CHAPTER 5

MULTI OBJECTIVE OPTIMIZATION OF
MULTI-ECHelon SUPPLY CHAIN
NETWORK ARCHITECTURES

5.1 INTRODUCTION

A single objective mathematical programming models are commonly used in many managerial and operational decision making processes. Although single objective decision models are sufficient for some decision making processes, but there are many situations, where the decisions depend upon multiple objectives. An important issue in real world supply chain management problem is how to measure the performance of a supply chain for a given set of decision variables, when involving several incommensurable and competing objectives. No matter how appropriate the methodology, if the performance measure is poor, the results could be misleading or false.

It is comprehensible that there are many independent entities in a supply chain, each of them try to maximize their own inherent objective functions (or interests) in business transactions. Many of their interests will be conflicting. Thus, a specific scenario giving an optimal design configuration using traditional approaches could actually be a non-optimal design of the supply chain, when we look at the design from a systems optimization perspective. When conflicting interests occur in a problem, modeling the system using traditional optimization techniques does not commensurate
intuitively with a robust formulation. The results could also be misleading in the very likely situation of a dynamic environment.

As reported in the literature, the genetic algorithm and evolutionary strategies are applied to two objectives minimization problems without constraint or with few constraints (see: Horn et al 1994, Murata et al 1996 and Zitzler and Thiele 1999). Most researchers did not attempt to solve real world supply chain management problems consisting of many constraints and mix of both minimization and maximization objective functions.

In this chapter, we have considered three stage and four stage multi echelon supply chain network problems for the study. Each supply chain network problem is attempted with different sets of conflicting objectives with outstanding new intelligent NLIW-PSO algorithm as solution methodology. It is noted that NLIW-PSO is out performed with respect to other PSO algorithm used for solving three echelon supply chain network problems in the chapter 3.

5.2 MULTI OBJECTIVE PROBLEM FORMULATION FOR THREE STAGE MULTI ECHELON SUPPLY CHAIN NETWORK

This section, specifically deals with the modeling of multi objective optimization of a three-stage supply chain network using the Non-linear inertia weight particle swarm optimization (NLIW-PSO) algorithm with weighted sum approach. The same model assumptions and parameters used in the three echelon SCN are considered in the mathematical formulation of three stage multi-objective SCN.
5.2.1 The mathematical formulation of multi-objective three stage multi echelon supply chain architecture

This study considers the same assumptions, model parameters and the mathematical model of the three stage multi echelon supply chain network architecture (equations 3.1 to 3.4 and constraints equations 3.7 to 3.10 of chapter 3) to quantify the relationship among all the decision variables involved in supply chain network. Two sets of conflicting objectives, the total supply chain operating Cost (TSCC) and ratio of Total Manufacturing Cost (TMC) to Total Supply Chain operating Cost (TSCC) are considered as the performance indicators. The problem of optimizing the supply chain configuration can be summarized in the following mathematical model.

5.2.2 Objective Functions

Set 1:

Objective Function 1: Minimize TSCC

\[
TSCC = \left[ \sum_c \sum_v \sum_p (CS_{c,v} \times X_{c,v,p}) \right] + \\
\left[ \sum_p \left( \sum_d (MC_p \times Y_{p,d}) \right) + \sum_p \left( \sum_c (IC_p \times IC_{c,p}) \right) \right] + \\
\left[ \sum_c \sum_v \sum_p (X_{c,v,p} \times STC_{c,v,p}) + \sum_p \sum_d (Y_{p,d} \times PTC_{p,d}) \right]
\]

(5.1)
Objective Function 2: Minimize \( \frac{TMC}{TSCC} \)

\[
\frac{TMC}{TSCC} = \left[ \sum_p \{ (MC_p) \times (\sum_d Y_{p,d}) \} + \sum_p \{ (IC_p) \times (\sum_c I_{c,p}) \} \right] / \left[ \sum_c \sum_v \sum_p (CS_{c,v} \times X_{c,v,p}) \right] + \left[ \sum_p \{ (MC_p) \times (\sum_d Y_{p,d}) \} + \sum_p \{ (IC_p) \times (\sum_c I_{c,p}) \} \right] / \left[ \sum_c \sum_v \sum_p (X_{c,v,p} \times STC_{c,v,p}) + \sum_p \sum_d (Y_{p,d} \times PTC_{p,d}) \right]
\]

(5.2)

A justification for using these objective functions is as follows. Minimizing the total operating cost is an important performance metric in supply chain management problems. The second objective function denotes minimizing the ratio of manufacturing costs to total operating cost.

As can clearly be seen from Set 1, the two objective functions are conflicting because total supply chain operating cost features in the denominator in the second objective. The analysis will highlight the trade-off between the objectives. We would like to ensure that our manufacturing costs fall within a certain permissible bound as a percentage of the total operating cost. The decision maker based on his/her knowledge and expertise would be able to make an intelligible decision in choosing a solution.

5.2.2.1 Fitness mapping of multi-response objective functions.

In our multi-objective supply chain network analysis following set of objectives have been considered for the analysis.
a. Objective Function 1: Minimize TSCC

b. Objective Function 2: Minimize TMC/TSCC

But both objective functions are in different units i.e. Objective 1 is in Rupees and other objective 2 is a unit less quantity i.e. in Ratio. Hence the mapping of objectives is done to bring it to the same units as follows.

Step 1: Mapping Objective functions into fitness

a. \( \text{Min } \text{fit}_1 = \frac{TSCC}{TSCC_{\text{Max}}} \) \hspace{1cm} (5.3)

b. \( \text{Min } \text{fit}_2 = \frac{(TMC/TSCC)}{(TMC/TSCC)_{\text{Max}}} \) \hspace{1cm} (5.4)

where, \( TSCC_{\text{Max}} \) and \( (TMC/TSCC)_{\text{Max}} \) have to be selected based on the problem in hand

Step 2: The overall Overall objective function is to be Minimized and can be written as:

\[
\text{Min Over All Obj} = (w_1 \times \text{fit}_1 + w_2 \times \text{fit}_2) + R_m \times (\text{Constraints}) \hspace{1cm} (5.5)
\]

where \( w_1 \) and \( w_2 \) has to be selected such way that the \( w_1 + w_2 = 1 \).

The values of \( w_1 \) and \( w_2 \) give importance to a particular objective. (For examples, \( w_1 = w_2 = 0.5 \) gives equal importance to both objectives) and \( R_m \) is the penalty parameter used in analysis (detailed explanation is given in chapter 1).
5.3 **MULTI OBJECTIVE PROBLEM FORMULATION FOR FOUR STAGE MULTI ECHELON SUPPLY CHAIN NETWORK**

This section briefly describes the objective of the research problem, the model assumptions, the mathematical formulation. The problem description of the four stage multi echelon supply chain network model is same as discussed in the chapter 4. In this model, we are considering some additional assumptions and additional modeling parameters for the multi objective analysis so as to make the supply chain network complex to match with the real world applications.

