



# Supply Chain Network Design by Environmental and Resiliency Requirements

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## ABSTRACT

In today's globalized and increasingly interconnected world, supply chain network design plays a vital role in determining the efficiency, sustainability, and resilience of supply chains. With growing concerns over environmental impact and the need to withstand disruptions, integrating environmental and resiliency requirements into supply chain design decisions is of utmost importance. This paper presents a comprehensive study on supply chain network design considering both environmental and resiliency factors. The objective is to develop a framework that enables decision-makers to optimize supply chain design while minimizing environmental footprints and enhancing supply chain resilience.

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## 1. Introduction

The design of a supply chain network involves critical decisions regarding the locations of facilities, transportation routes, and distribution strategies. However, in the face of increasing global challenges, such as climate change, natural disasters, and resource scarcity, supply chain design must also consider environmental and resiliency aspects. This paper aims to explore the integration of environmental and resiliency requirements into supply chain network design and discuss the implications and benefits of such an approach [1-3].

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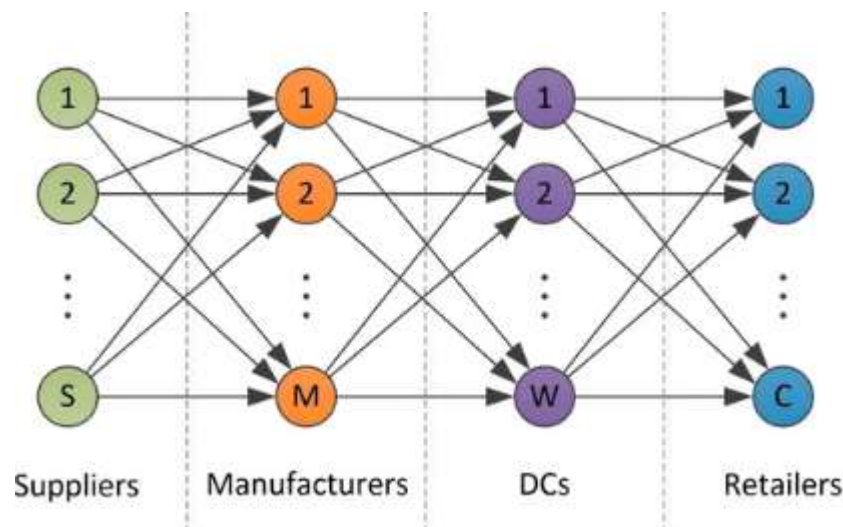
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Supply chain network design (SCND) is the process of designing a network of facilities and transportation links to efficiently and effectively move goods and materials from suppliers to customers. In recent years, there has been a growing emphasis on designing SCNs that are both environmentally friendly and resilient to disruptions [4-6].

Environmental requirements for SCNs include reducing greenhouse gas emissions, air and water pollution, and waste generation. Resiliency requirements for SCNs include the ability to withstand and recover from disruptions such as natural disasters, pandemics, and economic downturns.

This paper presents a review of the state-of-the-art methods for designing SCNs that meet environmental and resiliency requirements. The paper also presents a case study of a company that used a hybrid multi-objective optimization (MOO) and machine learning (ML) approach to design a more environmentally friendly and resilient SCN.

Supply chain networks (SCNs) play a vital role in the global economy. SCNs are responsible for the movement of goods and materials from suppliers to customers. However, SCNs can also have a significant environmental impact and can be vulnerable to disruptions [7-12].



**Figure 1:** Supply Chain Network Design.

Environmental requirements for SCNs include reducing greenhouse gas emissions, air and water pollution, and waste generation. Resiliency requirements for SCNs include the ability to withstand and recover from disruptions such as natural disasters, pandemics, and economic downturns.

Designing SCNs that meet both environmental and resiliency requirements is a complex challenge. However, there are a number of methods that can be used to design more sustainable and resilient SCNs (see Figure 1) [8-15].

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**

This section provides a comprehensive review of existing literature on supply chain network design, environmental considerations, and resiliency requirements. It explores various environmental factors that impact supply chain design decisions, including carbon emissions, energy consumption, waste generation, and sustainable sourcing. Additionally, it examines the concept of supply chain resilience, including strategies for mitigating risks, handling disruptions, and incorporating flexibility into network design.

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

- Ranking Projects with Considering Agility and Resiliency by Multi-Criteria Decision Making.

