of decision variables and vector of K objective functions, respectively as well as χ is the space of feasible solutions (Mavrotas and Florios, 2013). Using the augmented e-constraint method, the multi-objective problem in (12)is converted to a single-objective model by equations (13)and(14) in which only objective function $F_k(x)$ is minimized as the primary objective function and other objective functions are converted to constraints.

$$Min_{x \in \chi} \{F_k(x) - \delta(s_1 + s_2 + ... + s_p)\} \tag{13}$$

$$F_i(x) = \varepsilon_i - s_i \qquad \forall i \in \{1, 2, ..., K\} / \{k\} \tag{14}$$

In equation(13), $s_1, s_2, ..., s_p$ are the surplus variables of the respective constraints and $\delta \in [10^{-6}, 10^{-3}]$.

In order to use the augmented e-constraint method in our proposed model, we have chosen the first objective function (Cost objective function in Eq.(1)) as the primary objective function and have considered the second objective function (satisfied demands objective function in equation (2))as the constraint. Therefore, our two-objective model is converted to a single objective model as follows:

$$Min(F_1 - \delta S) \tag{15}$$

Subject to:

$$F_2 = S + \varepsilon \tag{16}$$

And Constraints (3) - (11).

5-Computational results

We design a variety set of experiments to (1) evaluate the proposed model and solution approach, (2) investigate the trade of between the objective functions, (3) investigate the impact of considering resilience strategy and (4) propose some managerial insights for the real life case similar to our assumed problem. The presented model is solved by GAMS software-version 24.1 and all the experiments performed by a laptop with 12GB RAM and core i7 CPU 2.6GHz. To assess the model performance, a random test instance is generated according to uniform (U) distribution defined in table 2and table 3, respectively.

To explore the impact of main parameters on the obtained results, parametric analyses are performed on the capacity of suppliers and holding capacity of DCs.

**Table 2.** The distributions from which the parameters used in the test instances are generated

Instance size	Scenario(s)	π_s	f_j^n	c_i	sd_{ijp}^s	sr_{ikp}^s	$dd_{jj'p}^s$
$\|I\|*\|J\|*\|K\|*\|P\|*\|S\|$	1	0.2			U(15,20)	U(40,50)	U(1,2)
	2	0.2			U(35,50)	U(60,80)	U(21,32)
10*6*8*3*5	3	0.3	U(750,800)	U (1000,2000)	U(65,80)	U(80,110)	U(41,62)
	4	0.1			U(85,110)	U(100,140)	U(61,92)
	5	0.2			U(105,140)	U(120,170)	U(81,112)

Table 3. The distributions from which the parameters used in the test instances are generated

Instance size	Scenario(s)	π_s	dc_j^n	sc_{ip}	dr_{jkp}^s	d_{kp}^s	λ_j^s
$\|I\|*\|J\|*\|K\|*\|P\|*\|S\|$	1	0.2			U(14,20)	U(250,300)	U(0.95,1)
	2	0.2			U(34,50)	U(270,330)	U(0.85,0.98)
10*6*8*3*5	3	0.3	U(1100,1200)	U (420,525)	U(64,80)	U(290,360)	U(0.75,0.96)
	4	0.1			U(84,110)	U(310,390)	U(0.65,0.94)
	5	0.2			U(104,140)	U(330,420)	U(0.55,0.92)

5-1-Trade between costs and satisfied demand

In this section, the impact of varying (ε) on the supply chain costs is investigated. Fromthe trade of curve depicted in figure 2, it is observed that supply chain costs increase as the fraction of satisfied demand rises.Such analysis enables decision makers to explore the trade-off between the total cost and the satisfied demand objectives.