**5.3.1 Objective of study**

This chapter specifically deals with the modeling and multi objective optimization of a four-stage supply chain using the Non-linear inertia weight particle swarm optimization (NLIW-PSO) with penalty function approach. Total Supply Chain operating Cost (TSCC) and Gross Margin Return On Investment (GMROI) of the supply chain network are considered as performance indicators.

**5.3.2 Model assumptions**

- Problem is strategic or snap shot pull based problem
- A product is made up of three components
- A single product flows through the supply chain network
- Distribution centers face average monthly customer demand.
- Quantity of goods at every installation takes integer values
- Linear installation holding cost rates exists only for manufacturing plants and warehouses in the supply chain
• Fixed costs for plants and warehouses are considered
• Inventory ordering and inventory holding cost are considered.
• There is no shortage cost (as shortages are not permitted)
• Average cycle inventory and Safety stocks maintained at warehouses only and is calculated on the basis of average lead time of a warehouse to supply goods to distribution centers
• Transportation costs are directly proportional to the quantity shipped
• Manufacturing costs are directly proportional to the quantity of products produced
• All installations have finite capacity

5.3.3 The mathematical model of four stage multi echelon supply chain architecture

This sub section develops a mathematical model to quantify the relationship among all the decision variables involved in supply chain network. The problem of optimizing the supply chain configuration can be summarized in the following mathematical model. The notations used in the formulation of mathematical model are shown below:
| Notations | Description |
|-----------|-------------|
| C         | Number of Components |
| V         | Number of Vendors |
| P         | Number of Plants |
| W         | Number of warehouses |
| D         | Number of Distribution Centers |
| C_p       | Average cost of product |
| L_c,v     | Capacity of vendor ‘v’ for component ‘c’ |
| CS_c,v    | Cost of making a component ‘c’ by vendor ‘v’ |
| STC_c,v,p | Transportation cost of a component ‘c’ from vendor ‘v’ to plant ‘p’/unit |
| U_p       | Capacity of plant ‘p’ |
| FC_p      | Fixed cost of plant ‘p’ per period |
| MC_p      | Manufacturing cost of plant ‘p’/unit |
| PTC_p,w   | Plant transportation cost from plant ‘p’ to Warehouse ‘w’ |
| I_c,p     | Inventory of component ‘c’ at plant ‘p’ |
| IC_p      | Inventory cost at plant ‘p’/unit/period |
| V_w       | Capacity of warehouse ‘w’ |
| FC_w      | Fixed cost of warehouse ‘w’ per period |
| EOQ_w     | Economic order quantity at warehouse ‘w’ |
| SL_w      | Required Service Level at warehouse ‘w’ |
| σ_w       | Standard deviation at warehouse ‘w’ |
| LT_w      | Average lead time of warehouse ‘w’ |
| Io_w      | Average Inventory ordering cost at warehouse ‘w’ |
| IC_w      | Inventory cost at Warehouse ‘w’/unit/period |
| I_w       | Inventory of products ‘Iw’ at Warehouse ‘w’ |
| WTC_w,d   | Warehouse transportation cost from warehouse ‘w’ to distributor ‘d’ |
| D_w       | Demand at Warehouse ‘w’ |
| D_d       | Demand at distributor center ‘d’ |
| SP_d      | Selling price at distributor center ‘d’/unit |
| X_c,v,p   | Amount of component shipped ‘c’ from vendor ‘v’ to plant ‘p’ |
| Y_p,w     | Amount of product shipped from plant ‘p’ to warehouse ‘w’ |
| Z_w,d     | Amount of product shipped from warehouse ‘w’ to distributor center ‘d’ |
| TSCC      | Total Supply Chain operating Cost |
| GMROI     | Gross Margin Return On Investment |
5.3.3.1 Mathematical formulation of Four stage multi echelon Supply Chain network

Supply chain cost components

1. Total Supplier Materials Cost

\[ TSMC = \sum_c \sum_v \sum_p (C \times S_{c,v} \times X_{c,v,p}) \]  \hspace{1cm} (5.6)

2. Total Transportation Cost

\[ TTC = \sum_c \sum_v \sum_p (X_{c,v,p} \times STC_{c,v,p}) + \sum_p \sum_w Y_{p,w} \times PTC_{p,w} \]  \hspace{1cm} (5.7)

3. Total Manufacturing cost

\[ TMC = \sum_p \{ FC_p + (MC_p) \times (\sum_w Y_{p,w}) \} + \sum_p \{ IC_p \times \sum_c I_{c,p} \} \]  \hspace{1cm} (5.8)

4. Total Warehouse Cost

\[ TWc = \sum_w \sum_d (Z_{w,d} \times WTC_{w,d}) + \sum_w FC_w \]  \hspace{1cm} (5.9)

5. Total safety stock carrying cost

\[ TSS = \sum_w (SL_w \times \sigma_w \times \sqrt{LT_w} \times C_p \times I_w) \]  \hspace{1cm} (5.10)
6. Economic order quantity

\[ EOQ = \sum_{w} \left( \sqrt{\frac{2*D_w * I_o_w}{IC_w * C_p}} \right) \]  

(5.11)

7. Total cycle inventory carrying cost

\[ TICC = \frac{\left( \sum_{w} \left( \frac{EOQ_w}{2} \right) \right) \times C_p \times IC_w}{12} \]  

(5.12)

8. Total ordering cost

\[ TOC = \frac{\left( \sum_{w} \left( \frac{D_w}{EOQ_w} \right) \times I_o_w \right)}{12} \]  

(5.13)

9. Average Inventory

\[ AVGINV = \sum_{w} \left( \frac{EOQ_w}{2} \right) \]  

(5.14)

10. Total Supply Chain operating Cost

\[ TSCC = TSMC + TTC + TWC + TOC + TSS + TICC \]  

(5.15)

11. Revenue

\[ REV = \sum_{d} \left( D_d \times SP_d \right) \]  

(5.16)
12. Profit

\[
PROF = \sum_d (D_d \times SP_d) - TSCC \tag{5.17}
\]

13. Gross margin return on investment

GMROI = GM / Average Inventory value

Gross Margin = Revenue - Total supply chain operating cost

Average inventory value = (cycle inventory + safety stock) * cost of product

\[
GMROI = \frac{PROFIT}{(TICC+TSS)} \tag{5.18}
\]

