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RESEARCH PAPER

Risk Management of Disruption and Sustainable Development of Supply Chains

Seyyed Reza Hashemi[1], Abdollah Arasteh[2*], Mohammad Mahdi Paydar[3]

1. MA Student of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran
2. Assistant Professor, Department of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran
3. Associate Professor, Department of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran

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Abstract

This study proposes a multi-stage supply chain model with direct and reverse flows of goods to assess the effects of risk on the profit of a supply chain network and the realization of demand. The studied network aims to maximize profit, minimize unmet demand, reduce delivery time, alleviate disruption risks in facilities and transportation, and decrease supply chain visibility. We created a system for quantifying the disruption risk ratings of supply chain components. To help the company better understand its suppliers, address essential network components, and prioritize risk management initiatives, the evaluation may be useful. For our supply chain optimization models, we rely on the predicted disruption risk ratings as a basis. Goal programming is used to solve the multi-criteria model. The resiliency of the supply chain network is shown numerically. In order to build the model, the designer had to make strategic judgments. Risk mitigation methods such as extra inventory and backup suppliers are adopted to increase the supply chain network's resiliency. Short-term disruptions may be mitigated by stockpiling additional raw materials to avoid component shortages. A cost-benefit analysis shows that every risk reduction strategy is worthwhile.

Keywords: multi-objective optimization, goal programming, lexicography, weighting method.

1. Introduction

In recent years, there have been major global improvements in the awareness of how risk can be detrimental to a business (Benjamin et al., 2015). The supply chain risk involves several stages, such as processes, control, requirements, support, and the environment. A supply chain faces different risks and requires special techniques, trends, and strategies for risk management (Bas, 2018).

Modern management challenges are effectively dealt with through a complex network of suppliers that can have a huge impact on business acquisition. Hence, new opportunities have arisen, a situation that has threatened management, too. Perceiving the supply chain risks facing companies can enable managers to better detect and cope with unexpected events (Zhao et al., 2011).

The potential risk can be traced back to the dawn of recorded human history. Not only are there many high-risk situations nowadays, but the development of modern technology has also provided an accurate awareness of their potential dangers (Enyinda et al., 2008).

* **Corresponding Author, Email:** arasteh@nit.ac.ir

Different facets of supply chain management can be specified. Simchi-Levy et al. (2008) have described it as a collection of techniques for the effective integration of suppliers, manufacturers, warehouses, and retailers. This definition states that, in addition to delivering the needed levels of service at the lowest system costs, suitable quality commodities are created and supplied to the right location at the right time.

Therefore, the following challenges should be taken into account in supply chain modeling: integrating all corporations that affect the success of the chain (e.g., vendors, producers, dealers, and retailers); introducing the various market roles as well as the financial, logistical, and operational options; meeting the demand and viability of customers through the system; and defining danger and risk in the supply chain. Hence, supply chain models include both the incorporation and the development of business functions. Moreover, the local optimization models are not inherently built into the objectives of the whole system (Boy et al., 2008).

Risk management is a strategy formulated to regulate operations to deal with the uncertainty that can cause deviation. These processes have provided interns and researchers with conceptual frameworks to better perceive how to handle supply chain disorders (A. R. Ravindran & D. P. Warsing Jr, 2016).

Customer demand, product quality, and delivery time are considered internal supply chain risks, whereas exchange rates, natural disasters, and terroristic threats are regarded as external supply chain risks (Moshood et al., 2022; A. R. Ravindran & D. Warsing Jr, 2016). For decades, the first type of supply chain literature has included consumer expectations and order planning time. External hazards have now become very critical with the global extension of supply chain activities. Supply chain disruption has always been a major threat to companies. Charlesworth et al. (2011) maintain that the following processes are usually considered in a common supply chain risk management framework: (1) risk recognition; (2) risk management; (3) risk mitigation; and (4) monitoring and assessment.

Known as incident management, risk assessment is more widespread than risk identification in supply chain management. Risk assessment involves identifying potentially dangerous occurrences as well as the instability of a mechanism or an environment in the crisis management literature.

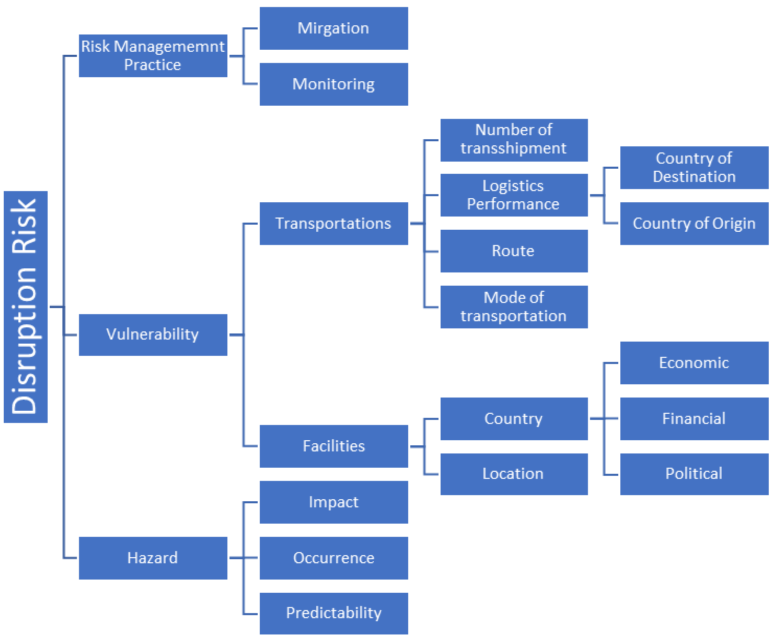

Figure 1. Disruption Risk Factors

Following that, we will have a look at a few more closely linked subjects. Other arenas of modern supply chain literature, such as supply chain network operations and supply chain visibility as a distinct supply chain analytic technique, are also discussed in this course. A multi-period supply chain tactical model is then provided to optimize profit margins in the supply chain by identifying the most efficient methods for procuring goods, producing them, transporting them, and making them visible to customers. In the event of a supply chain component breakdown, the supply chain network's vulnerability is examined. In order to illustrate the increase in supply chain performance, we next assess the cost-benefits of risk-mitigation strategies like backup suppliers and excess inventory. Finally, we conclude the article and recommend future research possibilities.

2. Literature Review

Since the management of risk and disruption in the supply chain has a wide range of applications in different areas, many relevant concepts and definitions have been proposed by researchers. Yang (2006) divided the risks into two types: target suspension risks and high-intensity risks. The first type refers to any missed goals by suppliers. Often occurring but having minor impacts, these risks include the delivery time and the defect rate. The second category refers to the rare but high-impact events that may disrupt suppliers.

Teuscher et al. (2006) illustrate the varied aspects of risk interference that may result in a scientific model of property supply chain management. The article illustrates, however, when customers ironed the food business to exclude GMO soybeans from their merchandise, a property soybean supply chain was established.

Giannakis and Papadopoulos (2016) fostered a functional viewpoint of supply chain sustainability by considering it as a danger of the executives' interaction. They investigated the idea of sustainability-related inventory network chances, recognized them from run-of-the-mill production network hazards, and fostered a scientific interaction for their administration. An experimental review was done to create the knowledge regarding how sustainability related dangers ought to be overseen in a coordinated manner. A blended strategy approach was embraced for information assortment and examination.

Some researchers evaluated and ranked external suppliers based on the reliability of suppliers, national threats (e.g., political risks, natural and human-produced disasters, and currency risks), and reliability of maritime transports across a hierarchical transition method (Mazza et al., 2013).

Chan et al. (2010) also designed an overall multi-criteria supplier selection dilemma model, in which risk is considered a selection criterion. Sub-risk factors include geographical locations, political stability, foreign policies, exchange rates, economic conditions, terrorism, and crime rates (Chan & Chan, 2010). A definition of a set of important criteria was also used to document ambiguous decision preferences (Choi et al., 2019). In a flurry of hierarchical analytic processes, Lee (2002) proposed selecting suppliers based on four metrics, i.e., incentives, opportunities, costs, and risks related to the applicant suppliers. Sub-risk requirements were said to include capabilities, limitations, pricing adjustments, financial parameters, supplier efficiency, credibility, and climate control.

