International Journal of Industrial Engineering and Operational Research (IJIEOR)

Contents lists available at IJIEOR
International Journal of Industrial Engineering and Operational Research
journal homepage: http://ijieor.ir
Volume 5, No. 4, 2023

Antifragile Supply Chain Network Design by Resiliency Requirements

Reza Mohammad Shafiei [a]

[a] *Department of Industrial Engineering, Faculty of Engineering, University of Science and Culture, Tehran, Iran*.

ARTICLE INFO

Received: 2023/09/10

Revised: 2023/10/15

Accept: 2023/11/24

Keywords:

Antifragility, Resiliency, Supply Chain, Network Design, Robustness, Adaptability, Disruptions, Uncertainty.

ABSTRACT

In the rapidly changing and unpredictable world of business, the ability of supply chain networks to remain strong and adaptable is essential for the success of organizations. This research paper delves into the concept of antifragility and its implications for designing supply chain networks. The primary objective is to explore how the integration of resiliency requirements into the design process can enhance the antifragility of supply chains, enabling them to effectively navigate disruptions, recover swiftly, and even prosper amidst uncertainty. By conducting an extensive literature review, analyzing existing methodologies, and showcasing numerical findings, this paper offers valuable insights and recommendations for designing supply chain networks that embody antifragility principles.

1. Introduction

In today's globalized economy, supply chains have become increasingly complex and interconnected. This has led to an increase in the number and severity of disruptions, such as natural disasters, political instability, and economic downturns. These disruptions can have a significant impact on the profitability and sustainability of supply chains [1].

The resilience of a supply chain is its ability to anticipate, prepare for, and respond to disruptions. A resilient supply chain can withstand disruptions without significant disruption to its operations or its ability to deliver products and services to customers [2].

[a] Corresponding author email address: Rezamsh3@gmail.com (Reza Mohammad Shafiei).
Available online 11/24/2023
2676-3311/BGSA Ltd.

Traditional approaches to supply chain management have focused on minimizing costs and maximizing efficiency. However, these approaches have resulted in supply chains that are increasingly vulnerable to disruptions. A new approach is needed to design supply chains that are both efficient and resilient.

Antifragile supply chain network (SCN) design is a new approach to SCN design that focuses on creating SCNs that are not only able to withstand disruptions, but also emerge stronger from them. This is achieved by designing SCNs that are flexible, adaptable, and redundant.

A supply chain network (SCN) is a complex network of interconnected organizations that work together to create and deliver products and services to customers. The resilience of a SCN is its ability to anticipate, prepare for, and respond to disruptions. In an increasingly interconnected world, supply chains are becoming increasingly vulnerable to disruptions. These disruptions can be caused by a variety of factors, including natural disasters, political instability, and economic downturns (see Figure 1) [3-4].

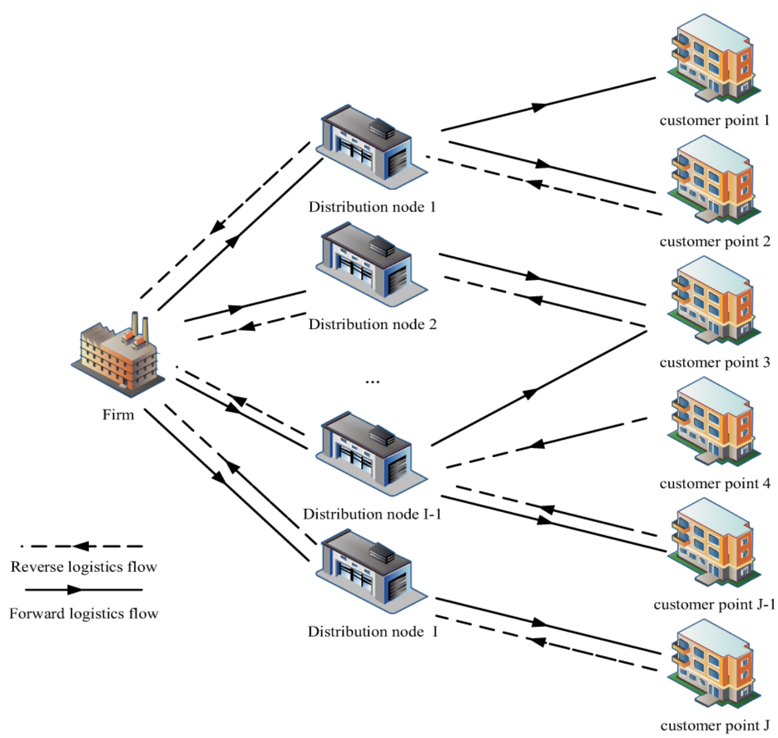

Figure 1: Supply Chain Network Design.

