PARTNER SELECTION FOR MULTI ECHELON DEFECTIVE SUPPLY CHAIN NETWORK USING PARTICLE SWARM OPTIMIZATION

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Abstract

In the era of borderless international marketing and e-commerce, selecting the appropriate partners is a precondition for success. This paper focuses on facilitating the partner selection process through the application of Particle Swarm Optimization (PSO) Algorithm. It also aims to resolve the problems of defective supply-chain, considering the uncertainties involved in real life. The uncertainties may occur in the production system as well as in transportation time, machine hour, the distance between the partners of different echelon etc. At first, we study these stochastic data and determine their parameters. Once the characteristics are determined, they are converted in a generalized form to be included into a model formulated for solving the defective supply chain. In the era of borderless international marketing and e-commerce, selecting the appropriate partners is a precondition for success. This paper focuses on facilitating the partner selection process through the application of Particle Swarm Optimization (PSO) Algorithm. It also aims to resolve the problems of defective supply-chain, considering the uncertainties involved in real life. The uncertainties may occur in the production system as well as in transportation time, machine hour, the distance between the partners of different echelons etc. At first, we study these stochastic data and determine their parameters. Once the characteristics are determined, they are converted in a generalized form to be included into a model formulated for solving the defective supply chain.

Keywords
Particle Swarm Optimization, defective supply-chain, uncertainty, transportation time

1. Introduction

Supply chain management encompasses such a wide range of functions that it can seem overwhelming, even to the most experienced business organization. However, the process can be effectively modeled by breaking it down into several main strategic areas. One common and very effective model is the Supply Chain Operations Reference (SCOR) model, developed by the Supply Chain Council to enable managers to address, improve and communicate supply chain management practices effectively (Huan, Sheoran, and Wang, 2004). The SCOR model runs through supply chain stages. Companies must weigh the benefits and disadvantages of different options presented by international supply chains.

This aspect of supply chain management involves organizing the procurement of raw materials and components. Procurement is the acquisition of goods and services at the best possible price, in the right quantity and at the right time. When sources have been selected and vetted, companies must negotiate contracts and schedule deliveries. Supplier performance must be assessed and payments to the suppliers made when appropriate. In some cases,

companies will be working with a network of suppliers. This will involve working with this network, managing inventory and company assets and ensuring that export and import requirements are met.
This stage is concerned with scheduling of production activities, testing of products, packing and release. Companies must also manage rules for performance, data that must be stored, facilities and regulatory compliance.
The delivery stage encompasses all the steps from processing customer inquiries to selecting distribution strategies and transportation options. Companies must also manage warehousing and inventory or pay for a service provider to manage these tasks for them. The delivery stage includes any trial period or warranty period, customers or retail sites must be invoiced and payments received, and companies must manage import and export requirements for the finished product

Return is associated with managing all returns of defective products, including identifying the product condition, authorizing returns, scheduling product shipments, replacing defective products and providing refunds. Returns also include "end-of-life" products (those that are at the end of their product lifetime and a vendor will no longer be marketing, selling, or promoting a particular product and may also be limiting or ending support for the product).
Supply chain system is an integrated production system of a product. This system is often assumed to be an equilibrium structure, but in the real production process, some members of different stages such as planning, making, delivering in this system usually cannot effectively complete their production task because of the losses of production, which will reduce the performance of the whole supply chain production system. This supply chain with the losses of production is called the defective supply chain (DSC) system. A defective supply chain is incapable of producing the desired output as it suffers from a proper combination of members in different echelon.

2. Literature Review

Supply chain management has become an important strategic process for the coordination of supply chain networks that increase a company‘s competitiveness in the current business environment (Vrijhoef and Koskela, 2000; Zhao, Qu and Liu, 2008; Zhao, Liu, and Qu, 2009) . Sadjady and Davoudpour (2012) stated that designing distribution networks – as one of the most important strategic issues in supply chain management – has become the focus of research attention in recent years and Das and Chowdhury (2012) pointed out consideration of reverse logistics as a significant part of overall business process has been gaining importance across the entire global market. Dowlatshahi (2000) also pointed out that reverse logistics is an important concept for logistics and supply chain management and that efficient reverse logistics management can increase the competitiveness of an enterprise and prevent expulsion from the market, especially when facing intense competition and low-profit margins.