Also depicted Pareto front shows the conflict between objective functions as the first objective (cost minimization) is getting worse while the second one (fraction of satisfied demand) is improving.
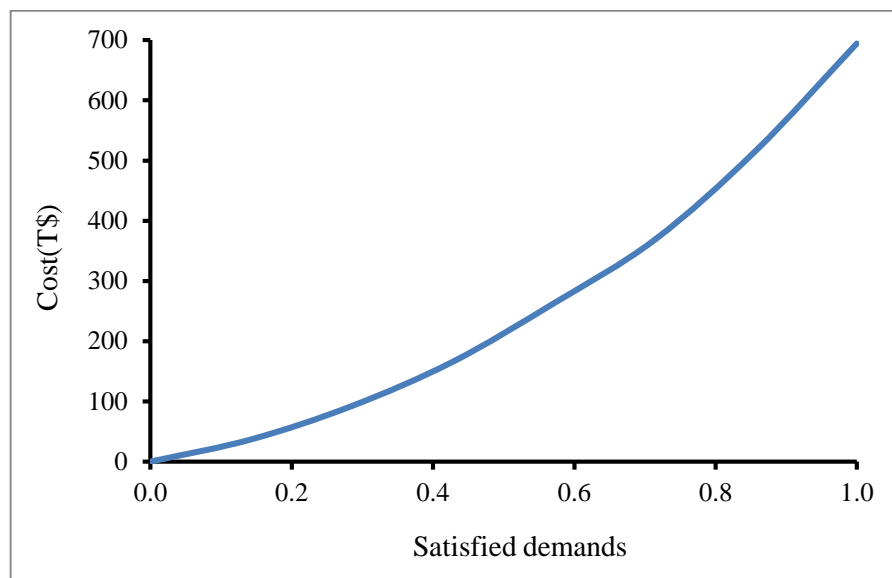
Fig 2. Pareto front surface for the cost and satisfied demand objectives

5-2-Sensitivity analysis on supply capacity and storage capacity of DCs

In this section, a sensitivity analysis is designed to examine whether changing in the facility storage capacity (suppliers and DCs) can improve supply chain costs. First the supplying capacity of suppliers as well as storage capacity of DCs are increased separately and then, raising the capacity of both of them is examined. The results presented in figure 3 indicate that reduction of supply chain costs is driven due to increasing the facilities capacities. As it is obvious in most cases, expansion of DCs capacity has more impact on reducing supply chain costs. One general reason can be the closer distance between DCs and retailers which reduce the total costs due to lower transportation costs between DCs and retailers in comparison with transportation costs between suppliers and retailers.
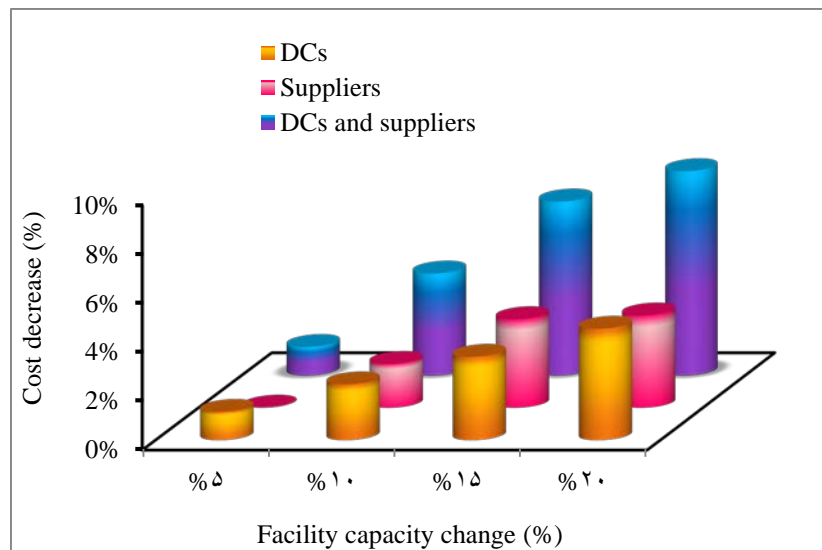

Fig 3. The percentage of increasing supply chain costs due to capacity expansion in facilities