Subject to following supply chain constraints:

14. Vendor capacity constraint

\[
\sum_p X_{c,v,p} \leq L_{(c,v)} \quad \forall \ c,v \tag{5.19}
\]

15. Plant capacity constraint:

\[
\sum_p Y_{p,w} \leq U_p \quad \forall \ w \tag{5.20}
\]

16. Warehouse Capacity Constraint:

\[
\sum_w (Z_{w,d} + SS_w) \leq V_w \quad \forall \ d \tag{5.21}
\]
17. Demand Constraint
\[ \sum_{w} Z_{w,d} \geq D_{d} \quad \forall \ d \] (5.22)

18. Inventory Balancing Constraint at Plants
\[ \sum_{v} X_{c,v,p} \geq \sum_{w} Y_{p,w} \quad \forall \ c,p \] (5.23)

19. Inventory Balancing Constraint at warehouse
\[ \sum_{p} Y_{p,w} \geq \sum_{d} Z_{w,d} \quad \forall \ w \] (5.24)

All the decision variables should be integers and non negative.

5.3.3.2 Objective Functions

Set 1:

Objective Function 1: Minimize TSCC

Min \( TSCC = \left[ \sum_{c} \sum_{v} \sum_{p} (CS_{c,v} \times X_{c,v,p}) \right] + \left[ \sum_{c} \sum_{v} \sum_{p} (X_{c,v,p} \times STC_{c,v,p}) + \sum_{p} \sum_{w} Y_{p,w} \times PTC_{p,w} \right] + \left[ \sum_{p} (FC_{p} + (MC_{p} \times (\sum_{w} Y_{p,w})) + (\sum_{p} (IC_{p} \times \sum_{c} I_{c,p})) \right] + \left[ \sum_{w} FC_{w} \right] + \sum_{w} \sum_{d} (Z_{w,d} \times WTC_{w,d}) + \left[ \sum_{w} (SL_{w} \times \sigma_{w} \times \sqrt{LT_{w}} \times C_{p} \times I_{w}) + \left[ \frac{(\sum_{w} (\frac{EOQ_{w}}{2}) \times C_{p} \times I_{w})}{12} \right] + \left[ \frac{(\sum_{w} (\frac{D_{w}}{EOQ_{w}}) \times I_{w})}{12} \right] \right] \] (5.25)
Typically, the objectives are to maximize revenue with minimal inventory while maximizing customer service. Multi-objective optimization problems are a major challenge in developing solution methodologies. Ideally, one would like to have a single performance measure that addresses all three of these issues. Unfortunately, traditionally used performance measures do not take into account all three. Gross Margin (GM) is a widely-used supply chain performance measure that takes into account the profitability of the company:

\[
GM = \text{Total Revenue (TR)} - \text{Cost}
\]

\[
= \text{TR} - (\text{Number of units purchased } \times \text{Whole cost/unit}).
\]

GM is a measure of revenue only. It neither takes into account the cost of carrying inventory and nor relates to the chain’s customer service level. In an effort to improve GM, Gross Margin Return on Investment (GMROI) adjusts GM for the average inventory held over the period and is an effective measure that takes into account the money earned and inventory held as calculated in the following formula:
GMROI = \frac{GM}{\text{Average Inventory Cost}}

It can be interpreted as the margin earned per Rupee or dollar invested in inventory. It is one of the measures that is used to evaluate the effectiveness of solution alternatives in the current decision support system. Lost sales are more important than the in-stock %. Minimizing the lost sales directly relates to maximizing customer service, while being out of stock for a SKU (Stock Keeping Unit) does not necessarily decrease customer service level in a particular period if there was no demand for that SKU during that period.

5.3.3.3 Fitness mapping of multi-response objective functions

The two objectives considered are,

- TSCC – which is to be minimized
- GMROI – which is to be maximized

But both objective functions are in different units i.e. one in Rupees and another is in Ratio. Hence the mapping of objectives is done to bring the objectives to the same units as follows.

Step -1 : Mapping Objective functions into fitness

\[
\text{Min } \text{fit}_1 = \frac{TSCC}{TSCC_{\text{MAX}}} \quad (5.27)
\]

\[
\text{Min } \text{fit}_2 = 1 - \frac{\text{GMROI}}{\text{GMROI}_{\text{MAX}}} \quad (5.28)
\]

where, TSCC_{\text{Min}} and GMROI_{\text{Max}} have to be selected based on the problem in hand.
Step 2: The multi – response weighted objective function of the defined problem can be expressed as

$$\text{Min Over All Obj} = (w_1 \times \text{fit}_1 + w_2 \times \text{fit}_2) + R_m \times (\text{Constraints}) \quad (5.29)$$

where  \( w_1 \) and \( w_2 \) has to be selected such way that the \( w_1 + w_2 = 1 \).

The values of \( w_1 \) and \( w_2 \) give importance to a particular objective (For examples, \( w_1 = w_2 = 0.5 \) gives equal importance to both objectives) and \( R_m \) is the penalty parameter used in analysis (detailed explanation is given in chapter 1).

### 5.4 MULTI OBJECTIVE OPTIMIZATION MULTI ECHELON SUPPLY CHAIN NETWORK ARCHITECTURE USING NLIW-PSO ALGORITHM

#### 5.4.1 Introduction

This section discusses particle representation, velocity calculation of all PSO algorithms, general structure of optimization, experimental design and results and discussions of three stage and four stage multi objective multi echelon supply chain network optimization.

#### 5.4.2 Particle representation of four echelon SCN configuration in PSO algorithm

One solution in a three echelon supply chain network configuration is represented by a particle i.e., one string of integers (decision variables). Three stage multi echelon supply chain network configuration considered in this study is represented by a particle which consists of 30 segments (see Figure 3.2 in chapter 3). Similarly, one solution in a four stage multi echelon supply chain network configuration is represented by a particle i.e., one string of integers (decision variables). Four echelon supply chain network
configuration considered in this study is represented by a particle which consists of 42 segments (see Figure 4.2 in chapter 4).

5.4.3 **Velocity calculation and position updating equations used for optimization of four echelon SCN architecture**

The NLIW-PSO variant used in this research study have been briefly explained in the section 1.6 of chapter 1. Following are the equations of NLIW-PSO variant used for velocity calculation and position updating of particles of PSO.