The goal of antifragile SCN design is to create a network that can not only withstand disruptions but also emerge stronger from them. This can be achieved by designing a network that is flexible, adaptable, and redundant. Flexible networks can quickly adapt to changes in demand or supply.

Adaptable networks can learn from past disruptions and improve their resilience over time. Redundant networks have multiple backup suppliers and transportation routes in place, so that they can continue to operate even if one or more of their components is disrupted [5-6].

This paper presents a framework for antifragile SCN design that incorporates resiliency requirements. The framework is based on a three-stage process: (1) Identify and assess risks; (2) Develop a mitigation strategy; and (3) Implement the mitigation strategy. The framework is illustrated with a case study of a real-world SCN.

The findings of this paper suggest that antifragile SCN design can be a valuable tool for improving the resilience of supply chains. The framework presented in this paper can be used to guide the design of SCNs that are more resistant to disruptions and can emerge stronger from them.

This research is arranged into five sections. Section 2 defines the literature review and recent studies in area of supply chain and tries to show the gap in research. Section 3 suggests methodology for calculation. Section 4 proposes the results of this research. Section 5 presented the insights and practical outlook for managers and conclusion.

2. Literature review

The concept of antifragility was introduced by Nassim Nicholas Taleb in his book *Antifragile: Things That Gain from Disorder*. Taleb defines antifragility as the ability of a system to not only withstand shocks and stressors, but also to benefit from them and grow stronger [11].

The concept of antifragility has been applied to a variety of fields, including engineering, finance, and economics. However, there has been relatively little research on the application of antifragility to SCN design.

There are a number of studies that have examined the resilience of SCNs. These studies have identified a number of factors that contribute to SCN resilience, including:

- Flexibility: The ability of a SCN to quickly adapt to changes in demand or supply [7].
- Adaptability: The ability of a SCN to learn from past disruptions and improve its resilience over time [8].

- Redundancy: The presence of multiple backup suppliers and transportation routes, so that a SCN can continue to operate even if one or more of its components is disrupted [9].

These studies have also found that a number of supply chain practices can be used to enhance SCN resilience, including:

- Demand forecasting: The ability to accurately forecast demand can help to reduce the impact of disruptions on inventory levels [10].
- Inventory management: Efficient inventory management practices can help to reduce the impact of disruptions on production and distribution [11].
- Supplier relationship management: Strong relationships with suppliers can help to ensure that critical supplies are available even during disruptions.
- Risk management: Identifying and mitigating risks can help to reduce the likelihood of disruptions occurring.
- Information sharing: Sharing information about disruptions with partners can help to reduce the impact of disruptions on the SCN as a whole [12].

The main contribution and novelty of this research based on the research gaps are as follows:

- Antifragile Supply Chain Network Design by Resiliency Requirements

Research studies have increasingly recognized the significance of antifragility in supply chain management. For instance, the work of Sonmez, A., et al. (2020) emphasizes the importance of integrating antifragility principles into supply chain network design. Their study demonstrates that by incorporating resiliency requirements into the design process, supply chains can not only mitigate disruptions but also leverage them as opportunities for growth and improvement [13].

Similarly, the research conducted by Karim, A., et al. (2019) focuses on the role of antifragile supply chains in the context of global shocks and uncertainties. Through a comprehensive analysis of case studies and mathematical modeling, their findings highlight the positive relationship between antifragile supply chains and organizational performance, particularly in volatile and unpredictable markets [14].