5-3-Impact of considering resilience strategies on supply chain costs

In this section, the impact of considering resilience strategies on the objective functionsis investigated. For the points on the Pareto front surface, some experiments are designed to investigate how each of resilience strategy impacts on the supply chain costs. As Figure 4 illustrates, considering resilience strategies raises costs for all of the assumed strategies while the fraction of unsatisfied demand reduces. Investigation of figure 4 indicates that increasing in supply chain costs using multiple sourcing strategy is less than the condition in which both multiple sourcing and direct shipment strategy are utilized. Also, figure 4 illustrates that using multiple sourcing strategy beside lateral transshipment between DCs have the lowest costs in designed experiments.
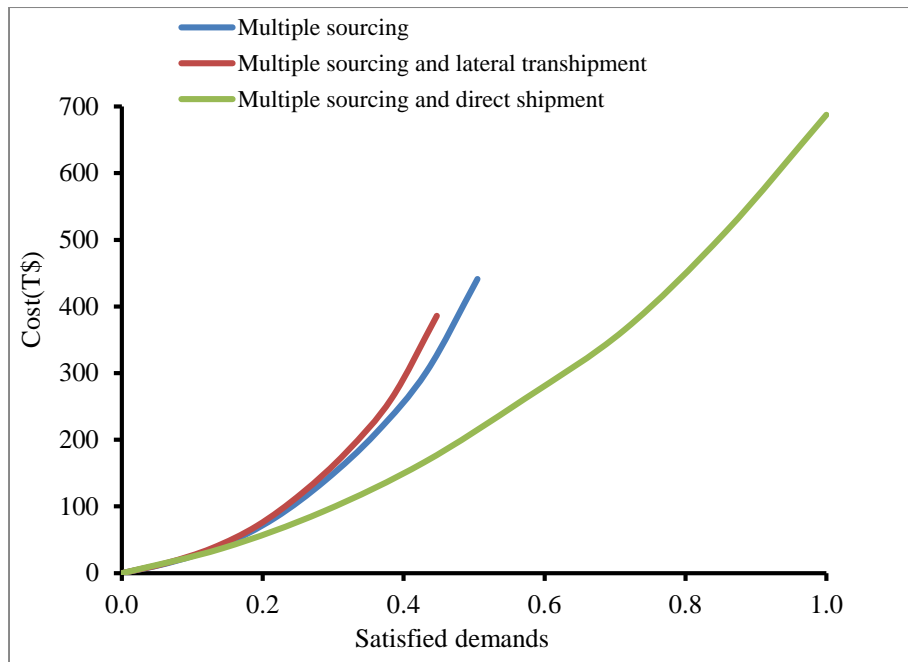
Fig 4. Impact of considering resilience strategies

6-Conclusion

Today, designing an integrated plan to help the decision makers in the field of risk management, is becoming a vital subject. The major trends in business market such as outsourcing, globalization, and customization create tremendous complexities in SC. Moreover, the global SCs are much more sensitive to large-scale natural disasters, terrorist attacks, electrical blackouts, and probable operational failure. Operational and disruption risks are main factors effecting SC responsibility. Also, competitiveness of SC is affected by these risks. Therefore, designing a responsive, profitable, and competitive SCis more critical compared to previous.

In this paper, a bi-objective model was proposed for designing a resilient supply chain including suppliers, distribution centers (DCs), and retailers under disruption risks.The first objective function minimize total costs. The second objective function maximizes satisfied demands. The augmented e-constraint method was used to solve the bi-objective problem.

In the proposed model, we considered the possibility of partial disruptions of DCs as well as complete disruptions of connection links between distribution centers and retailers. In order to decrease the disruption risks, proactive resilient strategies such as using multiple sourcing, direct shipment of products from suppliers to retailers, and lateral transshipment between distribution centers were used.We utilized a two-stage stochastic programming method to deal with disruption risks. The decisions of the first stage of the method consist selection of suppliers and location of DCs.Quantity of products delivered from suppliers to DCs and retailers, quantity of products delivered from DCs to retailers, and lateral transshipment between distribution centers under any scenario are among the decisions of the second stage.