Zhao et al. (2011) conducted a case scenario to assess the resilience of the four concepts in a military logistics network to both unintentional and deliberate disruptions (i.e., natural disasters, unforeseen economic events, terrorist attacks, and military attacks). Bas argued that an integrated risk management approach adapted from the International Labor Office (ILO) to calculate the surgical flow disruption (SFD), surgical flow disruption effects (SFDEs), and OSH hazards through the proposed fuzzy cognitive mapping (FCM) could act as a risk prioritization tool (Bas, 2018).

Dimitri and Alexander explored two new perspectives on supply chain disruption risk management, namely ripple and flexible effects. They discussed different ways of reducing SC disorders and making improvements when severe disorders occur. They analyzed the reasons and strategies for alleviating the ripple effect in the SC and provided a containment framework that consists of redundancy, flexibility, and flexibility. Even if different types of valuable insights have been generated in recent years, new research pathways and classifications of ripple effects should be identified before long. The special focus is on the supply chain risk analysis for the risks of disruption and wave impacts on digital supply chains (Ivanov & Dolgui, 2019).

Wide (2020) analyzed the operational management of disruptions in the transportation chains with a focus on the post-disruption stages. Instead of focusing on risk reduction strategies before the onset of a disorder, this paper considered the recovery stage of the disorder at the operational level to provide insights into operational disruption management to provide improved decision support for the recovery phase.

Valinejad & Rahmani (2018) proposed an exhaustive and trustworthy system for dealing with the sustainability dangers of the supply chain for broadcast communications organizations in view of another way to deal with sustainability. As a case study, some significant Iranian network access suppliers were examined and dissected using this methodology by utilizing the disappointment mode and the impact examination technique. In the wake of distinguishing the underlying drivers and possible results of each hazard, a treatment was proposed dependent on the limits of the business. Therefore, the most perilous sustainability hazards in the considered telecom organizations are specialized and institutional ones, which represent practically 66% of the basic dangers. Likewise, providers with a 53% portion of basic dangers are the most likely to take steps to support the store network in these organizations. The proposed structure, which is not just utilized by chiefs and specialists in the media communications industry, yet can very well be acclimated to some other industry by related directors to keep up with the manageability of the production network execution in the long haul.

El Baz and Ruel studied the role of supply chain risk management (SCRM) in mitigating the effects of disruption on supply chain resilience due to the prevalence of COVID-19. Structural equation modeling was employed to survey the data from 470 French companies. The results confirmed the basic principles of the resource-based view and theories of organizational information processing regarding the combination of dynamic resources for uncertainty against perturbations (El Baz & Ruel, 2021).

Vandchali et al. examined the effect of supply chain network (SCN) structure on central firms' relationship management strategies (RMS) and recognized techniques that might be utilized to carry out manageability rehearsals all through the SCN. An online study attempted to gather information from an example of 66 Australian food producers and providers inside two enormous retailers' SCNs. The paper's building blocks were approved by means of an exploratory factor examination, and various levels of relapse investigations were led to test the theories. The results showed various connections between each factor and RMS, providing new insights into the execution of supportability rehearsals in the SCN. The discoveries could help administrators decide an equilibrium in dispensing assets to oversee manageability rehearses inside their organizations' SCNs (Vandchali et al., 2021).

Many concepts have been developed for supply chain risk management. Table 1 presents an overview of studies on risk as well as their key findings.

Table 2 gives in the important criteria that have been studied in the articles in the field of risk. In addition, the influences that are in the results and their models are presented in a categorized way so that the studies can be easily reviewed.

Table 1. Examining the Types of Risks in Different Researches

Authors	Risk
Wagner & Bode (2008)	The demand side, supply side, regulatory and legal control risk, infrastructure risk, and catastrophic risks
Yu & Goh (2014)	Internal operational risks: demand, production, distribution, and supply External operational risks: terrorist attacks, natural disasters, and exchange rate fluctuations
Chakraborty et al. (2011)	Risks associated with supply and demand, process, and the environment
Samvedi et al. (2013)	Supply, demand, process, and environmental risks
Loh & Van Thai (2015)	The risk of disruption prevention, disruption reduction, delay, and deviation from the transportation plan
Waters (2011)	External risk: the risk of disruption reduction abroad, as well as the risk of foreign suppliers Internal risk: risk of purchasing costs, logistics costs, internal supplier risk
Choi et al. (2019)	Procurement, demand management, supply management, and demand coordination
Hosseini-Motlagh et al. (2020)	Disruption risk, sustainability risk, demand management, whole chain profitability

Table 2. Important Criteria in the Field of Risk

Authors	Consider customer preferences/ prioritization method	Supply chain decision	Objective (s) function	Risk factors	Research methodology / solution method	Consider decision maker	Components that have been damaged or interrupted	Aiming for a risk-based approach
Manikandan (2009)	Yes/ AHP	Supply chain	Cost	Price, uncertainty	MILP	No	Transportation	Vulnerability
Solo (2009)	Yes/ AHP	Supply chain network	Profit, lack of time	Disruption of transportation	MILP/ GP	Yes	Transportation	Resiliency
Zhao et al. (2011)	No	Supply chain network	Availability, connectivity, accessibility	Probability of occurrence	Simulation	No	Facility	Vulnerability/ Resilience
Smith (2012)	No	Supply chain network	The cost of using the network	Disorders and supplier reliability	Simulation	Yes	Transportation	Resiliency
Sawik (2013)	No	Inventory supply chain	Cost of supplier support, inventory, shipping	Capacity, consumption, shortage cost, protection cost	MILP	No	Facility	Resiliency
Shu et al. (2014)	No	Inventory supply chain	Costs (production, transportation)	Product sales, production costs, purchase costs, and shipping costs	Simulation, genetic algorithm	No	Facility	Resiliency
Mensah et al. (2015)	No	Supply chain network	Implementation of ICT in collaboration with specific strategies	Skills, disruption of the transport network	Simulation	No	Facility	Resiliency
Oliveira et al. (2019)	Yes	Supply chain management	Analysis of maps and partnerships	Demand chain disorder, Informational	Simulation	No	Facility	Resiliency
Diabat et al. (2019)	Yes	Supply chain network	Time and cost of delivering products to customers	Disruption of demand	Lagrange function	No	Transportation	Resiliency
Ri et al. (2020)	No	Supply chain design	Inventory management	Risk of disruption at work, job costs	Simulation	Yes	Facility	Resiliency
Xu et al. (2020)	No	Supply Chain network	Fuzzy decision testing and evaluation	Risk of disorders	Scenario analysis	Yes	Facility	Resiliency
This paper	Yes/ AHP	Supply Chain network	Profit, demand fulfillment, delivery time, and disruption risks	Remove node / link (Problems occurring in nodes/loss of communication nodes)	Multi-objective model	Yes	Facility/ transportation	Vulnerability

2.1. Research Gap

Many multi-criteria supply chain network design models may fail to withstand redundancy due to network structures. In other words, a model should be modified to reduce the impact of a failure by including continuity (e.g., backup) or spreading risks (e.g., multiple providers or multiple transportation links). Most of the reviewed strategic supply chain models consider definite demand, cost, and lead time. It is also necessary to consider the uncertainty of the model parameters. Recent studies have neglected a topic that is supply chain visibility maximization. Therefore, supply chain visibility should be improved to mitigate the supply chain risk. By creating a comprehensive view of a single integrated system, many potentially disrupting situations can be identified and neutralized before they develop into a critical state. This study reviewed the papers on risk and analyzed the types of risk models both structurally and contextually. The papers were then categorized and compared. Risk studies, according to the findings of this section, are frequently dependent on a decision maker's attitude toward risk variables and their attributes. It was also important to examine qualitative evaluations by taking into account the responsibilities of numerous decision-makers. Future research can also increase supply chain visibility since a good supply chain vision can bring benefits to related operations and improve planning efficiency.

3. Modeling

In this part, we developed a multi-criteria optimization model to help design a global supply chain network under interruption. Profit, customer responsiveness (demand fulfillment and delivery), and supply chain component disruption risk were among the factors for selection (facilities and transportation links). To deal with the various competing objectives, we used goal programming (GP) methodologies. Companies might use the model to assess the tradeoff between the advantages and hazards of alternative design choices. The supply chain network strategic model, as shown in Figure 2, is the second module in the disruption risk management framework.