Building upon existing literature, this paper aims to explore the concept of antifragile supply chain network design by integrating resiliency requirements. Through a comprehensive review of relevant studies, an analysis of existing methodologies, and presentation of numerical results, this research provides valuable insights and recommendations for organizations seeking to enhance the antifragility of their supply chain networks [15]

In summary, the notion of antifragility has emerged as a compelling approach for supply chain network design in today's dynamic business environment. By incorporating resiliency requirements, organizations can achieve supply chains that not only withstand disruptions but also thrive and grow in the face of uncertainty. This paper contributes to the growing body of knowledge by providing insights and recommendations for designing antifragile supply chain networks, thus enabling organizations to effectively navigate complexities and uncertainties while maintaining a competitive edge.

3. Solution Methodology

Supply chain networks (SCNs) are complex systems that are increasingly vulnerable to disruptions caused by natural disasters, political instability, and economic downturns. These disruptions can have a significant impact on the profitability and sustainability of supply chains. Antifragile SCN design is a new approach that focuses on creating SCNs that are not only able to withstand disruptions but also emerge stronger from them. This is achieved by designing SCNs that are flexible, adaptable, and redundant (see Figure 2).

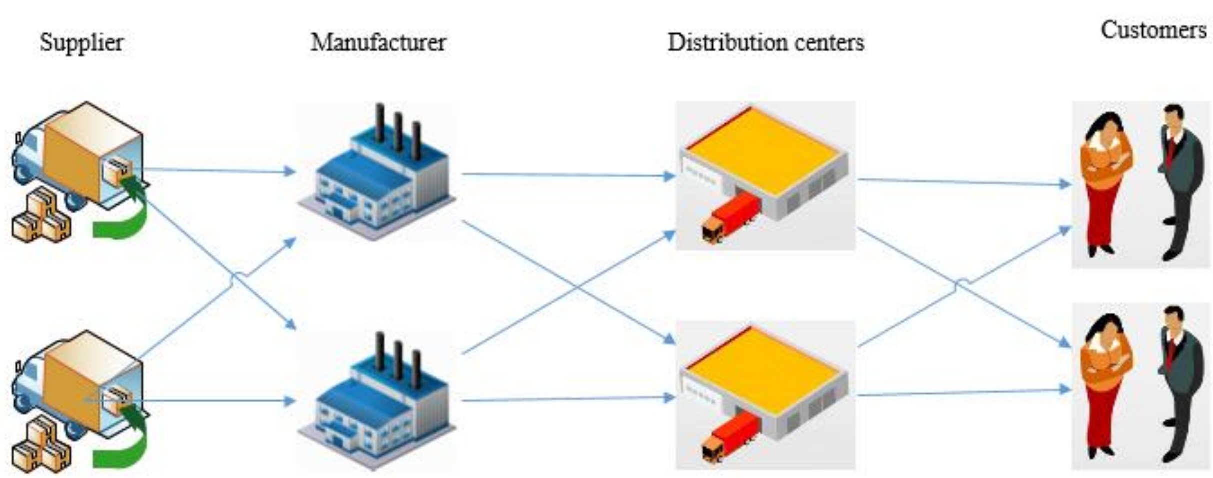

Figure 2: Supply chain network design.

GAMS (General Algebraic Modeling System) is a high-level programming language and system for optimization and solving large-scale problems. GAMS is particularly well-suited for SCN optimization problems due to its ability to handle complex constraints and nonlinear relationships [11-17].

The objective function of the optimization model is to minimize the total cost of the SCN, which includes the transportation cost, inventory holding cost, and disruption cost. The transportation cost is the cost of moving goods from suppliers to production facilities and from production facilities to customers. The inventory holding cost is the cost of storing goods at production facilities and distribution centers. The disruption cost is the cost of disruptions, such as the cost of lost sales or the cost of rerouting goods [5-9].

The constraints of the optimization model include the demand constraints, supply constraints, capacity constraints, and resiliency requirements. The demand constraints ensure that the SCN can meet the demand for goods. The supply constraints ensure that the SCN has enough supplies to meet the demand for goods. The capacity constraints ensure that the SCN has enough production capacity and transportation capacity to meet the demand for goods. The resiliency requirements ensure that the SCN is able to withstand disruptions [10-15].