The validity of the proposed model was then evaluated by introducing a numerical example and performing different sensitivity analyses on it. The results highlight the impact of disruptions on the objective functions and show which kinds of disruption have more impacts on the performance of supply chain. Such analysesenable strategic managers of the SC to consider proactive resilient strategies for reducing the negative impact of disruptions.

For future works, following suggestions are presented:
1. Designing resilient supply chain by considering various tactical decisions such as routing and scheduling of vehicles used for the transportation of different products.
2. Proposing efficient algorithms to solve large-scale problems.

3. Developing the proposed model to a multi-period one, and taking the possibility of disruptions of suppliers in to the account.

References

Ahmadi, G., Torabi, S. A. & Tavakkoli-Moghaddam, R. 2016. A bi-objective location-inventory model with capacitated transportation and lateral transshipments. *International Journal of Production Research,* 54**,** 2035-2056.

Alvarez, E. M., Van Der Heijden, M., Vliegen, I. M. & Zijm, W. 2014. Service differentiation through selective lateral transshipments. *European journal of operational research,* 237**,** 824-835.

Aqlan, F. & Lam, S. S. 2016. Supply chain optimization under risk and uncertainty: A case study for high-end server manufacturing. *Computers & Industrial Engineering,* 93**,** 78-87.

Bhamra, R., Dani, S. & Burnard, K. 2011. Resilience: the concept, a literature review and future directions. *International Journal of Production Research,* 49**,** 5375-5393.

Birge, J. R. & Louveaux, F. 2011. *Introduction to stochastic programming*, Springer Science & Business Media.

Bode, C. & Wagner, S. M. 2015. Structural drivers of upstream supply chain complexity and the frequency of supply chain disruptions. *Journal of Operations Management,* 36**,** 215-228.

Cardona-Valdés, Y., Álvarez, A. & Ozdemir, D. 2011. A bi-objective supply chain design problem with uncertainty. *Transportation Research Part C: Emerging Technologies,* 19**,** 821-832.

Cardoso, S. R., Barbosa-Póvoa, A. P., Relvas, S. & Novais, A. Q. 2015. Resilience metrics in the assessment of complex supply-chains performance operating under demand uncertainty. *Omega,* 56**,** 53-73.

Cardoso, S. R., Barbosa-Póvoas, A. P. F., Relvas, S. & Novais, A. Q. 2014. Resilience assessment of supply chains under different types of disruption.

Christopher, M. & Peck, H. 2004. Building the resilient supply chain. *The international journal of logistics management,* 15**,** 1-14.

Dixit, V., Seshadrinath, N. & Tiwari, M. 2016. Performance measures based optimization of supply chain network resilience: A NSGA-II+ Co-Kriging approach. *Computers & Industrial Engineering,* 93**,** 205-214.

Ehrgott, M. & Ruzika, S. 2008. Improved ε-constraint method for multiobjective programming. *Journal of Optimization Theory and Applications,* 138**,** 375-396.

Fahimnia, B. & Jabbarzadeh, A. 2016. Marrying supply chain sustainability and resilience: A match made in heaven. *Transportation Research Part E: Logistics and Transportation Review,* 91**,** 306-324.

Fahimnia, B., Jabbarzadeh, A., Ghavamifar, A. & Bell, M. 2015. Supply chain design for efficient and effective blood supply in disasters. *International Journal of Production Economics*.

Gedik, R., Medal, H., Rainwater, C., Pohl, E. A. & Mason, S. J. 2014. Vulnerability assessment and re-routing of freight trains under disruptions: A coal supply chain network application. *Transportation Research Part E: Logistics and Transportation Review,* 71**,** 45-57.

Giri, B. C. & Bardhan, S. 2015. Coordinating a supply chain under uncertain demand and random yield in presence of supply disruption. *International Journal of Production Research***,** 1-15.