Shih (2001) suggested that the reverse logistics system is an essential part of business operations when the recovery rates and service coverage are broadened, in the future. Desai and Mital (2003) suggested that enterprises should work on the reuse, reworking, recycling, and re-utilization of products at the end of the product lifecycle. Hu et al. (2002) stated that reverse logistics involves the complex logistics of management procedures, which includes planning, management and control of the discarded logistics generated by rework and the disposal of discarded products.

Imree et al. (2003) proposed that reverse logistics involves the recycling of materials that could be reused in the market. If reverse logistics is economically viable, it could protect the environment and reduce resources waste, which might provide a new use for recycled products. According to one conservative estimate, reverse logistics may account for 4% of total logistical costs (Rogers and Tibben-Lembke, 2001). According to Daugherty‘s study, the average reverse logistics may account for 9.49% of total logistical costs (Daugherty, Autry, and Ellinger, 2001). Therefore, reverse logistics may become critical to the success of many enterprises. Gen and Cheng (2000) pointed out that a multi-stage logistic problem with the capacitated location-allocation problem is an NP-hard problem. Russell and Krajewski (1991) stated that solving a quantity discount function with mixed integer formulation is very time-consuming to be solved.

In this study, the development of an optimization mathematical model was emphasized by integrating cost and time criteria for in multi-echelon unbalanced supply chain planning. Multiple products, production loss, transportation loss, quantity discount, production capacity, and starting-operation quantity has been simultaneously taken into consideration. Thus, the supply chain planning problem discussed in this study is even more difficult.

3. Model Formulation

This section proposes an optimization mathematical model which integrates cost and time criteria for multi-echelon unbalanced supply chain planning. The model also considers the uncertainties involved in order processing.

3.1 Assumptions and notations

The assumptions for partner selection and production distribution planning are as follows:
1) The customer demand of each product is known.
2) Production–distribution planning is conducted based on the production capacity and starting-operation quantity. The production and shipping information for each partner and route are already known.
3) Production cost, as well as transportation cost of the partners, are considered.

The notations used in the optimization mathematical model are listed as follows:
e: supply chain echelon
E: number of supply chain echelon
SE: set of supply chain echelon, {1,. . .,E}
p^e: partner in echelon e
P^e: number of partner in echelon e
SPe: set of partner in echelon e,{1,. . .,}
t: product type
T: number of product types
ST: set of product type,{1,. . .,T}
$UPo\_C^t p^e$: unit cost of product t of partner p^e
$UTra\_C^t p^e$: unit transportation cost of product t of partner p^e
$Tra\ Q^t p^e.\acute{p}^{e+1}$: quantity of product t transported from partner p^e to $\acute{p}^{e+1}$
$Po\ CPp^e$: production capacity of partner p^e
SO_Qp^e : starting-operation quantity of partner p^e
Po_LRp^e : production loss rate of partner p^e
$Mar\ D^t p^e$: market demand quantity of product t of partner p^e
α: elasticity factor for the partner of echelon

3.2 Objective function for fulfillment of customer demand:

The evaluation criteria of this model include only cost and the objective function Z is to be minimized.