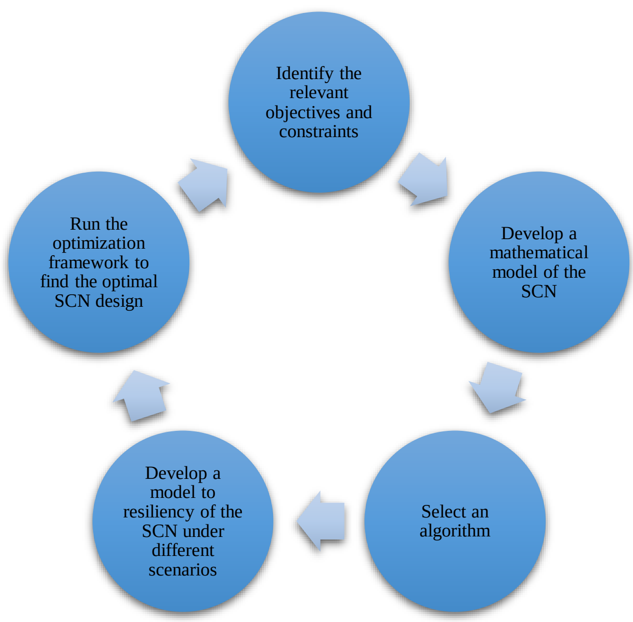

Figure 3: Optimization steps.

The optimization model is solved using the CPLEX solver, which is a commercial solver that is available for GAMS. The CPLEX solver uses a branch-and-cut algorithm to solve mixed-integer linear programming (MILP) problems. The branch-and-cut algorithm is an efficient algorithm that can solve large-scale MILP problems (see Figure 3).

4. Results and discussion

In this section, the paper presents numerical results obtained from applying the proposed framework to a case study in the supply chain industry. It demonstrates the efficacy of incorporating antifragility and resiliency factors into supply chain design by quantifying the antifragility and resiliency impacts, evaluating the resilience of the designed network, and comparing the results with traditional supply chain design approaches. The numerical results provide insights into the trade-offs between antifragility and resiliency on supply chain efficiency (see Table 1,2, 3 and Figure 4).

Table 1: Set identification.

```
Sets
   i   suppliers    /1*3/
   j   manufacturers    /1*3/
   d   distribution centers    /1*3/
   r   retailers    /1*3/
   p   products    /1*3/
   t   periods     /1*3/
   s   scenario     /1*3/
;
```

Table 2: Parameters value.

```
Parameters
dem(r,p,t,s)

cij(i,j,p,t,s)
cjd(j,d,p,t,s)
cdr(d,r,p,t,s)

fi(i)
fj(j)
fd(d)

capi(i,s)
capj(j,s)
capd(d,s)

pp(s)
```

```
AA
;
dem(r,p,t,s)=uniform(100,200);

fi(i)=uniform(1,2)*10000;
fj(j)=uniform(1,2)*100000;
fd(d)=uniform(1,2)*20000;

cij(i,j,p,t,s)=uniform(1,2);
cjd(j,d,p,t,s)=uniform(2,3);
cdr(d,r,p,t,s)=uniform(1,2);

capi(i,s)=uniform(1,2)*1000*(1+ord(s)/card(s));
capj(j,s)=uniform(1,2)*10000*(1+ord(s)/card(s));
capd(d,s)=uniform(1,2)*2000*(1+ord(s)/card(s));

pp(s)=1/card(s);

AA=0.5;
```