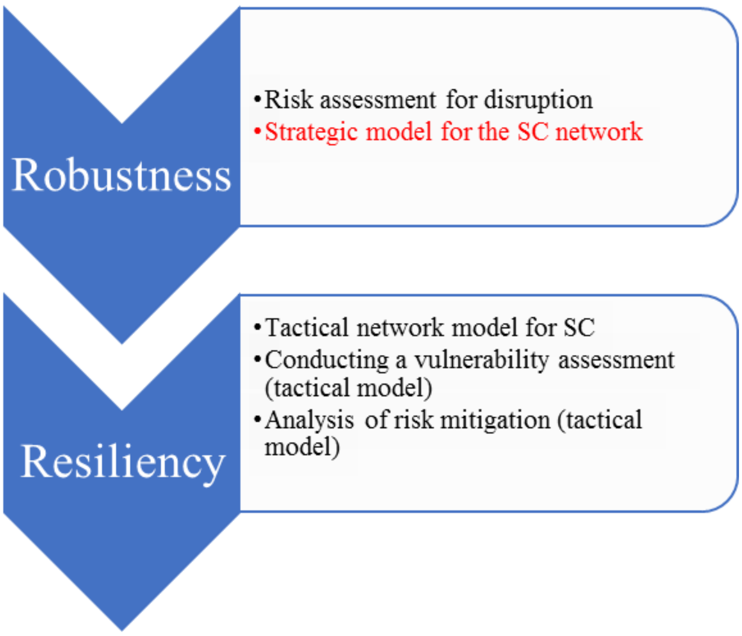

Figure 2. Supply Chain Network Strategic Model

In addition to facilities like suppliers, manufacturing plants, distribution hubs, and demand zones, physical models of supply chains contain transportation connections. Global supply chains are made up of facilities located in many countries, and these facilities are connected by a variety of transportation networks. Global supply chain networks are shown in Figure 3.

Figure 3. A Global Supply Chain Network

To move goods between facilities in a typical supply chain network made up of possible suppliers, potential plant locations, and distribution hubs, many modes of transportation may be used. Disruption to transportation infrastructure is a possibility. One goal of a company's global supply chain network is to minimize customer delivery times (Z1), maximize demand fulfillment or minimize unfulfilled demand (Z2), maximize profits (Z3), maximize supply chain visibility (Z4), minimize disruption risk to transportation links (Z5), and minimize disruption risk to facilities (Z6). Figure 4 shows the criteria for the supply chain network.

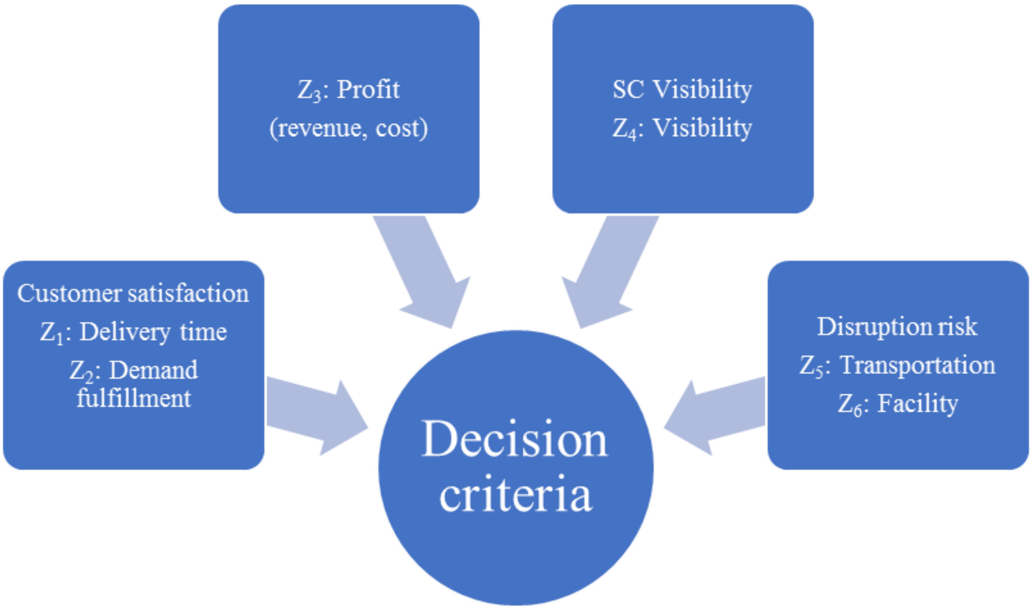

Figure 4. Design Criteria for Supply Chains

To achieve the intended global supply chain network robustness, the final two objectives are utilized. Disruptions are less likely to cause problems for supply chain components with a lower disruption risk score. If the supply chain is made up of low-risk components, it will be more stable than a network made up of high-risk ones.

We developed a multi-criteria optimization model for a global company to make the following decisions: (I) supply chain network structure, including which suppliers, manufacturing plants, and DCs to use; (II) production and distribution planning (e.g., which plants should manufacture which completed goods); and (III) transportation selection (e.g., which carrier should convey things to and from facilities).

We now fully explain the assumptions of the stated model. A supply chain network will be designed for the emerging goods. There is a wide range of potential sources, including sites for factories, storage centers, and available transportation connections, whereas extra costs are incurred for the shipment of commodities (i.e., raw materials or finished goods) overseas (e.g., import and export duties and export taxes). The cost of importing raw materials into the factory will also be added as a share of the net cost of raw materials. Moreover, export costs apply to the finished goods directly exported from factories to consumers in various countries with no tariffs because finished goods are delivered from suppliers to company-owned distribution centers. It should be remembered that the corporate climate is definite. The goods can be directly delivered from the manufacturers to the areas of need where demand is low. Furthermore, the regular currency (USD) values and costs are available.

In the production sector, there is only one production stage (corresponding to a machine or the whole factory) in which all products are manufactured. The production unit capacity is limited, specific, and known. In addition to the variable costs of production, which depend on the number of products at a factory, production also requires commission costs or fixed production costs. Every distribution center also has a predefined, limited capacity. Customers have definite levels of demand. Product shortages are allowed for customers in distribution centers and factories (shortages are lost in the form of sales). The maximum allowable shortage is considered for each product.

The danger points of disturbances for facilities and transportation communications are determined by organizations (including providers, warehouses, and dispatch centers) and can vary in the locations of plants.

The supply chain network is planned to include four tiers, including suppliers, production facilities, distribution hubs, and demand regions. The main objectives of the chain include minimizing the total costs of the supply, production, and distribution programs for profit maximization. The proposed chain is also meant to minimize unmet demand and delivery time, mitigate the disruption risk of facilities and transportation, and maximize chain visibility.

The proposed model is described as below:

Sets:

s	A list of providers of raw material
f	A group of factories
c	A network of distribution points
b	A group of clients
j	A collection of raw ingredients
n	A group of completed goods
u	Transportation links connecting facilities
o	Origin nodes or facilities
d	Destination nodes or facilities
p	Item depicting a final product or raw material

Parameters:

MN_{js}	In order to acquire raw material *j* from supplier *s*, you must meet the following minimum order quantity:
MN_{nf}	Quantity needed to make product *n* in plant *f*
MF	Minimum order to allow direct shipment between a plant and a customer (cumulative overall products)
MN_{uod}	Fixed transportation cost of link *u* if used between facilities o and *d*

LT_{uod} Average lead-time when using link u between facilities o and d
CAP_o The capacity of facility o
CAP_{po} The capacity of item n at facility o
CAP_{uod} The capacity of transportation link u between facilities o and d
G_f Percentage of import fees applied to the variable purchasing cost at plant f
H_f Percentage of export fees applied to the revenue of plant f
E_o Disruption risk scores of facility o
E_{uod} The disruption risk score of transportation link u between facilities o and d
V_{po} Ability to see the supply chain if item p is allocated to facilitate o
FC_o Fixed cost of selecting the facility
FC_{po} Fixed operating cost when assigning item p to facility o
FC_{pod} Fixed cost, which may occur, when assigning item p between facilities o and d
O_{uod} Fixed transportation cost of link u if used between facilities o and d
TC_{puod} The unit shipping cost of item p via link u from facility o to facility d
M_{js} Cost per unit of raw material j shipped from supplier s
$PROC_{nf}$ The unit production cost of producing product n at plant f
D_{nb} Product n's predicted demand for customer b
F_{nb} Price per unit sold of n to client b for which the firm aims to meet demand.
R_j Quantity of raw material j required based on the forecasted demand
N_n The amount of room needed in a distribution facility to keep a single instance of item n
SVC_{nc} At DC, the cost per square foot of product j's storage
A_{jn} Raw material quantity j required to create one unit of a final product n
P_{nob} The selling price of product n from facilities o to customer b
α Percentage of defective products returned to the factory
$Vmin_p$ Minimum visibility required for the product P
CV_{pf} The cost of increasing visibility for product p by facilitating f
B_p Available budgets to increase product visibility p