Minimize Z (cost) = Production Cost+ Transportation Cost
$=\sum_{t\in ST}\sum_{e\in SE}\sum_{P^e\in SP^e}(UPo\_C^t p^e + UTra\_C^t p^e).\mathrm{Tra\_Q}^t\, p^e.\acute{p}^{e+1}$

Subjected to:
Fulfillment of the customer demands
$\sum_{p\in SP^e}(Tra_{Q^t p^e}.\acute{p}^{e+1})^{\alpha}(1-Po\_LRp^e)= Mar\ D^t\acute{p}^{e+1}$
e=E−1, $\acute{p}^e \in SP^e$,t∈ ST

Flow equilibrium

$$\sum_{p\in SP^e}(Tra_{Q^t p^e}.\acute{p}^{e+1})^{\alpha}(1-Po\_LRp^e) = \sum_{p\prime\prime\in SP^e} Tra\_Q^t p^e.\acute{p}'^{e+2}$$

e=1,2,3,………….. E−2 , $\acute{p}^e \in SP^e$

Fulfillment of the starting-operation quantity and the production capacity for each partner,
$SO\_Qp^e \le \sum_{t\in SP}\sum_{p\in SP^e} Tra\_Q^t p^e.\acute{p}^{e+1} \le Po\_CPp^e$
e = 1, . . . , E ; $\acute{p}^e \in SP^e$
Non-negative for transportation quantity

$$Tra_{Q^t p^e}.\acute{p}^{e+1} \ge 0 \ and \ \in integer\ , e \in SE\ and\ \acute{p}^e \in SP^e, t \in ST$$

3.3 Objective function for order reprocessing:
The evaluation criteria of this model also include only cost and the objective function Z is to be minimized.

Minimize Z (cost) = Production Cost
$=\sum_{t\in ST}\sum_{e\in E-1,E-2}\sum_{P^e\in SP^e} \text{Tra\_Qt}\, p'^{e+1}.\, p^e$

Subjected to:

Fulfillment of the customer demands

$\sum_{p\in SP^e} Ro\_Tra\_Q^t p'^{e+1}.\, p^e(1 - Po\_LRp'^{e+1}) = Ro\_rate * Mar\ D^t \acute{p}^{e+1}$

e=E−1, $\acute{p}^e \in SP^e$,$t\in ST$

Flow equilibrium

$$\sum_{p\in SP^e} Ro\_Tra\_Q^t p'^{e+2}.\, p^{e+1}(1 - Po\_LRp'^{e+2}) = \sum_{p'\in SP^e} Ro\_Tra\_Q^t p'^{e+1}.\, p^e$$

e=E−2,E−3 , $\acute{p}^e \in SP^e$

Fulfillment of the starting-operation quantity and the production capacity for each partner for order reprocessing,

$Ro\_SO\_Qp^e \le \sum_{t\in SP}\sum_{p\in SP^e} Ro\_Tra\_\, Q^t p^e.\, \acute{p}^{e+1} \le Ro\_Po\_CPp^e$

e = 1, . . . , E ; $\acute{p}^e \in SP^e$

Non-negative for transportation quantity

$$Ro\_Tra_{Q^t p^e}.\, \acute{p}^{e+1} \ge 0 \text{ and } \in integer\,, e \in SE \text{ and } \acute{p}^e \in SP^e, t \in ST$$

4. Case Study

Nowadays users are being very conscious about the quality of the product so quality assurance is getting more important day by day. Companies sometimes also have to deal with the backward flow of product as a result of return the of the delivered product. This results in additional cost in the supply chain. So while designing an effective supply chain this is also to be considered during partner selections in different stages of supply chain. For the validation of the proposed model, the supply chain of a ceramic manufacturing company was taken into consideration.

While studying the supply chain of the ceramic manufacturing company effective partner selection that will fulfill the customer demand as well as can deal with the order re-processing were kept in mind. For simplification of the model only four suppliers for all of the ingredients are considered. There are three separate manufacturing plants to produce the finished goods. To deal with the vast competitive market they have five distributors and six retailers throughout the country.

They have a daily demand of 4.5 metric ton for Porcelain products 2.5 metric ton for Bone ceramics. So in total, they are to produce a minimum of 7 metric ton products. To deal with this market demand they need an effective supply chain model to minimize the supply chain surplus. As their business is mainly import oriented the face a backward flow of 5% on an average due to some quality issues or problems during the production phase. For this reason, order reprocessing is crucial for them.