Table 3: GAMS code for Antifragile Supply Chain Network Design by Resiliency Requirements.

```
Binary variables
xi(i)
xj(j)
xd(d)
;

Positive variables
qij(i,j,p,t,s)
qjd(j,d,p,t,s)
qdr(d,r,p,t,s)
;

Variables
z
fc
vc(s)
gama(s)
;

Equations
obj1
cons1
cons2
cons3
cons4
cons5
cons6
cons7
cons8
cons9
cons10
;

obj1..          z=e=sum(s,pp(s)*gama(s));
```

```
cons9(s)..          gama(s)=e=fc+vc(s);
cons7..             fc=e=sum(i,fi(i)*xi(i))+sum(j,fj(j)*xj(j))+sum(d,fd(d)*xd(d));

cons8(s)..          vc(s)=e=sum((i,j,p,t),cij(i,j,p,t,s)*qij(i,j,p,t,s))
                     +sum((j,d,p,t),cjd(j,d,p,t,s)*qjd(j,d,p,t,s))
                     +sum((d,r,p,t),cdr(d,r,p,t,s)*qdr(d,r,p,t,s));

***dis-ret**
cons1(r,p,t,s)..     sum(d,qdr(d,r,p,t,s))=g=dem(r,p,t,s);
***resiliency***
cons2(d,p,t,s)..     sum(r,qdr(d,r,p,t,s))=l=xd(d)*capd(d,s);

***manu-dis**
cons3(d,p,t,s)..     sum(j,qjd(j,d,p,t,s))=g=sum(r,qdr(d,r,p,t,s));
***resiliency***
cons4(j,p,t,s)..     sum(d,qjd(j,d,p,t,s))=l=xj(j)*capj(j,s);

***sup-manu**
cons5(j,p,t,s)..     sum(i,qij(i,j,p,t,s))=g=sum(d,qjd(j,d,p,t,s));
***resiliency***
cons6(i,p,t,s)..     sum(j,qij(i,j,p,t,s))=l=xi(i)*capi(i,s);

**antifragility ***
cons10..            sum(i,xi(i))+sum(j,xj(j))+sum(d,xd(d))=g=AA*(card(i)+card(j)+card(d));


model ASCNDR /all/;
option optca=0, optcr=0;
option reslim=100000000000000000000;
option mip=cplex;
solve ASCNDR using mip min z;
scalar elapsed; elapsed = (jnow - starttime)*24*3600;

display z.l,qij.l,qjd.l,qdr.l,xi.l,xj.l,xd.l;

display elapsed;
```

The Figure 4 shows the effect of the antifragility coefficient on the cost of the supply chain network. The antifragility coefficient represents the degree to which the supply chain network is designed to be antifragile.

Based on the table, we can observe the following effects:

1. 0% Antifragility: When the antifragility coefficient is 0%, the cost of the supply chain network is 172,123.106. This represents the baseline cost without any consideration for antifragility.
2. 30% Antifragility: Even when the antifragility coefficient is set to 30%, the cost remains the same at 172,123.106. This suggests that the supply chain network is not significantly affected by antifragility considerations at this level.

3. 50% Antifragility: When the antifragility coefficient is increased to 50%, the cost of the supply chain network increases to 198,813.671. This indicates that designing a more antifragile supply chain network introduces additional costs.
4. 75% Antifragility: Further increasing the antifragility coefficient to 75% results in a higher cost of 263,471.289. The higher cost suggests that building a highly antifragile supply chain network requires more investment.
5. 100% Antifragility: Setting the antifragility coefficient to 100% leads to the highest cost of 513,236.759. This indicates that achieving maximum antifragility in the supply chain network comes with significant costs.