Model Variables:

Q_{puod} Quantity of item p shipped via transportation link u between facilities o and d
X_{nf} Quantity of product n produced at plant f
L_{nb} Quantity of unfulfilled demand of product j to customer c
Y_o Binary variable equals 1 if facility o is selected; 0 otherwise
Y_{po} Binary variable equals to 1 if item p (raw material or product) is assigned to facility o; 0 otherwise
Y_{pod} Quantity of item p shipped via transportation link u between facilities o and d
Y_{uod} Binary variable equals to 1 if link u is used to ship items between facilities o and d; 0 otherwise
$S1_o$ Fraction of items handled by facility o
$S2_o$ Fraction of items handled by link u connecting facilities o and d
Re The number of defective products returned to the factory

Objective Functions:

$$\text{Min } Z_1 = \sum_b \sum_f \sum_u LT_{ufb} \times (\sum_n Q_{nufb}) + \sum_b \sum_c \sum_u LT_{ucb} \times (\sum_n Q_{jucb}) \quad (1)$$

$$\text{Min } Z_2 = \sum_n \sum_b L_{nb} \quad (2)$$

$$\begin{aligned}\text{Max } Z_3 = & [\sum_n \sum_f \sum_u \sum_b P_{nfb} \times Q_{nufb} + \sum_c \sum_n \sum_u \sum_b P_{ncb} \times Q_{nucb}] - [\sum_j \sum_s FC_{js} \times Y_{js} + \sum_j \sum_s M_{js} \times (\sum_f \sum_u Q_{jusf})] - \\ & [(\sum_n \sum_c FC_{nc} \times Y_{nc}) + (\sum_n \sum_c SVC_{nc} \times N_n (\sum_f \sum_u Q_{nufc}))] - [(\sum_f \sum_n FC_{nf} \times Y_{nf}) + (\sum_f \sum_n PROC_{nf} \times X_{nf})] - \\ & [\sum_s FC_s \times Y_s + \sum_f FC_f \times Y_f + \sum_c FC_c \times Y_c] - [(\sum_d \sum_o \sum_u O_{uod} \times Y_{uod}) + (\sum_d \sum_u \sum_o \sum_p TC_{puod} \times Q_{puod})] - \\ & [\sum_d \sum_o \sum_p FC_{pod} \times Y_{pod}] - [(\sum_j \sum_s V_{js} \times CV_{js} \times Y_{js}) + (\sum_n \sum_f V_{nf} \times CV_{nf} \times Y_{nf}) + (\sum_c \sum_n V_{nc} \times CV_{nc} \times Y_{nc})] - \\ & [(\sum_f G_f \sum_s \sum_j M_{js} (\sum_u Q_{jusf})) + (\sum_f H_f \sum_b \sum_n P_{nfb} \times (\sum_u Q_{nufb}))] - [\sum_n \sum_u \sum_f \sum_b TC_{nufb} \times \mathrm{Re}_{nbf}]\end{aligned} \quad (3)$$

$$\text{Max } Z4 = (\sum_j \sum_s V_{js} \times Y_{js}) + (\sum_n \sum_f V_{nf} \times Y_{nf}) + (\sum_n \sum_c V_{nc} \times Y_{nc}) \quad (4)$$

Min Z5 = $\sum_{d}\sum_{o}\sum_{u} S2_{uod} \times E_{uod}$ (5)

Min Z6 = $\sum_{o} S1_{o} \times E_{o}$ (6)

Subject to:

$$\sum_{f}\sum_{s}\sum_{u} Q_{jusf} \geq R_{j} \qquad \forall j \tag{7}$$

$$MN_{js} \times Y_{js} \leq \sum_{f}\sum_{u} Q_{jusf} \leq CAP_{js} \times Y_{js} \qquad \forall j,s \tag{8}$$

$$MN_{nf} \times Y_{nf} \leq X_{nf} \leq CAP_{nf} \times Y_{nf} \qquad \forall n,f \tag{9}$$

$$Y_{js} \leq Y_{s} \qquad \forall j,s \tag{10}$$

$$Y_{jsf} \leq Y_{js} \qquad \forall j,s,f \tag{11}$$

$$Y_{nf} \leq Y_{f} \qquad \forall n,f \tag{12}$$

$$Y_{nfc} \leq Y_{nf} \qquad \forall n,f,c \tag{13}$$

$$Y_{nc} \leq Y_{c} \qquad \forall n,c \tag{14}$$

$$Y_{ncb} \leq Y_{nc} \qquad \forall n,c \tag{15}$$

$$((1-\alpha)\times\sum_{f}\sum_{u} Q_{nufb} + (1-\alpha)\times\sum_{c}\sum_{u} Q_{nucb}) + L_{nb} = D_{nb} \qquad \forall n,b \tag{16}$$

$$L_{nb} \leq (1-f_{nb})\times D_{nb} \times (1+\alpha) \qquad \forall n,b \tag{17}$$

$$\sum_{n} a_{jn} \times X_{nf} \leq \sum_{s}\sum_{u} Q_{jusf} \qquad \forall j,f \tag{18}$$

$$\sum_{n} a_{jn} \sum_{f} X_{nf} \leq \sum_{f}\sum_{s}\sum_{u} Q_{jusf} \qquad \forall j \tag{19}$$

$$\sum_{f} X_{nf} \geq \sum_{b} f_{nb} \times D_{nb} \times (1+\alpha) \qquad \forall n \tag{20}$$

$$\sum_{f} X_{nf} \leq (1+\alpha)\times\sum_{b} D_{nb} \qquad \forall n \tag{21}$$

$$\sum_{u}\sum_{c} Q_{nufc} + \sum_{u}\sum_{b} Q_{nufb} \leq X_{nf} \qquad \forall n,f \tag{22}$$

$$\sum_{n} N_{n} (\sum_{f}\sum_{u} Q_{nufc}) \leq CAP_{c} \times Y_{c} \qquad \forall c \tag{23}$$

$$\sum_{u}\sum_{b} Q_{nucb} \leq \sum_{u}\sum_{f} Q_{nufc} \qquad \forall n,c \tag{24}$$

$$Y_{uod} \leq \sum_{p} Y_{pod} \qquad \forall u,o,d \tag{25}$$

$$Q_{nufb} \geq MF \times Y_{ufb} \qquad \forall n,u,f,b \tag{26}$$

$$MN_{uod} \times Y_{uod} \leq \sum_{p} Q_{puod} \leq CAP_{uod} \times Y_{uod} \qquad \forall u,p,o,d \tag{27}$$

$$\sum_{k} V_{js} \times CV_{js} \times Y_{js} \leq B_{j} \qquad \forall j \tag{28}$$

$$\sum_{f} V_{nf} \times CV_{nf} \times Y_{nf} + \sum_{c} V_{nc} \times CV_{nc} \times Y_{nc} \leq B_{n} \qquad \forall n \tag{29}$$

$$\sum_{s} V_{js} \times Y_{js} \geq V\ \min_{j} \qquad \forall j \qquad (30)$$

$$\sum_{f} V_{nf} \times Y_{nf} + \sum_{c} V_{nc} \times Y_{nc} \geq V\ \min_{n} \qquad \forall n \qquad (31)$$

$$\sum_{j}\sum_{u}\sum_{s} Q_{jusf} + \sum_{b} \mathrm{Re}_{nbf} = \sum_{u}\sum_{b} Q_{nufb} + \sum_{u}\sum_{c} Q_{nufc} \qquad \forall n,f \qquad (32)$$

$$(1-\alpha)\times(Q_{nufb} + Q_{nucb}) = D_{nb} \qquad \forall n,b \qquad (33)$$

$$\sum_{f} \mathrm{Re}_{nbf} = \alpha \times \left(\sum_{u}\sum_{f} Q_{nufb} + \sum_{u}\sum_{c} Q_{nucb}\right) \qquad \forall n,b \qquad (34)$$