For the ceramic manufacturing company, the model can be written as followed:
Fulfillment of Customer Demand:

Minimize: $UPo_{s1}*S_1 + UPo_{s2}*S_2 + UPo_{s3}*S_3 + UPo_{s4}*S_4 + UPo_{m1}*M_1 + UPo_{m2}*M_2 + UPo_{m3}*M_3$

$+ UPo_{d1}*D_1+ UPo_{d2}*D_2+ UPo_{d3}*D_3+ UPo_{d4}*D_4+ UPo_{d5}*D_5 + UPo_{r1}*R_1+ UPo_{r2}*R_2+ UPo_{r3}*R_3+ UPo_{r4}*R_4+ UPo_{r5}*R_5+ UPo_{r6}*R_6$

Subjected to:

Fulfillment of the customer demands

$Po\_L_{r1}*R_1+ Po\_L_{r2}*R_2+ Po\_L_{r3}*R_3+ Po\_L_{r4}*R_4+ Po\_L_{r5}*R_5+ Po\_L_{r6}*R_6=Mar\_D$

Flow equilibrium

$Po\_L_{d1}*D_1+ Po\_L_{d2}*D_2+ Po\_L_{d3}*D_3+ Po\_L_{d4}*D_4+ Po\_L_{d5}*D_5=R_1+ R_2+ R_3+ R_4+ R_5+ R_6$

$Po\_L_{m1}*M_1+ Po\_L_{m2}*M_2+ Po\_L_{m3}*M_3=D_1+D_2+D_3+D_4+D_5$

$Po\_L_{r1}*S_1+ Po\_L_{r1}*S_2+ Po\_L_{r1}*S_3+ Po\_L_{r1}S_4=M_1+M_2+M_3$

Fulfillment of the starting-operation quantity and the production capacity for each partner,

$SO_{s1} \leq S_1 \leq Po_{s1}$

$SO_{s2} \leq S_2 \leq Po_{s2}$

$SO_{s3} \leq S_3 \leq Po_{s3}$

$SO_{s4} \leq S_4 \leq Po_{s4}$

$SO_{m1} \leq M_1 \leq Po_{m1}$

$SO_{m2} \leq M_2 \leq Po_{m2}$

$SO_{m3} \leq M_3 \leq Po_{m3}$

$SO_{d1} \leq D_1 \leq Po_{d1}$

$SO_{d2} \leq D_2 \leq Po_{d2}$

$SO_{d3} \leq D_3 \leq Po_{d3}$

$SO_{d4} \leq D_4 \leq Po_{d4}$

$SO_{d5} \leq D_5 \leq Po_{d5}$

$SO_{r1} \leq R_1 \leq Po_{r1}$

$SO_{r2} \leq R_2 \leq Po_{r2}$

$SO_{r3} \leq R_3 \leq Po_{r3}$

$SO_{r4} \leq R_4 \leq Po_{r4}$

$SO_{r5} \leq R_5 \leq Po_{r5}$

$SO_{r6} \leq R_6 \leq Po_{r6}$

Where,

$S_1;S_2;S_3;S_4$:Units transported from different suppliers

$M_1;M_2;M_3$:Units transported from different manufacturer

$D_1;D_2;D_3$; $D_4;D_5$:Units transported from different distributors

$R_1;R_2;R_3$; $R_4;R_5;R_6$: Units transported from different retailors

SO_x : Starting production capacity of the respected partner

Po_x : Production capacity of the respected partner

Order Reprocessing:

Minimize: $Ro\_UPo_{m1}*Ro\_M_1+ Ro\_UPo_{m2}* Ro\_M_2+ Ro\_UPo_{m3}* Ro\_M_3$
$+ Ro\_UPo_{d1}* Ro\_D_1+ Ro\_UPo_{d2}* Ro\_D_2+ Ro\_UPo_{d3}* Ro\_D_3$
$+ Ro\_UPo_{d4}* Ro\_D_4+ Ro\_UPo_{d5}* Ro\_D_5$