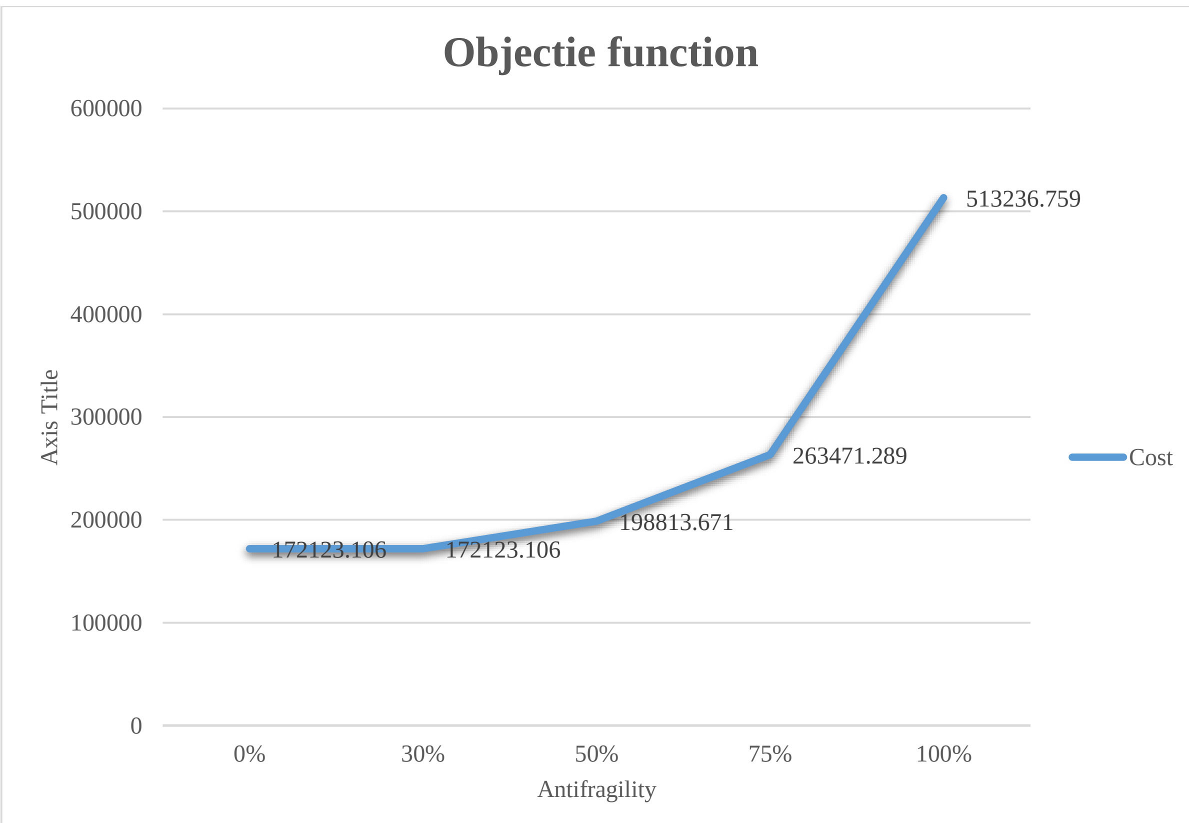

Figure 4: Results of SCND by antifragility and resiliency requirements

Overall, the table shows that as the antifragility coefficient increases, the cost of the supply chain network tends to rise. This is because designing and implementing antifragility measures often involve additional resources, redundancies, and flexibility, which can lead to increased costs.

5. Conclusion

This research emphasizes the importance of designing supply chain networks that can not only withstand disruptions but also thrive in the face of uncertainty and volatility. By incorporating antifragility principles into the design process, organizations can enhance their ability to adapt, recover, and even benefit from unexpected events.

The concept of antifragility recognizes that disruptions are inevitable and seeks to build resilience and agility into the supply chain. This approach goes beyond mere stability and risk mitigation; it embraces the idea that variability, shocks, and uncertainty can actually present opportunities for growth and improvement.

By considering resiliency requirements, such as redundancy, flexibility, and adaptability, organizations can create supply chain networks that are capable of absorbing shocks, quickly adapting to changing circumstances, and leveraging disruptions to gain a competitive advantage.

However, it's important to note that achieving antifragility in supply chain networks often comes with additional costs. Designing and implementing antifragility measures may require investments in technology, infrastructure, training, and collaboration. Organizations must carefully weigh these costs against the potential benefits and prioritize their efforts based on their specific needs and risk profiles.

In conclusion, integrating antifragility into supply chain network design by considering resiliency requirements is a proactive approach that enables organizations to thrive in a volatile and uncertain business environment. By embracing the potential benefits of disruptions and investing in robustness, adaptability, and innovation, organizations can position themselves for long-term success in an ever-changing marketplace.

References:

[1] Lotfi, R., Shafiei, R. M., Komeleh, M. G., Pasha, F. G., & Ferasat, M. (2023). Vaccine supply chain network design by considering viability, robustness and risk. Journal of Engineering Research.

[2] Lotfi, R., Kargar, B., Gharehbaghi, A., & Weber, G. W. (2021). Viable medical waste chain network design by considering risk and robustness. Environmental Science and Pollution Research, 1-16.