$$Y_{nfc} \leq Y_{nc} \qquad \forall n,f,c \qquad (35)$$

$$Y_{nfb} \leq Y_{nf} \qquad \forall n,f,b \qquad (36)$$

$$Y_{o}, Y_{po}, Y_{pod}, Y_{uod} \in \{0,1\} \qquad (37)$$

$$Q_{puod}, X_{nf}, L_{nb}, S1_{o}, S2_{uod} \geq 0 \qquad (38)$$

- Objective Function 1 represents the delivery time that is a measure of customer response in addition to the realization of demand.
- Objective Function 2 indicates the achieved customer responsiveness by maximizing the realization of customer demand.
- Objective Function 3 maximizes the supply chain profit, which is the difference between revenue and total cost.
- Objective Function 4 represents visibility maximization in the supply chain.
- Objective Function 5 denotes the reduction of disruption risk in the transport link, whereas Objective Function 6 denotes the reduction of disruption risk in the facility.
- Equation 7 ensures that supply is met.
- Equation 8 shows the control of supplier capacity and minimum order quantity.
- Equation 9 guarantees the number of products in terms of the number of raw materials received from the supplier.
- Equation 10 indicates that raw materials are purchased if this source is already selected.
- Equation 11 shows that factory *f* can supply raw material *j* from supplier *s* if supplier *s* is selected to supply raw material *j*.
- Equation 12 indicates that the final product *n* can be produced in factory *f* only if factory *f* is selected.
- Equation 13 shows that the distribution center *c* can receive the final product *n* produced in factory *f* when the factory *f* produces product *n*, and the distribution center *c* also accepts product *n*.
- Equation 14 means that the final product *n* can be stored in the distribution center if the desired distribution center is selected.
- Equation 15 indicates that the distribution center *c* can meet the demand of the final product *j* for the customer *b* if the product is stored in that distribution center.
- Equation 16 ensures that the customer demand is met to the desired extent of the company.
- Equation 17 allows the company to have a different level of customer responsiveness, especially when the shortage is due to disruption (Note that the limit-to-limit (2) indicates the maximum allowable shortage).
- Equation 18 guarantees that the total amount of raw materials used *i* will not exceed the number of materials purchased from suppliers.

- Equations 19 and 20 ensure that the production quantity meets at least the goal of demand satisfaction but does not produce more than expected demand.
- Equation 21 shows that the amount produced in factories will not exceed the demand.
- Equation 22 ensures that the total amount of goods *n* delivered from the factory *f* to customers and distribution centers cannot exceed the amount produced in the factory.
- Equation 23 shows that the total space used by the products cannot exceed the capacity of the desired distribution center.
- Equation 24 indicates that the amount of product *j* sent from the distribution center *n* to customers cannot exceed the amount available in the factory.
- Equation 25 shows that the u-link transport between the source and destination nodes can be used if the goods are assigned to these nodes.
- Equation 26 indicates that direct transport is allowed between factory *f* and customer *b* if the minimum order quantity is met.
- Equation 27 shows that the quantity carried by each transport link must exceed the minimum required for that transport link but cannot exceed its capacity.
- Equation 28 limits the supply chain visibility cost under a planned budget for all suppliers.
- Equation 29 limits the supply chain visibility cost for the final product *n* under the planned budget for all factories and distribution centers.
- Equation 30 analyzes the minimum visibility required for raw material *j*.
- Equation 31 analyzes the minimum amount of visibility required for each final product *n*.
- Equation 32 indicates the balance between factory inputs and outputs.
- Equation 33 shows that an acceptable percentage of goods without defects can meet demand.
- Equation 34 indicates that the percentage of defective goods should be returned to the factory.
- Equation 35 shows that the product can be transferred from factory *f* to distribution center *c* when the desired distribution center has a sufficient capacity.
- Equation 36 indicates that factory *f* can send the product directly to the customer if it is produced in factory *f*.
- Equations 37 and 38 also indicate binary and positive variables, respectively.

4. Solving Method

A supply chain network architecture was modeled using a multi-criteria mathematical programming problem (MCMP). With the help of goal programming, many conflicting goals will be handled. Decision makers' preferences are taken into account while using goal programming to tackle MCMP issues. All goals may be reached with the help of goal programming. In addition, the proportionality of aims is taken into account while assessing their significance. The decision maker aspires to meet these target values, which may be thought of as goal restrictions. These ideas may or may not come to fruition. It is the purpose of goal programming to come up with an ideal solution that is close to the goals but also takes into account what the decision makers want to accomplish. It is the primary objective of GP to minimize the deviations from the goal values. Preemptive Goal Programming (P-GP), Non-preemptive Goal Programming (NP-GP), MinMax Goal Programming (or Tchebysheff GP), and Fuzzy Goal Programming are the four types of GP formulations. The way the goal functions are prioritized and target deviations are managed differs across these formulations. Masud and Ravindran (2008) provide a full discussion of GP techniques. In this study, we solve the supply chain network design model using the preemptive GP and non-preemptive GP formulations.

4.1. Preemptive Goal Programming (Lexicographic)

In P-GP, the objective functions are prioritized according to the ordinal preferences of the decision maker. In other words, the more important objectives take precedence over the less important ones. In addition, each goal's deviations from target values are prioritized in order of importance (Masud & Ravindran, 2008). This method is very convenient when decision-makers can prioritize their ideals. It also uses sequential decision-maker information about the rankings of objective functions. This method can also obtain preferential information and a mixture of rank types, as well as the quantitative type of decision-making. Multi-objective decision-making through the lexicography method is a multi-objective optimization strategy that emerges from a prioritization framework.

Therefore, the problem is first solved with a goal function having the highest priority for the decision-maker with the problem constraints. Table 3 shows the prioritization order of functions.

Table 3. Prioritize Functions from the Decision Maker's Point of View

Objective function	Order of priority
Z_3	First priority
Z_2	Second priority
Z_1	Third priority
Z_6	Fourth priority
Z_4	Fifth priority
Z_5	Sixth priority

According to the prioritization order, the first objective function (i.e., profit maximization) is used first to obtain the optimal value. It is then set equal to the optimal value and added to the constraints. These steps continue until the optimal solution to the objective function is reached, with the last priority being the achievement of the optimal values of the variables and objective functions, taking into account all the objectives simultaneously.

4.1.1. Results of Solving the Model by Lexicographic

The results of the solution show that the first and third suppliers, the first and second factories, the first distribution center, and the second link were activated. The active centers of communication between them can be seen in Figure 5.

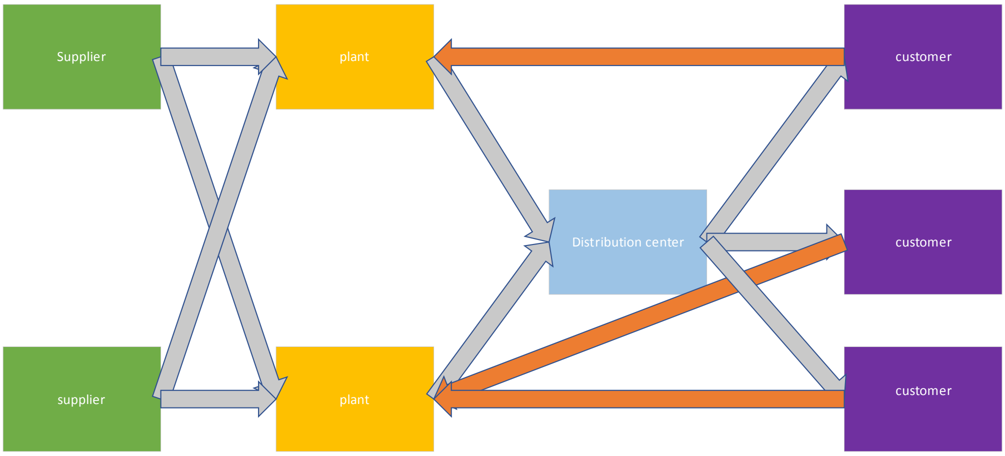

Figure 5. The P-GP Approach to Supply Chain Network Design

4.2. Non-Preemptive Goal Programming (Weighting Method)

NP-GP uses numerical weights to indicate the importance of the goal functions. Criterion weights may be determined in a variety of methods, including the basic rating technique, the comparison method, the Borda Count, and the Analytic Hierarchy Process (AHP).