Subjected to:

$Ro\_Po\_L_{d1}* Ro\_D_1+ Ro\_Po\_L_{d2}* Ro\_D_2+ Ro\_Po\_L_{d3}* Ro\_D_3+ Ro\_Po\_L_{d4}* Ro\_D_4 + Ro\_Po\_L_{d5}* Ro\_D_5=0.05*Mar\_D$

$Ro\_Po\_L_{m1}* Ro\_M_1+ Ro\_Po\_L_{m2}* Ro\_M_2+ Ro\_Po\_L_{m3}* Ro\_M_3= Ro\_D_1+ Ro\_D_2+ Ro\_D_3 + Ro\_D_4+ Ro\_D_5$

Fulfillment of the starting-operation quantity and the production capacity for each partner for order reprocessing,

$Ro\_SO_{m1} \leq Ro\_M_1 \leq Ro\_Po_{m1}$

$Ro\_SO_{m2} \leq Ro\_M_2 \leq Ro\_Po_{m2}$

$Ro\_SO_{m3} \leq Ro\_M_3 \leq Ro\_Po_{m3}$

$Ro\_SO_{d1} \leq Ro\_D_1 \leq Ro\_Po_{d1}$

$Ro\_SO_{d2} \leq Ro\_D_2 \leq Ro\_Po_{d2}$

$Ro\_SO_{d3} \leq Ro\_D_3 \leq Ro\_\ Po_{d3}$

$Ro\_SO_{d4} \leq Ro\_D_4 \leq Ro\_Po_{d4}$

$Ro\_SO_{d5} \leq Ro\_D_5 \leq Ro\_Po_{d5}$

Where,

$Ro\_M_1; Ro\_M_2 ; Ro\_M_3$:Units transported from different manufacturer

$Ro\_D_1; Ro\_D_2 ; Ro\_D_3 ; Ro\_\ D_4; Ro\_D_5$:Units transported from different distributors

Ro_SO_x : Starting reprocessing capacity of the respected partner

Ro_Po_x : Reprocessing capacity of the respected partner

5. Result & Analysis

In this section, all the partner in the supply chain is considered active and it is determined the optimum quantity each member is to transfer through the supply chain. While determining the optimum quantity to be transferred from each partner to the next partners of the echelon some additional comparisons are also performed in fulfilling the customer demand.

After 100 iterations, the values of different decision variables are shown in the table 1 and the optimum value is shown in table 2.

Table 1. Best values of decision variables

Variable	Best Values
S1	150
S2	100
S3	200
S4	250
M1	200
M2	100
M3	300
D1	400
D2	250
D3	250
D4	200
D5	150
R1	1000
R2	200
R3	1500
R4	100
R5	200
R6	400

Table 2. Function value & time required to perform optimization

Best function value	2244360
Time for evaluation	1.2000163 sec

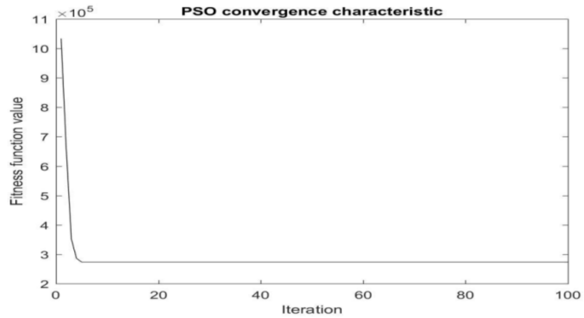

Figure 1: PSO converging graph for 100 iterations

In order to determine the most efficient partners of the supply chain, several combinations have been studied applying the PSO algorithm. Some of the combinations are given in Table 3.