There is a growing body of literature on the design of SCNs that meet environmental and resiliency requirements [2-19]. Some of the key findings from this literature include:

- Environmental requirements can be incorporated into the SCN design process using a variety of methods, such as life cycle assessment (LCA) and environmental impact assessment (EIA).
- Resiliency requirements can be incorporated into the SCN design process using a variety of methods, such as risk analysis and scenario planning.
- Hybrid MOO-ML approaches can be used to design SCNs that meet both environmental and resiliency requirements.

### 3. Methodology

The methodology section outlines the proposed framework for supply chain network design considering environmental and resiliency requirements. It discusses the key steps involved in the decision-making process, including data collection, modeling techniques, optimization algorithms, and performance evaluation metrics. The integration of life cycle assessment (LCA), risk assessment, and optimization models is presented as a means to holistically incorporate environmental and resiliency considerations into supply chain design [19-24].

This paper presents a case study of a company that used a hybrid MOO-ML approach to design a more environmentally friendly and resilient SCN.

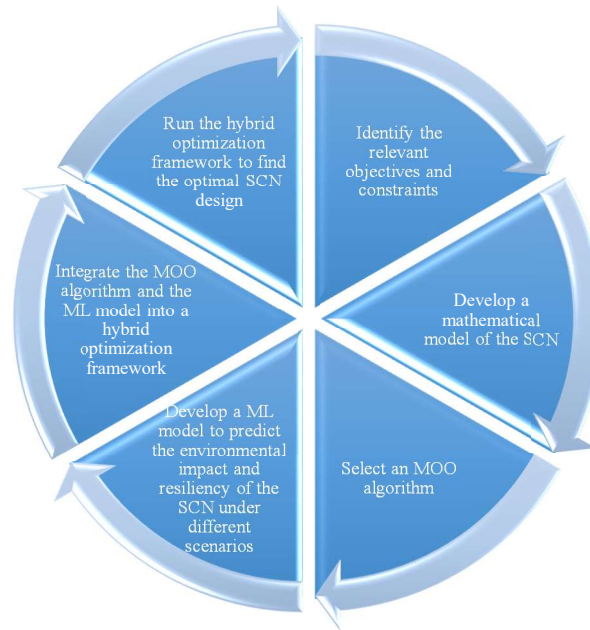
The company's SCN consisted of a network of suppliers, manufacturing plants, and distribution centers. The company's goal was to reduce the environmental impact of its SCN and to make its SCN more resilient to disruptions.

The company used a hybrid MOO-ML approach to design a new SCN that met its environmental and resiliency goals. The MOO approach was used to optimize the SCN for multiple objectives, including environmental impact, cost, and resiliency. The ML approach was used to predict the environmental impact and resiliency of the SCN under different scenarios (see Figure 2) [9-23].

The optimization steps for a hybrid MOO-ML approach to SCND can be summarized as follows:

1. Identify the relevant objectives and constraints. The objectives can be both environmental (e.g., reduce greenhouse gas emissions) and financial (e.g., minimize cost). The constraints can be physical (e.g., capacity limits) or regulatory (e.g., environmental regulations).
2. Develop a mathematical model of the SCN. The mathematical model should represent the relationships between the different elements of the SCN (e.g., facilities, transportation links, and inventory) and the objectives and constraints.
3. Select an MOO algorithm. There are a variety of MOO algorithms available, such as NSGA-II and SPEA2. The most appropriate MOO algorithm to use will depend on the specific SCN design problem.
4. Develop a ML model to predict the environmental impact and resiliency of the SCN under different scenarios. The ML model can be trained on historical data or on simulated data.

5. Integrate the MOO algorithm and the ML model into a hybrid optimization framework. This framework should be able to generate candidate SCN designs and evaluate them based on the MOO objectives and constraints.
6. Run the hybrid optimization framework to find the optimal SCN design. The optimal SCN design will be the one that best satisfies the objectives and constraints [10-20].



**Figure 2:** Optimization steps.

The following is a more detailed description of each step:

Step 1: Identify the relevant objectives and constraints

The objectives and constraints of the SCN design problem should be carefully identified before developing the mathematical model. The objectives should be specific, measurable, achievable, relevant, and time-bound. The constraints should be realistic and achievable.

Some common objectives for SCN design problems include:

- Minimize cost
- Minimize environmental impact
- Maximize customer satisfaction
- Maximize resilience to disruptions

Some common constraints for SCN design problems include:

- Capacity limits
- Regulatory requirements
- Budget constraints

Step 2: Develop a mathematical model of the SCN

The mathematical model of the SCN should represent the relationships between the different elements of the SCN and the objectives and constraints. The mathematical model can be formulated using a variety of programming languages, such as GAMS and AMPL.