In this type, unintended deviations from the intended goal are weighed according to their relationship to the importance determined by the decision-maker, and their sum is minimized. This type of GP is presented as the weighted ideal plan. Having the flexibility of linear programming, ideal programming includes contradictory goals and provides the optimal solution according to the priorities of the goals from the perspectives of decision-makers.

4.2.1. Results of solving the model by WGP

The solution results show that the first supplier, the first and second factories, the first and second distribution centers, and the first link were activated. Figure 6 demonstrates the activated centers and their relationships.

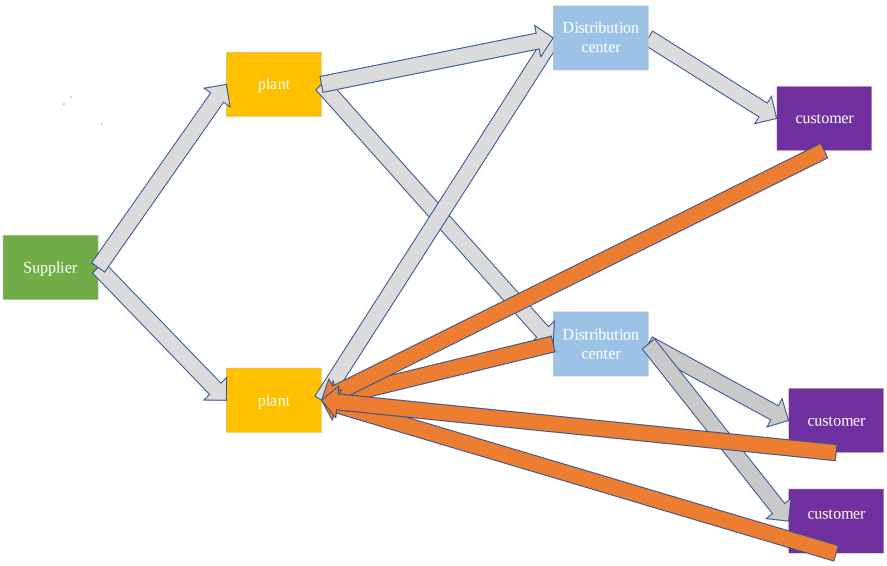

Figure 6. Supply Chain Network Design From the NP-GP

4.3. Sensitivity Analysis for Service Level Parameters

To review and analyze the results of the proposed model and the process of changing the parameters, a sensitivity analysis was conducted on the parameter under management control in this chain, i.e., the percentage of customer demand that the factory tends to meet. The choice of the value of this parameter is entirely related to the corporate policies in terms of the question whether the company wants to have a high level of service or not.

In the main model, the response percentage parameter was set at 0.9. By reducing this value to 0.7, the values of the objective functions will be as follows:

Table 4. The Optimal Value of Goals Considering Sensitivity Analysis

Function	The optimal amount
Z_1	357333.3
Z_2	79200
Z_3	85363944.58
Z_4	19.95
Z_5	33.73
Z_6	31.21

According to the resultant values, as the level of responsiveness decreases, the chain profit decreases, whereas the shortage increases. At the same time, the risk visibility decreases; therefore, the disruption risks will increase. The delivery time will also grow. Considering the 9% and 7% response rates, the following graphs are drawn:

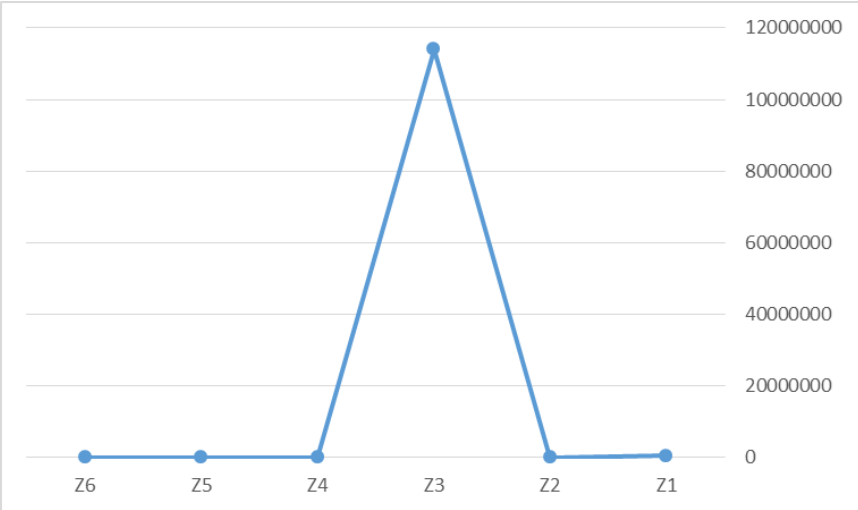

Figure 4. Values of Objective Function Taking Into Account the 0.9 Level of Response

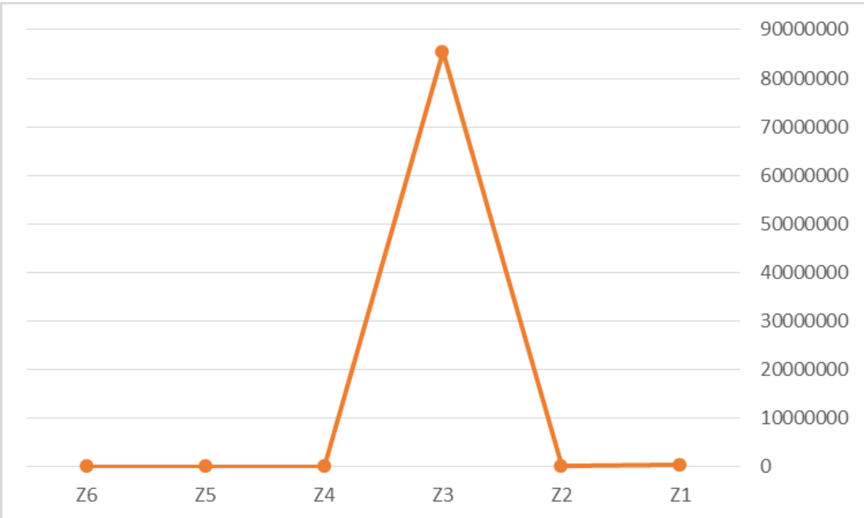

Figure 5. Values of Objective Function Taking Into Account the 0.7 Level of Response

Since the first and second priorities in the functions are to maximize profits and minimize deficits, respectively, it is preferable to have a higher level of account chain.

4.4. Comparison of Solution Methods

Table 5 reports the optimal values of objective functions, which are solved through lexicographic and ideal planning methods. One method is not better than the other, and the choice can be based on priority. The decision-maker selected a method and used its solutions. Since the priority of the organization is to increase the chain profit, it can be concluded that the lexicographic method provides better solutions according to the decision maker’s priorities. The solutions provided by the lexicographic method are preferable to those of activating two suppliers, two factories, and a distribution center to offer a more favorable solution.

Table 5. Results Obtained From the Ideal Goal Programming Method

Supply chain network design		P_GP	NP_GP
Suppliers	Supplier 1	Select	Select
	Supplier 2	-	-
	Supplier 3	Select	-
Plants	Plant 1	Select	Select
	Plant 2	Select	Select
DCs	DC 1	Select	Select
	DC 2	-	Select
Transportation links	U1	-	Select
	U2	Select	-
Direct route of goods to receive from the factory to the customer		-	Select

The decision-maker set the optimal values until the ideal value was decided for each objective function. In this model, 99% of the optimal profit value was considered the goal value of profit. Table 6 presents a complete overview of these values.