Table 3: Determining the most efficient partners to fulfill customer needs

Variables	Combination 1	Combination 2	Combination 3	Combination 4
S_1	150	0	150	0
S_2	100	100	0	100
S_3	0	0	250	250
S_4	0	200	0	0
M_1	4000	4000	4000	4000
M_2	5000	0	5000	5000
M_3	0	400	0	0
D_1	0	0	250	200
D_2	200	200	0	0
D_3	250	0	250	0
D_4	0	150	0	0
D_5	150	0	150	150
R_1	275	1000	275	0
R_2	2000	0	2000	200
R_3	0	300	0	2000
R_4	2500	100	2500	2500
R_5	200	0	0	0
R_6	0	3500	400	0
Best Function value	414360	192360	2052360	2022360

After examining all the combinations it can be said that the combination 2 provides the minimum function value which corresponds to the minimum production cost. In figure 2, the red colored ones are the selected partners in the supply chain. The convergence of the function using PSO is shown in figure 3-6.

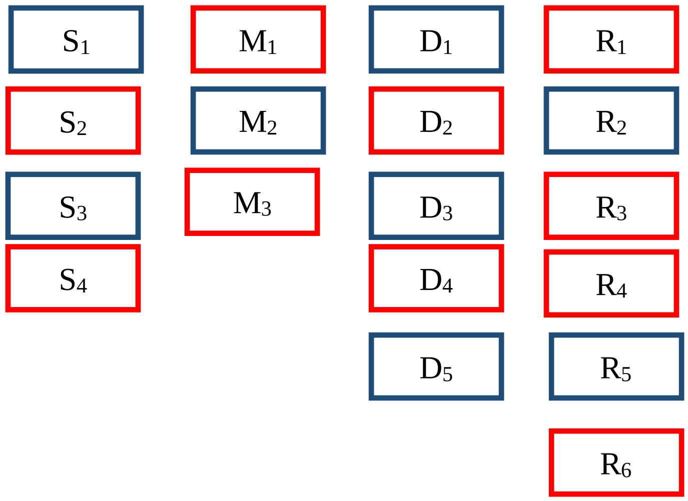

Figure 2. The selected partners and suppliers for the optimized supply chain

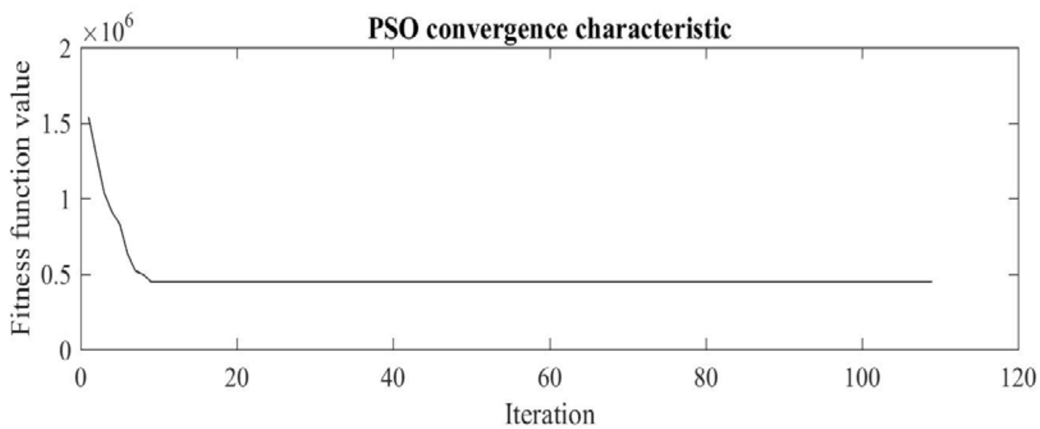

Figure 3. PSO convergence curve for combination 1 (forward flow)