Velocity,

\[
v_{kd}^{\text{new}} = w_{\text{iter}} \times v_{kd} + c_1 \times \left[ r_1 \times (P_{kd} - X_{kd}) \right] + c_2 \times \left[ r_2 \times (G_d - X_{kd}) \right]
\]

\[
w_{\text{iter}} = \left( \frac{\text{iter}_{\max} - \text{iter}}{\text{iter}_{\max}} \right)^n \left( w_{\text{initial}} - w_{\text{final}} \right) + w_{\text{final}}
\]

\[
w_{\text{final}} = w_{\text{initial}} + m \times \text{iter}_{\max}
\]

\[
m = \frac{w_{\text{initial}} - w_{\text{final}}}{\text{iter}_{\max}}
\]

New position of particle, \( X_{kd}^{\text{new}} = X_{kd} + v_{kd}^{\text{new}} \)

5.4.4 **Multi objective PSO algorithm for multi-echelon SCN problem**

General procedural steps involved in multi objective analysis using PSO algorithm with weighted sum approach is given below.
Step 1: Initializing the particle position \( X_{kd}, \ d = 1, 2, \ldots, D \)
Where ‘k’ denotes the number of particles, ‘D’ denotes maximum number of dimensions within the minimum and maximum limits for each dimension.

Step 2: Initialize the particle velocity \( v_{kd}, \ d = 1, 2, \ldots, D \)
Where ‘k’ denotes the number of particles, ‘D’ denotes maximum number of dimensions within the minimum and maximum limits for each dimension.

Step 3: Calculate the maximum velocity of the particles \( v_{\text{max}} = 0.5 \times \text{Maximum limit for each dimension, D} \)

Step 4: If \( v_{kd} > v_{\text{max}} \), then Set \( v_{kd} = v_{\text{max}} \) for all ‘k’ and ‘d’.

Step 5: Choose the weights \( w_1 \) and \( w_2 \) for objectives 1 and objective 2, such that \( w_1 + w_2 = 1 \).

Step 6: Evaluate over all objective \( Z\{X_{kd}\} \) (Calculate the functional values for all particles).
Initialize /update \( \{P_{kd}\} \) (best point of the particle, i.e., particle best).
and \( \{G_d\} \) (global best).
Go to Step 7.

Step 7: Calculate new velocity \( V_{kd}^{\text{new}} \)
\[
V_{kd}^{\text{new}} = w_{\text{iter}} \times v_{kd} + c_1 \times [r_1 \times (P_{kd} - X_{kd})] + c_2 \times [r_2 \times (G_d - X_{kd})]
\]
Check if \( V_{kd}^{\text{new}} > v_{\text{max}} \)
Set \( V_{kd}^{\text{new}} = v_{\text{max}} \) for all ‘k’ and ‘d’.

Step 8: Updated position of the particle
\( X_{kd}^{\text{new}} = V_{kd}^{\text{new}} + X_{kd} \)
Set \( X_{kd}^{\text{new}} = X_{kd} \)
Evaluate \( Z\{X_{kd}\} \)

Step 9: If termination criteria satisfied then Go to Step 10
else Go to step 6

Step 10: Print \( \{G_d\} \) and \( Z\{G_d\} \); Stop

Figure 5.1 Multi objective PSO algorithm for multi echelon SCN
5.4.5 Generation of initial particles in the proposed PSO algorithms

Generate k (Swarm Size) solutions \( \{X_{kd}, \ d = 1,2,\ldots ,D\} \), (k = 1,2,\ldots ,5), as follows:

Set \( X_{kd} = LL_{d} + (UL_{d} - LL_{d}) \times U (0,1) \), for \( d = 1,2,\ldots ,D \).

where \( LL_{d} \) and \( UL_{d} \) denotes the minimum and maximum limits on value of \( X_{kd} \) with respect to dimension space \( d \), and \( U (0,1) \) denotes the uniformly distributed random number in the range (0,1).

5.4.6 Generation of initial velocities in the proposed PSO algorithms

Generate k (Swarm Size) solutions \( \{v_{kd}, \ d = 1,2,\ldots ,D\} \), (k = 1,2,\ldots ,5), as follows:

Set \( v_{kd} = LL_{d} + (UL_{d} - LL_{d}) \times U (0,1) \), for \( d = 1,2,\ldots ,D \).

where \( LL_{d} \) and \( UL_{d} \) denotes the minimum and maximum limits on value of \( X_{kd} \) with respect to dimension space \( d \), and \( U (0,1) \) denotes the uniformly distributed random number in the range (0,1).

5.5 PERFORMANCE ANALYSIS OF FOUR STAGE MULTI ECHELON SUPPLY CHAIN NETWORK ARCHITECTURE USING NLIW-PSO VARIANT

5.5.1 Experimental design

In this research an attempt has been made to apply best performing PSO variant i.e. NLIW-PSO algorithm to study its effectiveness for real world multi objective supply chain network management problems with the two sets of objectives. These two sets objectives are used as the performance indicators for SCN architectures.
For multi objective performance analysis of three stage multi echelon supply chain, the same data of Supply chain setting - I discussed in the chapter 3 is used. For four stage multi echelon supply chain network performance analysis, the same data of the supply chain setting - I of four echelon SCN of previous chapter 4 is used with additional parameter given in this chapter are considered in the present computational study. The measure of performance is observed different weight combinations for both the objectives are computed.

The proposed algorithm is coded in the C Language and are implemented on the Intel[R]Core[TM] centrino processor 2CPU 6320 running @1.86 GHz with 0.98 GB of RAM. Taillard random number generator (1993) is used to generate the unbiased uniform random numbers.

5.5.2 The various parameters used in the algorithm

Pilot studies have been conducted in this research work to arrive at the best values of parameters in the proposed applications of PSO variants to multi echelon supply chain networks such as swarm size, learning parameters ($c_1$ and $c_2$), inertia weights and penalty increment and initial penalty parameters.

From the studies, following parameters are set and worked well for the proposed NLIW-PSO multi-objective analysis of three and four stage multi echelon supply chain network optimization.
Table 5.1 Parameter setting for Three stage SCN

| S.No. | Parameter                  | Notation | Value |
|-------|----------------------------|----------|-------|
| 1     | Particle size              | $k$      | 5     |
| 2     | Learning factor            | $c_1$    | 2     |
| 3     | Learning factor            | $c_2$    | 1.45  |
| 4     | Initial inertia weight     | $w_{\text{min}}$ | 0.2   |
| 5     | starting iteration number  | $\text{iter}$ | 0     |
| 6     | Maximum number of iterations | $\text{iter}_{\text{max}}$ | 2000  |
| 7     | Coefficient for best results | $n$    | 1.2   |
| 8     | Coefficient for best results | $m$     | $-2.5 \times 10^{-4}$ |
| 9     | Penalty parameter          | $R_m$    | 0.0001|
| 10    | Penalty multiplication factor | $f$     | 10    |