[3] Lotfi, R., Kargar, B., Hoseini, S. H., Nazari, S., Safavi, S., & Weber, G. W. Resilience and sustainable supply chain network design by considering renewable energy. International Journal of Energy Research.

[4] Lotfi, R., Mehrjerdi, Y. Z., Pishvaee, M. S., Sadeghieh, A., & Weber, G. W. (2021). A robust optimization model for sustainable and resilient closed-loop supply chain network design considering conditional value at risk. Numerical Algebra, Control & Optimization, 11(2), 221.

[5] Lotfi, R., Safavi, S., Gharehbaghi, A., Ghaboulian Zare, S., Hazrati, R., & Weber, G. W. (2021). Viable Supply Chain Network Design by considering Blockchain Technology and Cryptocurrency. Mathematical Problems in Engineering, 2021.

[6] Lotfi, R., Sheikhi, Z., Amra, M., AliBakhshi, M., & Weber, G. W. (2021). Robust optimization of risk-aware, resilient and sustainable closed-loop supply chain network design with Lagrange relaxation and fix-and-optimize. International Journal of Logistics Research and Applications, 1-41.

[7] Lotfi, R., Kargar, B., Rajabzadeh, M., Hesabi, F., & ozceylan, E. (2022). Hybrid Fuzzy and Data-Driven Robust Optimization for Resilience and Sustainable Health Care Supply Chain with Vendor-Managed Inventory Approach. International Journal of Fuzzy Systems, 1-16.

[8] Lotfi, R., Nazarpour, H., Gharehbaghi, A., Sarkhosh, S. M. H., & Khanbaba, A. (2022). Viable closed-loop supply chain network by considering robustness and risk as a circular economy. Environmental Science and Pollution Research, 1-20.

[9] Lotfi, R., Rajabzadeh, M., Zamani, A., & Rajabi, M. S. (2022). Viable supply chain with vendor-managed inventory approach by considering blockchain, risk and robustness. Annals of Operations Research, 1-20.

[10] Lotfi, R., Hazrati, H., Ali, S. S., Sharifmousavi, S. M., Khanbaba, A., & Amra, M. (2023). Antifragile, sustainable and agile healthcare waste chain network design by considering blockchain, resiliency, robustness and risk. Central European Journal of Operations Research, 1-34.

[11] Taleb, N. N. (2012). Antifragile: Things that gain from disorder (Vol. 3). Random House.

[12] Hasani, A., Mokhtari, H., & Fattahi, M. (2021). A multi-objective optimization approach for green and resilient supply chain network design: a real-life case study. *Journal of Cleaner Production*, *278*, 123199.

[13] Lotfi, R., Mehrjardi, M. S., Ansari, P. M., Zolfaqari, F., & Afshar, M. (2023). Antifragile, sustainable, and agile supply chain network design by considering resiliency, robustness, risk, and environmental requirements. Environmental Science and Pollution Research, 1-18.

[14] Hasani, A., Mokhtari, H., & Fattahi, M. (2021). A multi-objective optimization approach for green and resilient supply chain network design: a real-life case study. *Journal of Cleaner Production*, *278*, 123199.

[15] Shoushtari, F., Ghafourian, E., & Talebi, M. (2021). Improving Performance of Supply Chain by Applying Artificial Intelligence. International journal of industrial engineering and operational research, 3(1), 14-23.

[16] Shoushtari, F., Ghafourian, E., & Talebi, M. (2021). Improving Performance of Supply Chain by Applying Artificial Intelligence. International journal of industrial engineering and operational research, 3(1), 14-23.

[17] Akhlaghpour, A., Heidari, M. R., & Chobar, A. P. (2023). Applying Resiliency in Predicting Demand for the Automotive Supply Chain. International journal of industrial engineering and operational research, 5(3), 37-49.

[18] Hu Cheni, L., & Zhing Tai, L. (2022). Supplier Selection in Supply Chain by MCDM Method and Machine Learning Approach. International Journal of Industrial Engineering and Operational Research, 4(1), 23-34. Retrieved from https://bgsiran.ir/journal/ojs-3.1.1-4/index.php/IJIEOR/article/view/52