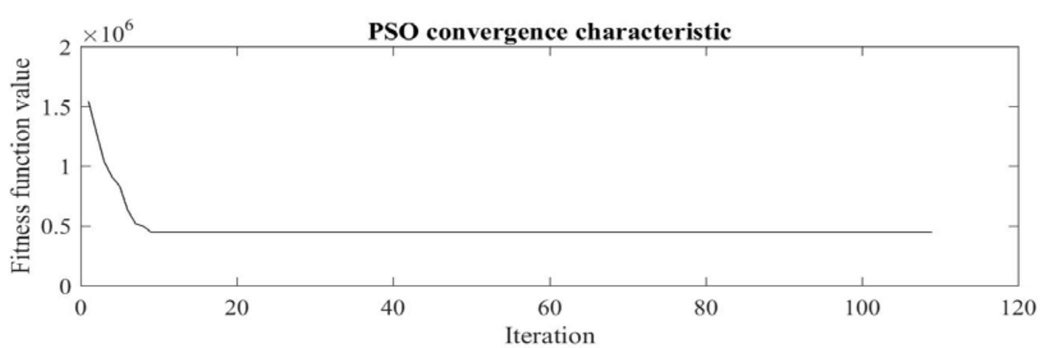

Figure 4. PSO convergence curve for combination 2 (forward flow)

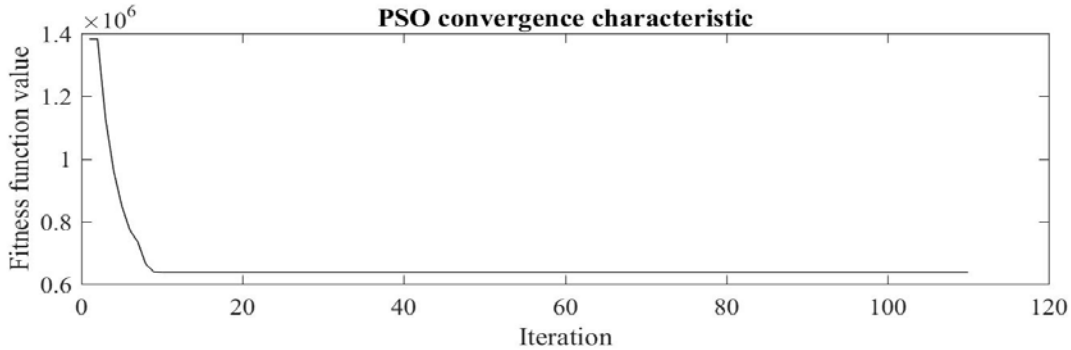

Figure 5. PSO convergence curve for combination 3 (forward flow)

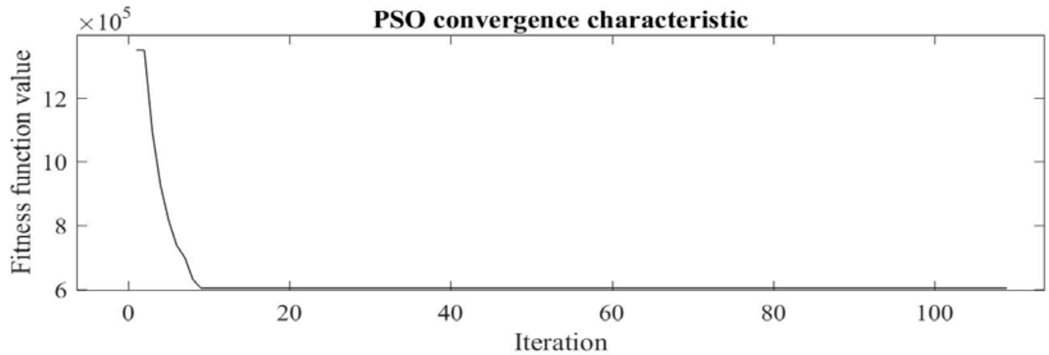

Figure 6. PSO convergence curve for combination 4 (forward flow)

6.3 Order Reprocessing

To determine the efficient partners for backward flow in the supply chain some partner combination has been studied. The results are given below:

Table 4 : Determining the most efficient partners in the backward flow of supply chain