Table 5.2 Parameter setting for four stage SCN

| S.No. | Parameter                  | Notation | Value |
|-------|----------------------------|----------|-------|
| 1     | Particle size              | $k$      | 5     |
| 2     | Learning factor            | $c_1$    | 2     |
| 3     | Learning factor            | $c_2$    | 1.52  |
| 4     | Initial inertia weight     | $w_{\text{min}}$ | 0.2   |
| 5     | starting iteration number  | $\text{iter}$ | 0     |
| 6     | Maximum number of iterations | $\text{iter}_{\text{max}}$ | 500  |
| 7     | Coefficient for best results | $n$    | 1.2   |
| 8     | Coefficient for best results | $m$     | $-2.5 \times 10^{-4}$ |
| 9     | Penalty parameter          | $R_m$    | 0.0001|
| 10    | Penalty multiplication factor | $f$     | 10    |
5.5.3 Results and discussions of PSO variants

5.5.3.1 Input data for the supply chain model

Input data related to vendors, manufacturers, warehouses, and distribution centers for analysis of three and four stage echelon supply chain network architectures are exhibited in Table 3.7 to 3.14 (for three stage SCN) and Tables 4.3 to 4.13 (for four stage SCN), the same data sets are considered for the multi-objective performance analysis SCN architectures. For four stage multi echelon SCN analysis, we require additional information regarding average monthly demand at each distribution center and average monthly demand (i.e., one period) occurring at all the warehouses from the various distribution centers for one year and are tabulated in Table 5.3(a) and (b). The average lead time required to replenish the goods from the different plants to the warehouses considered is given in the Table 5.3(c) and also the value of ‘Z’ corresponding to the service level is provided in the Table 5.4.

5.5.3.2 Results and discussions of particle swarm optimization algorithm

This subsection discusses and summarizes the results of the test problem considered. For the specified maximum number of iterations, 15 simulation experiments are carried out to evaluate objective function values for each set weights of \( w_1 \) and \( w_2 \). An experiment is carried out to determine the trade-off solutions considering the weighted objective as shown in the equation (5.5) (for three stage SCN) and equation (5.29) (for four stage SCN), which was subjected to constraints as defined earlier.
Table 5.3(a) Average monthly Demand faced by distribution centers for SCN

| Distribution centers | DC1 | DC2 | DC3 | DC4 | DC5 | DC6 |
|----------------------|-----|-----|-----|-----|-----|-----|
| Demand (in Units)    | 82  | 98  | 55  | 57  | 89  | 88  |

Table 5.3(b) Demand information for four stage SCN

| Data required for safety stock & AVG INV Calculations | Warehouse 1 | Warehouse 2 | Warehouse 3 |
|-------------------------------------------------------|-------------|-------------|-------------|
| Month                                                 |             |             |             |
| JAN 2007                                              | 180         | 175         | 145         |
| FEB 2007                                              | 176         | 135         | 165         |
| MAR 2007                                              | 197         | 120         | 120         |
| APR 2007                                              | 155         | 176         | 125         |
| MAY 2007                                              | 188         | 193         | 136         |
| JUN 2007                                              | 165         | 120         | 176         |
| JUL 2007                                              | 140         | 165         | 176         |
| AUG 2007                                              | 183         | 198         | 143         |
| SEP 2007                                              | 100         | 100         | 154         |
| OCT 2007                                              | 134         | 145         | 134         |
| NOV 2007                                              | 165         | 165         | 142         |
| DEC 2007                                              | 138         | 125         | 120         |
| Yearly Demand                                         | 1921        | 1817        | 1736        |
| AVE Monthly Demand                                    | 160         | 151         | 145         |
| STD.DEV                                               | 28          | 32          | 20          |
| *Cost of product (Cp) Rs 2000/-                      |             |             |             |
Table 5.3(c) Lead time information for four stage SCN

| Warehouses | Warehouse 1 | Warehouse 2 | Warehouse 3 |
|------------|-------------|-------------|-------------|
| Avg Lead time (in months) | 1.2         | 1.5         | 1           |

Table 5.4 Value of Z corresponding to service levels

| Service Level in % | 50 | 80 | 84.1 | 85 | 90 | 93 | 95 | 97 | 97.7 | 99 | 99.5 | 99.9 |
|--------------------|----|----|------|----|----|----|----|----|------|----|------|------|
| Value of Z         | 0  | 0.84 | 1  | 1.04 | 1.28 | 1.48 | 1.64 | 1.88 | 2  | 2.33 | 2.58 | 3    |

The weighted objective is optimized for different values of weight factors, $w_1$ and $w_2$ (varying from 0.1 to 0.9 in steps of 0.1), the results obtained by the multi-objective NLIW-PSO of performance evaluation of three stage multi echelon and four stage multi echelon supply chain network for average demand of supply chain setting-I are exhibited in the Tables 5.5 to 5.15. The corresponding the different weight combinations the decision variables are tabulated in Table 5.6. The near optimal trade off solutions obtained for all combination of weights for three echelon is shown in Figure 5.1 and best near optimal trade off solutions for each set of weights is depicted in the Figure 5.2. The total supply chain operating cost (TSCC) seems to vary between the values of Rs.11,77,483 and Rs.14,12,830, while the ratio of TMC/TSCC varies between 0.69 to 0.79. It is seen from the figure that increasing TSCC causes a decrease in TMC/TSCC. There is a clear trade off this set of objective functions. The decision maker can, thus the intelligible decision making by choosing any weight combinations based on his expertise to satisfy his /her requirements for the stated objectives for three stage multi echelon SCN architecture from the Table 5.5 and would be beneficial to the system from a systems optimization perspective.
Figure 5.2(a) Solutions obtained for all combinations of weights for (for different seeds for each set of weights) three stage multi echelon SCN