Table 6. Values for the Objective Functions and Scaled Values

Function value	Ideal values	Target values	P_GP method	NP_GP method
Z_1	261066.6	4553.58	4746666 (+83%)	261.066.6 (+1.01%)
Z_2	29040	749.28	26400 (-8.2%)	29.40 (+1.01%)
Z_3	102660195	173501653	114066883.7 (-82.5%)	102660195 (-84.5%)
Z_4	44.45	44	22.23 (-49.5%)	32.74 (-25.6%)
Z_5	41.44	41.02	62.64 (+52.03%)	41.44 (+0.5%)
Z_6	22.42	22.19	35.23 (+58.76%)	25.67 (+15.68%)

According to the comparisons, the following conclusions can be drawn:

- Non-preventive (weighted) ideal preparation has a remote chance of failure (lexicographic) due to the sequential optimization model being the preventive approach. The process is solved in a sequence. The decision-maker then gives the respective priority. Since the target is the greater benefit, the scheme offers a cheaper solution, whereas the model of transport facilities and the cost-effective connections are selected accordingly. Therefore, the business can spend less on preparing for and reducing possible damage. It also leads to a low-profit loss.
- The risk of disease prevention is very high when compared to non-preventive interventions, because risk accidents occur frequently when risk monitoring and risk control methods are not in place.
- The organization should also closely track vendors and plants and implement discount plans. As the suppliers in the research sample originate from reasonably stable economies in the developing world, risk control policies are not completely applied. Thus, risk mitigation mechanisms must be developed, and emergency planners should be trained gradually. Finally, a strategy can be formulated to reduce the outputs of future plants to other plants for risk minimization.

4.5. An alternative Method for Resolving the Multi-Criteria Mathematical Problem (MCMP)

The goal programming approach used in the preceding section to solve MCMP requires a decision maker's totally pre-specified choice. Furthermore, non-preemptive goal programming (NP-GP) requires that the utility function of a decision maker be linear. In reality, statistically quantifying preference may be tricky. To address this issue, another MCMP methodology known as an interactive method might be utilized. An interactive technique does not require pre-specified preferences, but rather depends on a decision maker's increasing articulation of preferences (Masud & Ravindran, 2008; Nahum & Hadas, 2020; Torres-Ruiz & Ravindran, 2019). Although several scholars have addressed this process in great depth (Davé & Klein, 2022; Hafezalkotob et al., 2019; Majumder, 2015; Odu & Charles-Owaba, 2013), the overall procedure can be summarized as follows:

Step 1: Locate an effective solution.

Step 2: Communicate with a decision maker to gain feedback on the provided solution.

Step 3: Repeat steps 1 and 2 until you are satisfied or a termination requirement is met.

In our numerical example, we used the interactive technique. The result is as follows: Step 1: As stated in Table 6, generate a set of efficient solutions using six distinct weight sets. It is worth noting that the first five weight settings correspond to individual optimization of each target while disregarding the others. Weight set 6 assigns equal weights to each aim.

Tables 8 and 9 illustrate the goal function values as well as the matching network architecture for each weight set. Table 9 yields five different efficient designs.

Table 7. Weight Sets to Generate Efficient Solutions

Criteria	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6
Z1	0.95	0.01	0.01	0.01	0.01	0.166
Z2	0.01	0.95	0.01	0.01	0.01	0.166
Z3	0.01	0.01	0.95	0.01	0.01	0.166
Z4	0.01	0.01	0.01	0.95	0.01	0.166
Z5	0.01	0.01	0.01	0.01	0.95	0.166
Z6	0.01	0.01	0.01	0.01	0.01	0.166
Sum	1.00	1.00	1.00	1.00	1.00	1.00

Table 8. Each Weight Set Corresponds to a Certain Objective Function Value

Criteria	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6
Z1	104,101,496.75	98,587,715.98	98,259,349.58	83,956,101.19	83,956,101.19	98,290,107.56
Z2	0.00	0.00	0.00	0.00	0.00	0.00
Z3	230,109.60	230,109.60	230,109.60	460,219.20	460,219.20	230,109.60
Z4	31.40	26.47	25.98	21.24	21.24	26.17
Z5	30.61	23.47	23.04	18.91	18.91	23.17
Z6	28.41	21.74	21.75	18.05	18.05	21.63

Table 9. Each Weight Set Corresponds to a Network Design

Part of the supply chain	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6
Suppliers	K1	K2, K3	K1, K2, K3	K1, K2	K1, K3	K1, K2, K3
Plants	M1, M2	M1, M2	M1, M2	M1, M2	M1, M2	M1, M2
DCs	N1	N2	N1	N2	-	N1, N2
Transportation links	U1, U2	U2	U1, U2	U1	U2	U1, U2
Direct shipment from plants to customers	No	Yes	No	Yes	No	No

Step 2: Consult with the decision maker to determine the best option. Assume a decision maker chooses the three design options from weight sets 2, 3, and 6 because their profit and disruption risk values are similar.

Step 3: Based on those three design solutions, a new set of efficient solutions is built. Adjust the weight values and re-optimize the NP-GP model based on weight sets 2, 3, and 6.

Repeat the second step until the achieved responses are different from the prior ones. Then, work with the decision maker to select the best option.

5. Conclusions and Suggestions for Future Research

Network architecture includes supplier selection, facility location, production and distribution planning, and transport network design. There is a limit on how often they may be altered, and any changes might have a significant influence on the whole network. If the interruption risk of the supply chain is not addressed, a supply chain network designed to improve profit and customer satisfaction may result in a network with a high disruption risk. A supply chain plan should take into account interruption risk in addition to profit and customer pleasure. This article discusses the need to assess supply chain disruption risks while making strategic supply chain choices. It is used to estimate supply chain disruption risks based on occurrences, vulnerabilities, and risk management practice characteristics of the supply chain disruption risk assessment framework. Goal programming (GP) is a method for bringing stakeholders into the process of designing a global supply chain network. Furthermore, by utilizing multiple GP procedures, a decision maker can produce a range of responses. The sample case shows how incorporating interruption risk into the supply chain network may improve its robustness.

A mathematical model was developed in this study. A multi-stage strategic supply chain model was developed to examine how the impacts of a disruption in one component of the supply chain affect the profitability of the supply chain network and the realization of the need for global supply chain network design. The proposed multi-objective model includes the goals of minimizing customer delivery time, minimizing unmet demand, maximizing profits, maximizing supply chain visibility to prevent disruption, minimizing the risk of transportation communications disruption, and finally minimizing the risk of facility disruption. A variety of design objectives necessitated the use of both preemption (P-GP) and nonpreemption (NP-GP) goal programming methodologies. AHP and NP-GP weights were determined based on a simple rating approach and AHP. In order to maximize profit and customer happiness, the P-GP and NP-GP algorithms found that low-cost facilities and transportation linkages with high disruption risk values were needed for the supply chain network. Designing a supply chain with low-risk facilities and low-risk transportation connections leads to a more resilient supply chain network since interruption risk is taken into account. Many goals might be traded off using goal programming approaches, such as increasing disruption risk value while reducing supply chain profit. The tradeoffs between the P-GP and NP-GP systems were shown graphically using the value path approach (VPA). This paper's primary contributions are as follows:

- A multi-criteria supply chain network design approach to improve supply chain network resilience and a technique for analyzing disruption risk.
- The vast bulk of supply chain risk management literature focuses on the incidence and effect of disruptions. We evaluated risk in this study based on hazard means the loss or problem of communication between two nodes in the supply chain network, supply chain component vulnerability, and available risk mitigation measures. In addition, we

calculated the likelihood of supply chain entities (facilities) and transportation linkages being interrupted.

- A strong supply chain network may be designed using the multi-criteria supply chain strategy model that takes disruption risk into account.

Finally, recommendations for future research can be expressed as follows:

- Based on one decision maker's assessment of risk variables and their characteristics, disruption risk is a qualitative evaluation method. It is best to have a multidisciplinary team carrying out the assessment in practice. Strengthening the qualitative review may be achieved by including several decision makers and taking into account the uncertainty of qualitative assessment. Furthermore, extreme value distributions may be used to create more complex quantitative risk occurrence and impact models for significant risk occurrences.
- Based on one decision maker's assessment of risk variables and their characteristics, disruption risk is a qualitative evaluation method. It is best to have a multidisciplinary team carry out the assessment in practice. Strengthening the qualitative review may be achieved by including several decision makers and the uncertainty of qualitative assessment. Furthermore, extreme value distributions may be used to create more complex quantitative risk occurrence and impact models for significant risk occurrences.
- Consideration of supply chain responsiveness factors based on its elements (internal integrity, supply chain agility, and flexibility) might be provided along with supply chain risk to identify suitable suppliers.
- A longer time horizon can be considered and the way to combine visibility, agility, flexibility, and integration can be explored.
- More constraints can be added to the supply chain disruption risk model, such as reverse ordering and lack of recovery as well as environmental risks.
- In the model, many parameters are considered definitively. They can be considered uncertain in future work.