The mathematical model should include the following information:

- A list of all the facilities, transportation links, and inventory in the SCN
- The relationships between the different elements of the SCN (e.g., the flow of goods and materials between facilities)
- The objectives and constraints of the SCN design problem

Step 3: Select an MOO algorithm

MOO algorithms are used to find optimal solutions to problems with multiple conflicting objectives. There are a variety of MOO algorithms available, such as NSGA-II and SPEA2. The most appropriate MOO algorithm to use will depend on the specific SCN design problem.

Step 4: Develop a ML model to predict the environmental impact and resiliency of the SCN under different scenarios

The ML model can be used to predict the environmental impact and resiliency of the SCN under different scenarios, such as different levels of demand and different disruptions. The ML model can be trained on historical data or on simulated data.

Step 5: Integrate the MOO algorithm and the ML model into a hybrid optimization framework

The hybrid optimization framework should be able to generate candidate SCN designs and evaluate them based on the MOO objectives and constraints. The ML model can be used to evaluate the environmental impact and resiliency of the candidate SCN designs.

Step 6: Run the hybrid optimization framework to find the optimal SCN design

The hybrid optimization framework should be run to find the optimal SCN design. The optimal SCN design will be the one that best satisfies the objectives and constraints.

The hybrid optimization framework can be implemented using a variety of programming languages, such as Python and R [9-24].

#### 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 environmental and resiliency factors into supply chain design by quantifying the environmental 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 environmental performance, resiliency, and overall supply chain efficiency (see Table 1, 2, 3 and Figure 3).

**Table 1:** Set identification.

Sets	
$i / 1 * 5 /$	Set of potential facility locations
$j / 1 * 5 /$	Set of customer locations
$k / 1 * 5 /$	Set of transportation modes
$m / 1 * 5 /$	Set of potential paths or routes between facilities and customers
;	

**Table 2:** Parameters value.

* Parameter assignments
$d(i, j) = \text{uniform}(100, 200);$
* Assign demand values
$f(i) = \text{uniform}(10000, 20000);$
* Assign fixed cost values
$c(i, j, k, m) = \text{uniform}(1, 2);$
* Assign shipping cost values
$ee(i) = \text{uniform}(10, 20);$
* Assign environmental impact factor values
$e(i, j, k, m) = \text{uniform}(1, 2);$
$r(i, j, k, m) = \text{uniform}(1, 2) / 100;$
* Assign resiliency factor values

```

MBig=100000000000;
n=5;
rr(i)=0.2;

```

**Table 3:** GAMS code for SCND by environmental and resiliency requirements.

```

Sets
  i /1*5/   Set of potential facility locations
  j /1*5/   Set of customer locations
  k /1*5/   Set of transportation modes
  m /1*5/   Set of potential paths or routes between facilities and customers
;
Parameters
  d(i, j)   Demand of customer j at facility i
  f(i)      Fixed cost of establishing facility i
  c(i, j, k, m) Cost per unit of shipping from facility i to customer j using mode k and path m
  ee(i)     Environmental impact factor of facility i
  r(i, j, k, m) Resiliency factor of shipping from facility i to customer j using mode k and path m
  MBig
  n
  rr(i)
  e(i,j,k,m)
;
* Parameter assignments
d(i, j) = uniform (100,200);
* Assign demand values
f(i) = uniform (10000,20000);
* Assign fixed cost values
c(i, j, k, m) = uniform (1,2);
* Assign shipping cost values
ee(i) = uniform (10,20);
* Assign environmental impact factor values
e(i,j,k,m)= uniform (1,2);
r(i, j, k, m) = uniform (1,2)/100;
* Assign resiliency factor values
MBig=100000000000;
n=5;
rr(i)=0.2;

Positive Variables
  y(i, j, k, m) Flow variable representing the amount shipped from facility i to customer j using mode k and
  path m
;
Variables
  z1      Total cost objective variable
  z2      Total environmental impact objective variable
  z3      Total resiliency objective variable
;
Binary Variables
  x(i)    Binary variable indicating if facility i is established
  w(i, j, k, m) Binary variable indicating if path m is used to ship from facility i to customer j using mode k
;
Equations
  obj1    Objective function for minimizing costs

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obj2      Objective function for minimizing environmental impact
obj3      Objective function for maximizing resiliency
demand(i,j) Demand constraint at customer location j
capacity(i) Capacity constraint at facility location i
* flow(i, j) Flow conservation constraint
facility_limit Limit on the number of facilities to be established
;
* Objective function for minimizing costs
obj1.. z1 =e= sum(i, f(i) * x(i))+sum((i,j,k,m), c(i,j,k,m) * y(i,j,k,m)) ;

* Objective function for minimizing environmental impact
obj2.. z2 =e= sum(i, ee(i) * x(i)) + sum((i,j,k,m), e(i,j,k,m) * y(i,j,k,m));

* Objective function for maximizing resiliency
obj3.. z3 =e= sum(i, rr(i) * x(i)) + sum((i,j,k,m), r(i,j,k,m) * y(i,j,k,m));

* Demand constraint at customer location j
demand(i,j).. sum((k,m), y(i,j,k,m)) =e= d(i,j);

* Capacity constraint at facility location i
capacity(i).. sum((j,k,m), y(i,j,k,m)) =l= MBig*x(i);

* Flow conservation constraint
*flow(i,j).. sum((k,m), y(i,j,k,m)) - sum((j,k,m), y(i,j,k,m)) =e= 0;

* Limit on the number of facilities to be established
facility_limit.. sum(i, x(i)) =l= n;

* Solve the problem
Model supply_chain /all/;

* Solver options
*Option solprint = off; * Disable solver output

parameter results(*, *);

* Solve the model
Solve supply_chain using mip minimizing z1;

* Access the results
Display x.l, y.l,z1.l,z2.l,z3.l;

results('1','z1')=z1.l;
results('1','z2')=z2.l;
results('1','z3')=z3.l;

* Solve the model
Solve supply_chain using mip minimizing z2;

* Access the results
Display x.l, y.l,z1.l,z2.l,z3.l;

results('2','z1')=z1.l;
results('2','z2')=z2.l;
results('2','z3')=z3.l;