Figure 5.2(b) Trade off solutions for each weight combinations for three stage multi echelon SCN
Similarly the multi objective analysis for second set of objectives i.e. TSCC and GMROI for four stage multi echelon supply chain network architecture assuming different weights for objectives and equal importance for the objectives, the performance analysis is performed for different service levels i.e. 50%, 84%, 97.7 % and 99.9 % and the results are tabulated in Table 5.7 to Table 5.10 and Table 5.12 to Table 5.15 respectively. Decision variables corresponding to different service levels with the equal weightage are tabulated in Table 5.11(a) and Table 5.11(b). With the above multi-objective performance analysis, it is concluded that as service levels increases, the TSCC of SCN also increases and as the service level increases, the GMROI decreases, because all the warehouses need to maintain safety stock depending on the service level required. GMROI varies from 2.8 to 3.6 and TSSC of SCN varies from Rs.12,37,000 to Rs.19,78,000 depending on the service level. From the Figure 5.3 to 5.9, the decision maker can, make the intelligible decision based on his expertise to satisfy his /her requirements (service levels to meet the customer demand) for the stated objectives for four stage multi echelon SCN architecture.
| S.No. | $W_1$ | $W_2$ | $x_{111}$ | $x_{112}$ | $x_{121}$ | $x_{122}$ | $x_{211}$ | $x_{212}$ | $x_{221}$ | $x_{222}$ | $x_{311}$ | $x_{312}$ | $x_{321}$ | $x_{322}$ | $Y_{11}$ | $Y_{12}$ | $Y_{13}$ | $Y_{14}$ | $Y_{15}$ | $Y_{16}$ | $Y_{21}$ | $Y_{22}$ | $Y_{23}$ | $Y_{24}$ | $Y_{25}$ | $Y_{26}$ |
|-------|-------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1     | 0.9   | 0.1   | 180       | 18        | 152       | 134       | 198       | 73        | 34        | 116       | 260       | 105       | 118       | 68        | 185      | 36      | 68      | 82      | 168      | 77      | 46      | 44      | 52      | 54      | 42      | 67      | 37      | 54      | 3       | 3       | 47      | 25      |
| 2     | 0.8   | 0.2   | 189       | 10        | 66        | 234       | 115       | 184       | 37        | 99        | 307       | 46        | 180       | 258       | 132      | 13      | 137     | 162     | 88       | 7       | 27      | 6       | 1       | 55      | 76      | 76      | 71      | 49      | 56      | 34      | 14      |
| 3     | 0.7   | 0.3   | 73        | 91        | 107       | 172       | 224       | 71        | 113       | 37        | 320       | 80        | 139       | 35        | 275      | 59      | 49      | 57      | 137      | 12      | 68      | 69      | 57      | 8       | 79      | 76      | 15      | 29      | 0       | 49      | 10      | 14      |
| 4     | 0.6   | 0.4   | 16        | 107       | 245       | 38        | 27        | 270       | 25        | 115       | 260       | 0         | 1         | 226       | 137      | 142     | 107     | 10      | 64      | 71      | 60      | 67      | 40      | 28      | 1       | 82      | 23      | 31      | 15      | 29      | 88      | 8       |
| 5     | 0.5   | 0.5   | 29        | 103       | 257       | 42        | 97        | 179       | 4         | 72        | 177       | 200       | 90        | 56        | 269       | 26       | 32      | 80      | 94      | 96      | 58      | 84      | 50      | 10      | 50      | 19      | 25      | 14      | 6       | 47      | 39      | 71      |
| 6     | 0.4   | 0.3   | 43        | 57        | 141       | 116       | 59        | 75        | 4         | 64        | 51        | 166       | 192       | 4         | 121      | 27      | 81      | 67      | 83      | 146     | 40      | 78      | 39      | 43      | 17      | 26      | 43      | 20      | 16      | 14      | 72      | 64      |
| 7     | 0.3   | 0.7   | 122       | 23        | 234       | 37        | 0         | 203       | 19        | 118       | 194       | 136       | 49        | 0         | 40       | 98      | 22      | 84      | 157     | 72      | 10      | 44      | 20      | 3       | 74      | 68      | 73      | 54      | 35      | 54      | 15      | 22      |
| 8     | 0.2   | 0.1   | 15        | 42        | 228       | 36        | 66        | 101       | 73        | 23        | 203       | 115       | 86        | 66        | 214       | 119     | 57      | 66      | 148     | 1       | 37      | 72      | 23      | 14      | 76      | 73      | 46      | 26      | 32      | 43      | 14      | 18      |
| 9     | 0.1   | 0.9   | 115       | 4         | 7         | 55        | 144       | 147       | 7         | 118       | 227       | 0         | 32        | 106       | 81        | 13      | 55      | 86      | 130     | 108     | 74      | 2       | 51      | 45      | 68      | 26      | 9       | 96      | 4       | 12      | 21      | 64      |
Table 5.7 Multi-objective analysis for SL=50%

| S No | Weights for Objectives | Fitness 1 | Fitness 2 | Overall objective | Objective 1 | Objective 2 |
|------|------------------------|-----------|-----------|------------------|-------------|-------------|
|      | w1  | w2  |           |           | TSCC         | GMROI       |
| 1    | 0.1 | 0.9 | 0.6333    | 0.09807   | 0.15159     | 1266590     | 3.607       |
| 2    | 0.2 | 0.8 | 0.6247    | 0.08176   | 0.19035     | 1249520     | 3.672       |
| 3    | 0.3 | 0.7 | 0.6304    | 0.09253   | 0.25389     | 1260800     | 3.629       |
| 4    | 0.4 | 0.6 | 0.6336    | 0.09884   | 0.31275     | 1267360     | 3.604       |
| 5    | 0.5 | 0.5 | 0.6192    | 0.07114   | 0.34557     | 1238400     | 3.715       |
| 6    | 0.6 | 0.4 | 0.61918   | 0.07114   | 0.3997      | 1238380     | 3.715       |
| 7    | 0.7 | 0.3 | 0.62077   | 0.07317   | 0.4561      | 1240540     | 3.707       |
| 8    | 0.8 | 0.2 | 0.61854   | 0.07417   | 0.5096      | 1237000     | 3.703       |
| 9    | 0.9 | 0.1 | 0.6285    | 0.09344   | 0.57502     | 1257060     | 3.626       |

Note: EOQ at warehouses = Q1+Q2+Q3=89+87+85=261 Units
Cycle inventory = (Q1+Q2+Q3)/2=89 Units
Safety stock = 0+0+0= Zero Units
Average Inventory value = Rs.261506

Table 5.8 Multi-objective analysis for SL=84.1%

| S No | Weights for Objectives | Fitness 1 | Fitness 2 | Overall objective | Objective 1 | Objective 2 |
|------|------------------------|-----------|-----------|------------------|-------------|-------------|
|      | w1  | w2  |           |           | TSCC         | GMROI       |
| 1    | 0.1 | 0.9 | 0.75036   | 0.5984    | 0.6133       | 1500730     | 1.6076      |
| 2    | 0.2 | 0.8 | 0.741     | 0.6034    | 0.6309       | 1482130     | 1.5863      |
| 3    | 0.3 | 0.7 | 0.7494    | 0.5996    | 0.6445       | 1498900     | 1.6013      |
| 4    | 0.4 | 0.6 | 0.75138   | 0.5992    | 0.6601       | 1502770     | 1.6029      |
| 5    | 0.5 | 0.5 | 0.7542    | 0.6051    | 0.6797       | 1508460     | 1.5084      |
| 6    | 0.6 | 0.4 | 0.7488    | 0.5963    | 0.6878       | 1497640     | 1.6146      |
| 7    | 0.7 | 0.3 | 0.7352    | 0.5968    | 0.6937       | 1470500     | 1.6126      |
| 8    | 0.8 | 0.2 | 0.7353    | 0.5974    | 0.7081       | 1471700     | 1.6102      |
| 9    | 0.9 | 0.1 | 0.7435    | 0.5997    | 0.7286       | 1487010     | 1.6185      |