Han, X., Chen, D., Chen, D. & Long, H. 2015. Strategy of Production and Ordering in Closed-loop Supply Chain under Stochastic Yields and Stochastic Demands. *International Journal of U-& E-Service, Science & Technology,* 8.

Hsu, C.-I. & Li, H.-C. 2011. Reliability evaluation and adjustment of supply chain network design with demand fluctuations. *International Journal of Production Economics,* 132**,** 131-145.

Ivanov, S. V. & Morozova, M. 2016. Stochastic problem of competitive location of facilities with quantile criterion. *Automation and Remote Control,* 77**,** 451-461.

Jabbarzadeh, A., Fahimnia, B. & Sheu, J.-B. 2015. An enhanced robustness approach for managing supply and demand uncertainties. *International Journal of Production Economics*.

Khosrojerdi, A., Zegordi, S. H., Allen, J. K. & Mistree, F. 2016. A method for designing power supply chain networks accounting for failure scenarios and preventive maintenance. *Engineering Optimization,* 48**,** 154-172.

Ko, H. J. & Evans, G. W. 2007. A genetic algorithm-based heuristic for the dynamic integrated forward/reverse logistics network for 3PLs. *Computers & Operations Research,* 34**,** 346-366.

Liberatore, F., Scaparra, M. P. & Daskin, M. S. 2012. Hedging against disruptions with ripple effects in location analysis. *Omega,* 40**,** 21-30.

Makui, A. & Ghavamifar, A. 2016. Benders Decomposition Algorithm for Competitive Supply Chain Network Design under Risk of Disruption and Uncertainty. *Journal of Industrial and Systems Engineering,* 9**,** 30-50.

Marufuzzaman, M., Eksioglu, S. D., Li, X. & Wang, J. 2014. Analyzing the impact of intermodal-related risk to the design and management of biofuel supply chain. *Transportation Research Part E: Logistics and Transportation Review,* 69**,** 122-145.

Mavrotas, G. 2009. Effective implementation of the ε-constraint method in multi-objective mathematical programming problems. *Applied mathematics and computation,* 213**,** 455-465.

Mavrotas, G. & Florios, K. 2013. An improved version of the augmented ε-constraint method (AUGMECON2) for finding the exact pareto set in multi-objective integer programming problems. *Applied Mathematics and Computation,* 219**,** 9652-9669.

Nooraie, S. V. & Parast, M. M. 2016. Mitigating supply chain disruptions through the assessment of trade-offs among risks, costs and investments in capabilities. *International Journal of Production Economics,* 171**,** 8-21.

Oke, A. & Gopalakrishnan, M. 2009. Managing disruptions in supply chains: A case study of a retail supply chain. *International Journal of Production Economics,* 118**,** 168-174.

Pan, F. & Nagi, R. 2010. Robust supply chain design under uncertain demand in agile manufacturing. *Computers & Operations Research,* 37**,** 668-683.

Park, S., Lee, T.-E. & Sung, C. S. 2010. A three-level supply chain network design model with risk-pooling and lead times. *Transportation Research Part E: Logistics and Transportation Review,* 46**,** 563-581.

Peng, P., Snyder, L. V., Lim, A. & Liu, Z. 2011. Reliable logistics networks design with facility disruptions. *Transportation Research Part B: Methodological,* 45**,** 1190-1211.

Pettit, T. J., Fiksel, J. & Croxton, K. L. 2010. Ensuring supply chain resilience: development of a conceptual framework. *Journal of business logistics,* 31**,** 1-21.

Rezaee, A., Dehghanian, F., Fahimnia, B. & Beamon, B. 2015. Green supply chain network design with stochastic demand and carbon price. *Annals of Operations Research***,** 1-23.

Rezapour, S., Allen, J. K. & Mistree, F. 2015. Uncertainty propagation in a supply chain or supply network. *Transportation Research Part E: Logistics and Transportation Review,* 73**,** 185-206.