References

Bas, E. (2018). An integrated OSH risk management approach to surgical flow disruptions in operating rooms. *Safety Science, 109*, 281-293.

Benjamin, M. F. D., Tan, R. R., & Razon, L. F. (2015). Probabilistic multi-disruption risk analysis in bioenergy parks via physical input–output modeling and analytic hierarchy process. *Sustainable Production and Consumption, 1*, 22-33.

Boy, M., Karl, T., Turnipseed, A., Mauldin, R. L., Kosciuch, E., Greenberg, J., Rathbone, J., Smith, J., Held, A., & Barsanti, K. (2008). New particle formation in the Front Range of the Colorado Rocky Mountains. *Atmospheric Chemistry and Physics*, *8*(6), 1577-1590.

Chakraborty, T., Shibata, Y., Zhou, L.-Y., Katsu, Y., Iguchi, T., & Nagahama, Y. (2011). Differential expression of three estrogen receptor subtype mRNAs in gonads and liver from embryos to adults of the medaka, Oryzias latipes. *Molecular and Cellular Endocrinology*, *333*(1), 47-54.

Chan, H. K., & Chan, F. T. (2010). A review of coordination studies in the context of supply chain dynamics. *International Journal of Production Research*, *48*(10), 2793-2819.

Charlesworth, S., De Miguel, E., & Ordóñez, A. (2011). A review of the distribution of particulate trace elements in urban terrestrial environments and its application to considerations of risk. *Environmental geochemistry and health*, *33*(2), 103-123.

Choi, T.-M., Wen, X., Sun, X., & Chung, S.-H. (2019). The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. *Transportation Research Part E: Logistics and Transportation Review, 127*, 178-191.

Davé, V. A., & Klein, R. S. (2022). The multitaskers of the brain: Glial responses to viral infections and associated post-infectious neurologic sequelae. Glia.

Diabat, A., Jabbarzadeh, A., & Khosrojerdi, A. (2019). A perishable product supply chain network design problem with reliability and disruption considerations. *International Journal of Production Economics, 212*, 125-138.

El Baz, J., & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. *International Journal of Production Economics, 233,* 107972.

Enyinda, C. I., Ogbuehi, A., & Briggs, C. (2008). Global supply chain risks management: A new battleground for gaining competitive advantage. *Proceedings of ASBBS, 15*(1), 278-292.

Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International Journal of Production Economics, 171*, 455-470.

Hafezalkotob, A., Hafezalkotob, A., Liao, H., & Herrera, F. (2019). An overview of MULTIMOORA for multi-criteria decision-making: Theory, developments, applications, and challenges. *Information Fusion*, *51*, 145-177.

Hosseini-Motlagh, S.-M., Ebrahimi, S., & Zirakpourdehkordi, R. (2020). Coordination of dual-function acquisition price and corporate social responsibility in a sustainable closed-loop supply chain. *Journal of Cleaner Production, 251*, 119629.

Ivanov, D., & Dolgui, A. (2019). New disruption risk management perspectives in supply chains: Digital twins, the ripple effect, and resileanness. *IFAC-PapersOnLine, 52*(13), 337-342.

Knisley, D., & Knisley, J. (2011). Predicting protein–protein interactions using graph invariants and a neural network. *Computational biology and chemistry, 35*(2), 108-113.

Lee, H. L. (2002). Aligning supply chain strategies with product uncertainties. *California Management Review, 44*(3), 105-119.

Loh, H. S., & Van Thai, V. (2015). Cost consequences of a port-related supply chain disruption. *The Asian Journal of Shipping and Logistics, 31*(3), 319-340.

Majumder, M. (2015). Multi criteria decision making. In *Impact of urbanization on water shortage in face of climatic aberrations* (pp. 35-47). Springer.

Manikandan, N. U. (2009). Modeling and analysis of a four stage multi-period supply chain.

Masud, A. S., & Ravindran, A. R. (2008). Multiple criteria decision making. In: CRC Press, An imprint of the Taylor and Francis Group.

Mazza, P. P., Lovari, S., Masini, F., Masseti, M., & Rustioni, M. (2013). A multidisciplinary approach to the analysis of multifactorial land mammal colonization of islands. *BioScience, 63*(12), 939-951.

Mensah, P., Merkuryev, Y., & Longo, F. (2015). Using ICT in developing a resilient supply chain strategy. *Procedia Computer Science, 43*, 101-108.
Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M. H., & AbdulGhani, A. (2022). Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution? *Current Research in Green and Sustainable Chemistry*, 100273.
Nahum, O. E., & Hadas, Y. (2020). Multi-objective optimal allocation of wireless bus charging stations considering costs and the environmental impact. Sustainability, 12(6), 2318.
Odu, G., & Charles-Owaba, O. (2013). Review of multi-criteria optimization methods–theory and applications. *IOSR Journal of Engineering*, *3*(10), 01-14.
Oliveira, J. B., Jin, M., Lima, R. S., Kobza, J. E., & Montevechi, J. A. B. (2019). The role of simulation and optimization methods in supply chain risk management: Performance and review standpoints. *Simulation Modelling Practice and Theory*, *92*, 17-44.
Ravindran, A. R., & Warsing Jr., D. P. (2016). *Supply chain engineering: Models and applications*. CRC Press.
Ri, J. S., Choe, S. H., Schleusener, J., Lademann, J., Choe, C. S., & Darvin, M. E. (2020). In vivo tracking of DNA for precise determination of the stratum corneum thickness and superficial microbiome using confocal Raman microscopy. *Skin Pharmacology and Physiology, 33*(1), 30-37.
Samvedi, A., Jain, V., & Chan, F. T. (2013). Quantifying risks in a supply chain through integration of fuzzy AHP and fuzzy TOPSIS. *International Journal of Production Research, 51*(8), 2433-2442.
Sawik, T. (2013). Selection of resilient supply portfolio under disruption risks. *Omega, 41*(2), 259-269.
Shu, T., Chen, S., Wang, S., & Lai, K. K. (2014). GBOM-oriented management of production disruption risk and optimization of supply chain construction. *Expert Systems with Applications, 41*(1), 59-68.
Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., & Shankar, R. (2008). *Designing and managing the supply chain: Concepts, strategies and case studies*. Tata McGraw-Hill Education.
Smith, S. A. (2012). *A network planning process and inventory strategy for high-mix low-volume markets* (Doctoral dissertation, Massachusetts Institute of Technology)..
Solo, C. J. (2009). *Multi-objective, integrated supply chain design and operation under uncertainty*. The Pennsylvania State University.
Teuscher, P., Grüninger, B., & Ferdinand, N. (2006). Risk management in sustainable supply chain management (SSCM): Lessons learnt from the case of GMO-free soybeans. *Corporate Social Responsibility and Environmental Management, 13*(1), 1-10.
Torres-Ruiz, A., & Ravindran, A. R. (2019). Use of interval data envelopment analysis, goal programming and dynamic eco-efficiency assessment for sustainable supplier management. Computers & Industrial Engineering, 131, 211-226.
Valinejad, F., & Rahmani, D. (2018). Sustainability risk management in the supply chain of telecommunication companies: A case study. *Journal of Cleaner Production, 203,* 53-67.
Vandchali, H. R., Cahoon, S., & Chen, S.-L. (2021). The impact of supply chain network structure on relationship management strategies: An empirical investigation of sustainability practices in retailers. *Sustainable Production and Consumption, 28*, 281-299.
Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of Business Logistics*, *29*(1), 307-325.
Waters, D. (2011). *Supply chain risk management: Vulnerability and resilience in logistics*. Kogan Page Publishers.
Wide, P. (2020). Improving decisions support for operational disruption management in freight transport. *Research in Transportation Business & Management, 37*, 100540.
Xu, S., Zhang, X., Feng, L., & Yang, W. (2020). Disruption risks in supply chain management: A literature review based on bibliometric analysis. *International Journal of Production Research, 58*(11), 3508-3526.
Yang, T. (2006). Multi objective optimization models for managing supply risk in supply chains.
Yu, M.-C., & Goh, M. (2014). A multi-objective approach to supply chain visibility and risk. *European Journal of Operational Research*, *233*(1), 125-130.
Zhao, K., Kumar, A., Harrison, T. P., & Yen, J. (2011). Analyzing the resilience of complex supply network topologies against random and targeted disruptions. *IEEE Systems Journal*, *5*(1), 28-39.