Note: EOQ at warehouses = Q1+Q2+Q3=89+87+85=261 Units
Cycle inventory = (Q1+Q2+Q3)/2=89 Units
Safety stock = 30+39+20=89 Units
Average Inventory value = Rs.4412554/-
Table 5.9 Multi-objective analysis for SL =97.4 %

| S No | Weights for Objectives | Fitness 1 | Fitness 2 | Overall objective | Objective 1 | Objective 2 |
|------|------------------------|-----------|-----------|------------------|-------------|-------------|
|      | w1  w2                 | w1  w2    | w1  w2    | w1  w2           | TSC         | GMROI       |
| 1    | 0.1  0.9               | 0.86414   | 0.806     | 0.8118           | 1728280     | 0.7758      |
| 2    | 0.2  0.8               | 0.8206    | 0.8677    | 0.8089           | 1735480     | 0.7643      |
| 3    | 0.3  0.7               | 0.8688    | 0.8098    | 0.8275           | 1737770     | 0.7607      |
| 4    | 0.4  0.6               | 0.8348    | 0.8704    | 0.8111           | 1740910     | 0.7555      |
| 5    | 0.5  0.5               | 0.8642    | 0.808     | 0.8361           | 1728520     | 0.7679      |
| 6    | 0.6  0.4               | 0.8626    | 0.8066    | 0.8402           | 1725230     | 0.7735      |
| 7    | 0.7  0.3               | 0.8555    | 0.8104    | 0.842            | 1711180     | 0.7583      |
| 8    | 0.8  0.2               | 0.8727    | 0.8129    | 0.842            | 1745520     | 0.7483      |
| 9    | 0.9  0.1               | 0.8725    | 0.8125    | 0.8661           | 1745530     | 0.7488      |

Note:  
EOQ at warehouses = Q1+Q2+Q3=89+87+85=261 Units  
Cycle inventory = (Q1+Q2+Q3)/2=89 Units  
Safety stock = 61+78+40=179 Units  
Average Inventory value = Rs.620983/-

Table 5.10 Multi-objective analysis for SL =99.97 %

| S No | Weights for Objectives | Fitness 1 | Fitness 2 | Overall objective | Objective 1 | Objective 2 |
|------|------------------------|-----------|-----------|------------------|-------------|-------------|
|      | w1  w2                 | w1  w2    | w1  w2    | w1  w2           | TSC         | GMROI       |
| 1    | 0.1  0.9               | 0.9834    | 0.9299    | 0.9352           | 1966890     | 0.2803      |
| 2    | 0.2  0.8               | 0.9812    | 0.9241    | 0.9355           | 1962480     | 0.3032      |
| 3    | 0.3  0.7               | 0.9867    | 0.9261    | 0.9443           | 1973600     | 0.2958      |
| 4    | 0.4  0.6               | 0.98732   | 0.9269    | 0.9508           | 1974640     | 0.2942      |
| 5    | 0.5  0.5               | 0.9872    | 0.9264    | 0.9568           | 1974400     | 0.2943      |
| 6    | 0.6  0.4               | 0.989     | 0.9295    | 0.9644           | 1978050     | 0.2898      |
| 7    | 0.7  0.3               | 0.987     | 0.9291    | 0.9642           | 1978055     | 0.2898      |
| 8    | 0.8  0.2               | 0.9756    | 0.9279    | 0.9661           | 1951320     | 0.2882      |
| 9    | 0.9  0.1               | 0.9821    | 0.9247    | 0.9764           | 1964360     | 0.3009      |

Note:  
EOQ at warehouses = Q1+Q2+Q3=89+87+85=261 Units  
Cycle inventory = (Q1+Q2+Q3)/2=89 Units  
Safety stock = 92+117+60=269 Units  
Average Inventory value = Rs.800711/-
Figure 5.3 Trade of solutions for SL=50%

Figure 5.4 Trade of solutions for SL=97.97%
Figure 5.5  Trade of solutions for different Service levels for giving equal weightage to both the objectives
### Table 5.11(a) Decision variables of near optimal solution by NLIW-PSO Algorithm for $w_1=w_2=0.5$

| S. No. | $X_{111}$ | $X_{112}$ | $X_{121}$ | $X_{122}$ | $X_{131}$ | $X_{132}$ | $X_{211}$ | $X_{212}$ | $X_{221}$ | $X_{222}$ | $X_{311}$ | $X_{312}$ | $X_{321}$ | $X_{322}$ | $X_{331}$ | $X_{332}$ | $Y_{11}$ | $Y_{12}$ | $Y_{13}$ | $Y_{21}$ | $Y_{22}$ | $Y_{23}$ |
|--------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------|-------|-------|-------|-------|-------|
| 50%    | 89         | 67         | 73         | 85         | 165        | 0          | 121        | 22         | 98         | 97         | 107        | 31         | 223        | 18         | 14         | 22         | 90     | 110   | 53    | 0     | 110   | 40    |
| 84.10% | 43         | 119        | 190        | 123        | 38         | 70         | 29         | 152        | 120        | 38         | 164        | 60         | 198        | 102        | 62         | 110        | 53     | 182   | 81    | 0     | 39    | 190   |
| 97.40% | 132        | 84         | 193        | 152        | 58         | 42         | 68         | 53         | 240        | 194        | 75         | 31         | 203        | 138        | 18         | 43         | 164        | 97     | 208   | 170   | 0     | 0     | 108   |
| 99.97% | 24         | 208        | 265        | 128        | 88         | 36         | 63         | 65         | 304        | 151        | 9          | 157        | 221        | 129        | 54         | 106        | 138        | 291    | 69    | 47    | 128   | 197   |