Risks, G. 2012. World Economic Forum.

Romeijn, H. E., Shu, J. & Teo, C.-P. 2007. Designing two-echelon supply networks. *European Journal of Operational Research,* 178**,** 449-462.

Sabouhi, F., Heydari, M. & Bozorgi-Amiri, A. 2016. Multi-objective routing and scheduling for relief distribution with split delivery in post-disaster response. *Journal of Industrial and Systems Engineering,* 9**,** 17-27.

Sadghiani, N. S., Torabi, S. & Sahebjamnia, N. 2015. Retail supply chain network design under operational and disruption risks. *Transportation Research Part E: Logistics and Transportation Review,* 75**,** 95-114.

Santoso, T., Ahmed, S., Goetschalckx, M. & Shapiro, A. 2005. A stochastic programming approach for supply chain network design under uncertainty. *European Journal of Operational Research,* 167**,** 96-115.

Schütz, P. & Tomasgard, A. 2011. The impact of flexibility on operational supply chain planning. *International Journal of Production Economics,* 134**,** 300-311.

Shen, Z.-J. M. & Daskin, M. S. 2005. Trade-offs between customer service and cost in integrated supply chain design. *Manufacturing & service operations management,* 7**,** 188-207.

Shin, H., Collier, D. A. & Wilson, D. D. 2000. Supply management orientation and supplier/buyer performance. *Journal of operations management,* 18**,** 317-333.

Snyder, L. V., Atan, Z., Peng, P., Rong, Y., Schmitt, A. J. & Sinsoysal, B. 2016. OR/MS models for supply chain disruptions: A review. *IIE Transactions,* 48**,** 89-109.

Snyder, L. V., Scaparra, M. P., Daskin, M. S. & Church, R. L. 2006. Planning for disruptions in supply chain networks. *Tutorials in operations research,* 2**,** 234-257.

Torabi, S., Baghersad, M. & Mansouri, S. 2015. Resilient supplier selection and order allocation under operational and disruption risks. *Transportation Research Part E: Logistics and Transportation Review,* 79**,** 22-48.

Torabi, S. & Moghaddam, M. 2012. Multi-site integrated production-distribution planning with transshipment: a fuzzy goal programming approach. *International Journal of Production Research,* 50**,** 1726-1748.

Torabi, S., Namdar, J., Hatefi, S. & Jolai, F. 2016. An enhanced possibilistic programming approach for reliable closed-loop supply chain network design. *International Journal of Production Research,* 54**,** 1358-1387.

Walker, B. & Salt, D. 2012. *Resilience thinking: sustaining ecosystems and people in a changing world*, Island Press.

Wieland, A. & Marcus Wallenburg, C. 2012. Dealing with supply chain risks: Linking risk management practices and strategies to performance. *International Journal of Physical Distribution & Logistics Management,* 42**,** 887-905.

Yin, S., Nishi, T. & Grossmann, I. E. 2015. Optimal quantity discount coordination for supply chain optimization with one manufacturer and multiple suppliers under demand uncertainty. *The International Journal of Advanced Manufacturing Technology,* 76**,** 1173-1184.

You, F. & Grossmann, I. E. 2008. Design of responsive supply chains under demand uncertainty. *Computers & Chemical Engineering,* 32**,** 3090-3111.

Yu, H., Zeng, A. Z. & Zhao, L. 2009. Single or dual sourcing: decision-making in the presence of supply chain disruption risks. *Omega,* 37**,** 788-800.

Zhang, Y., Qi, M., Lin, W.-H. & Miao, L. 2015. A metaheuristic approach to the reliable location routing problem under disruptions. *Transportation Research Part E: Logistics and Transportation Review,* 83**,** 90-110.

Zsidisin*, G. A., Melnyk, S. A. & Ragatz, G. L. 2005. An institutional theory perspective of business continuity planning for purchasing and supply management. *International journal of production research,* 43**,** 3401-3420.