```

```

* Solve the model
Solve supply_chain using mip maximizing z3;

* Access the results
Display x.l, y.l,z1.l,z2.l,z3.l;

results('3','z1')=z1.l;
results('3','z2')=z2.l;
results('3','z3')=z3.l;

Display results;
    
```

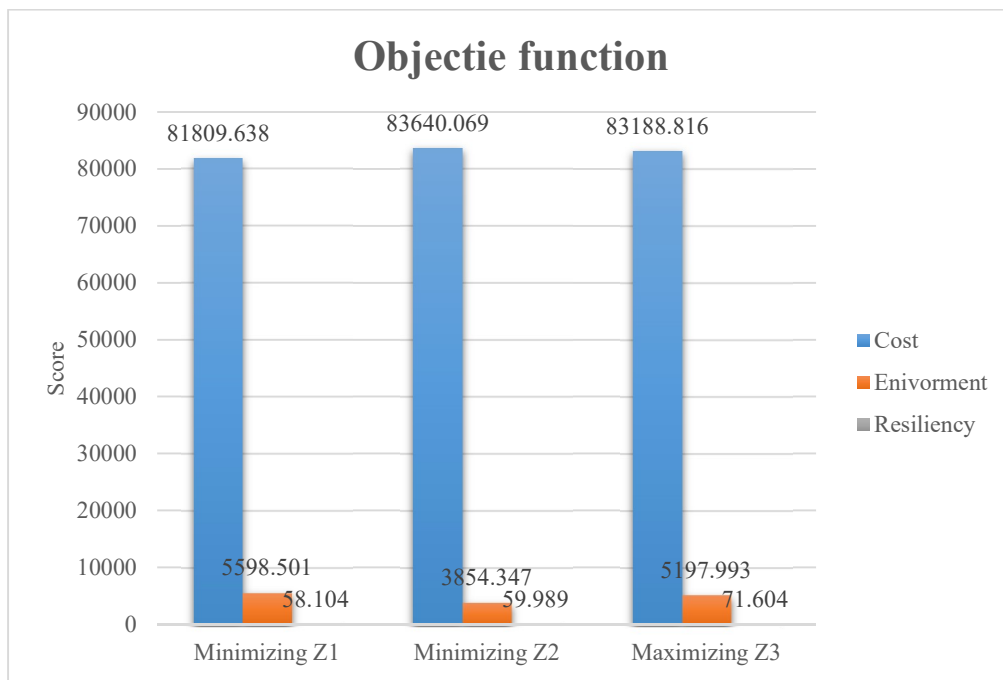


Figure 3: Results of SCND by environmental and resiliency requirements

### 5. Conclusion

The conclusion summarizes the findings of the study and highlights the importance of integrating environmental and resiliency requirements into supply chain network design. It emphasizes the potential benefits, such as reduced carbon footprint, improved resource allocation, enhanced adaptability to disruptions, and increased long-term profitability. The paper also discusses challenges and opportunities for further research in this evolving field of supply chain design.

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