### Table 5.11(b) Decision variables of near optimal solution by NLIW-PSO Algorithm for $w_1=w_2=0.5$

| S. No. | $Z_{11}$ | $Z_{12}$ | $Z_{13}$ | $Z_{14}$ | $Z_{15}$ | $Z_{16}$ | $Z_{21}$ | $Z_{22}$ | $Z_{23}$ | $Z_{24}$ | $Z_{25}$ | $Z_{26}$ | $Z_{31}$ | $Z_{32}$ | $Z_{33}$ | $Z_{34}$ | $Z_{35}$ | $Z_{36}$ |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 50%    | 16       | 5        | 9        | 58       | 46       | 24       | 43       | 92       | 38       | 0        | 28       | 23       | 24       | 2        | 9        | 0        | 16       | 42       |
| 84.10% | 33       | 99       | 7        | 6        | 22       | 23       | 50       | 0        | 17       | 40       | 66       | 58       | 0        | 0        | 32       | 11       | 2        | 8        |
| 97.40% | 50       | 79       | 1        | 0        | 12       | 4        | 13       | 16       | 32       | 27       | 26       | 85       | 20       | 4        | 22       | 31       | 52       | 0        |
| 99.97% | 9        | 99       | 6        | 24       | 62       | 45       | 0        | 0        | 32       | 13       | 13       | 21       | 74       | 0        | 18       | 21       | 15       | 23       |
Table 5.12  Performance evaluation-MOA of four stage SCN for GMROI and TSCC for service level 50%

| Seed | Overall Objective | GMROI   | TSCC    |
|------|------------------|---------|---------|
| 1    | 1.25194          | 3.53302 | 1262630 |
| 2    | 1.25035          | 3.55969 | 1279150 |
| 3    | 1.28136          | 3.60436 | 1239470 |
| 4    | 1.25571          | 3.57376 | 1275470 |
| 5    | 1.2657           | 3.56325 | 1250220 |
| 6    | 1.27121          | 3.57771 | 1246440 |
| 7    | 1.28115          | 3.60381 | 1239610 |
| 8    | 1.27403          | 3.58511 | 1244500 |
| 9    | 1.2759           | 3.59003 | 1243210 |
| 10   | 1.27025          | 3.58148 | 1250250 |
| 11   | 1.26616          | 3.56446 | 1249900 |
| 12   | 1.24864          | 3.54916 | 1277310 |
| 13   | 1.26962          | 3.57354 | 1247530 |
| 14   | 1.27577          | 3.58968 | 1243310 |
| 15   | 1.27577          | 3.58968 | 1243310 |

Figure 5.6  Near optimal trade off solutions for each service level 50% for four stage multi echelon SCN
Table 5.13 Performance evaluation-MOA of four stage SCN for GMROI and TSCC for service level 84.1 %

| Seed | Overall Objective | GMROI  | TSCC      |
|------|------------------|--------|-----------|
| 1    | 0.650959         | 1.57664| 1486400   |
| 2    | 0.651237         | 1.57723| 1486140   |
| 3    | 0.66065          | 1.59723| 1477320   |
| 4    | 0.64273          | 1.55915| 1494120   |
| 5    | 0.637502         | 1.54805| 1499020   |
| 6    | 0.655409         | 1.58609| 1482230   |
| 7    | 0.649838         | 1.57426| 1487450   |
| 8    | 0.635465         | 1.54372| 1500930   |
| 9    | 0.656208         | 1.58779| 1481480   |
| 10   | 0.655858         | 1.58705| 1481810   |
| 11   | 0.648598         | 1.57162| 1488620   |
| 12   | 0.651974         | 1.57884| 1485450   |
| 13   | 0.663756         | 1.60384| 1474400   |
| 14   | 0.663758         | 1.60384| 1474405   |
| 15   | 0.658179         | 1.59198| 1479630   |

Figure 5.7 Near optimal trade off solutions for each service level 84.1 %
Table 5.14 Performance evaluation-MOA of four stage SCN for GMROI and TSCC for service level 97.7%

| Seed | Overall Objective | GMROI | TSCC   |
|------|------------------|-------|--------|
| 1    | 0.321247         | 0.7356| 1725310|
| 2    | 0.328124         | 0.74787| 1717690|
| 3    | 0.344605         | 0.77727| 1699430|
| 4    | 0.334257         | 0.75881| 1710890|
| 5    | 0.320319         | 0.73394| 1726330|
| 6    | 0.325495         | 0.74318| 1720600|
| 7    | 0.315448         | 0.72525| 1731730|
| 8    | 0.315348         | 0.72508| 1731840|
| 9    | 0.328854         | 0.74917| 1716880|
| 10   | 0.316477         | 0.72709| 1730590|
| 11   | 0.322984         | 0.7387 | 1723380|
| 12   | 0.31364          | 0.72203| 1733730|
| 13   | 0.317459         | 0.72884| 1729500|
| 14   | 0.325114         | 0.7425 | 1721020|
| 15   | 0.332323         | 0.75946| 1715090|
| 16   | 0.340815         | 0.77051| 1703630|
| 17   | 0.32638          | 0.74476| 1719620|

Figure 5.8 Near optimal trade off solutions for each service level 97.7%
Table 5.15 Performance evaluation-MOA for GMROI and TSCC for service level 99.97%

| Seed | Overall Objective | GMROI    | TSCC     |
|------|------------------|----------|----------|
| 1    | 0.0857974        | 0.27192  | 1964370  |
| 2    | 0.0953686        | 0.28664  | 1952580  |
| 3    | 0.0782258        | 0.26028  | 1973690  |
| 4    | 0.0830886        | 0.26776  | 1967700  |
| 5    | 0.0934883        | 0.28375  | 1954900  |
| 6    | 0.085375         | 0.27128  | 1964890  |
| 7    | 0.077589         | 0.26976  | 1979700  |
| 8    | 0.0792242        | 0.26866  | 1975880  |
| 9    | 0.0900729        | 0.2785   | 1959100  |
| 10   | 0.0844288        | 0.26982  | 1966050  |
| 11   | 0.0875631        | 0.27464  | 1962190  |
| 12   | 0.0843987        | 0.26977  | 1966090  |
| 13   | 0.0872503        | 0.27762  | 1964310  |
| 14   | 0.0865828        | 0.27313  | 1963400  |
| 15   | 0.091556         | 0.28078  | 1957280  |
| 16   | 0.0859752        | 0.2722   | 1964150  |
| 17   | 0.0896579        | 0.27786  | 1959610  |

Figure 5.9 Near optimal trade off solutions for each service level 99.9 %
5.6 CONCLUSION

An attempt is made to solve a two objective integer programming constrained supply chain network problem model. Since there is no well accepted Operation Research technique to find the optimum solutions for such multiple objective combinatorial optimization problems. Non Linear Inertia Weight PSO algorithm with penalty function approach is used for solving constrained multi-objective supply chain network problem. The experimental results shows that the new algorithm produces better quality trade off near optimal solutions for stated set of objectives for three stage and four stage multi echelon supply chain network architecture.