Variables	Values for combination 1	Values for combination 2	Values for combination 3
Ro_M_1	100	0	0
Ro_M_2	0	150	100
Ro_M_3	0	0	0
Ro_D_1	0	180	180
Ro_D_2	100	0	0
Ro_D_3	0	0	50
Ro_D_4	0	250	0
Ro_D_5	300	0	0
Best Function value	98360	438360	1360

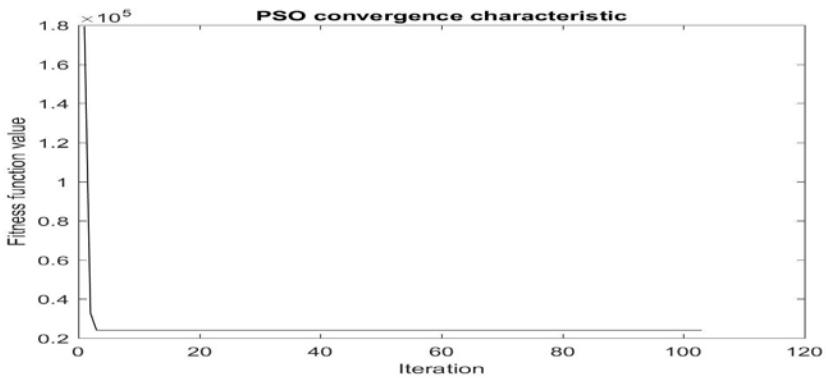

Figure 7. PSO convergence curve for combination 1 (backward flow)

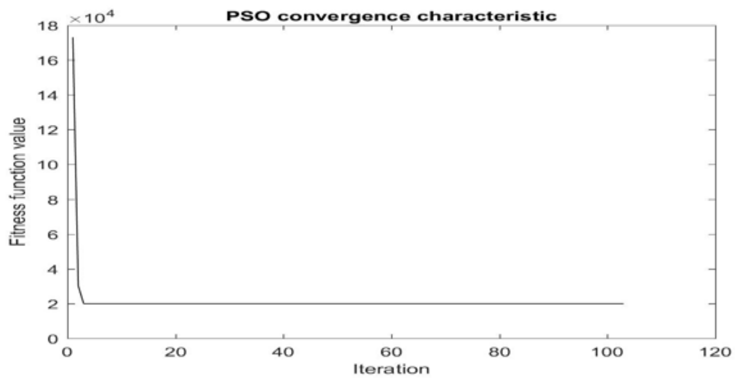

Figure 8. PSO convergence curve for combination 2 (backward flow)

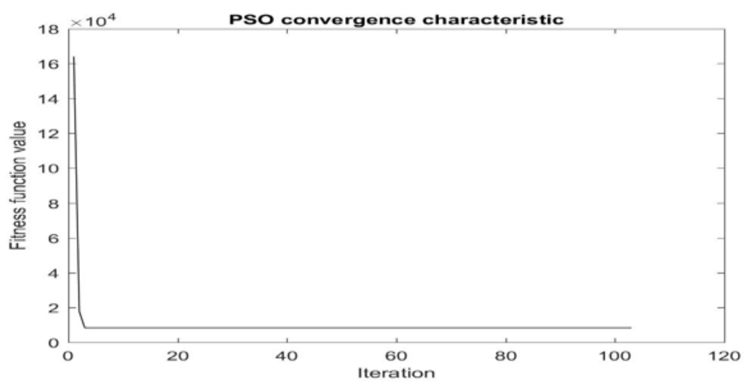

Figure 9. PSO convergence curve for combination 3 (backward flow)

6. Conclusion:

Usually, particle swarm optimization is used for non-linear problems but despite this supply chain disruption problem being a linear problem PSO or other Metaheuristic algorithms can be used. Because the target is to maximize the supply chain surplus by choosing appropriate partners both in the forward and backward flow of the supply chain. This model helps to generate the proper supply chain network considering various real-life situations. From the results, it is evident that any supply chain can run successfully by selecting the proper partners in different echelon for different circumstances. This model can further be modified by incorporating several considerations like a quantity discount, transportation ease, time limit considerations and so on.

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