Optimization of an Integrated Steel Retail Supply Chain Distribution in Multi-echelon Environment

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***Abstract*—This paper presents the integrated, multi-objective, multi-product, multi-echelon environment optimization model for steel distribution network. Model formulated covers retail supply chain processes applicable for steel products starting from production of different grades of material, its transfer to company warehouse, then to distributor warehouse cum service centre and finally to retailer. The input parameters considered are; cost of opening new warehouse, order costs, administrative cost, inventory holding cost, transportation costs and desired service level. In order to solve the problem a Territory Defined Evolutionary Algorithm (TDEA) is applied. The model developed supports organization and distributor in deciding the optimal location for minimizing inventory and transportation cost after taking into account desired service level requirements of retail customers. The framework presented further assist distributor in allocating the retailers to respective DC. Moreover, the model formulated benefits distributor and retailers in maintaining optimal regular and safety stocks after taking into account variation in lead time and demand.**

Keywords*—Facility, Location, Steel, Retail, Distribution Network; Evolutionary Algorithm.*

1. Introduction

Michael Porter, one of the leading thinkers in the development of our understanding of competitive advantage drew our attention to the importance of value chain. The value chain signifies all the actions that happens inside the organization to create worth for clienteles.

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Under the circumstances, a firm under study felt the need to break away from the commoditization of the Industry and move toward innovation and responsiveness to gain competitive advantage. Distribution of retail products through a network of distributors and their retailers were identified as a principle source of sustainable competitive advantage and a means of delivering customer value. Initial study had identified that though there was a distinct brand pull for steel company retail products, however steel company was unable to capture the full value of it because of company's inability to reach the fragmented base of end users. Before year 2000, material flow in steel industry was typically controlled by De-bulkers who operated through a long and complex chain of financiers who sold through brokers to wholesalers who in turn sold to retailers. The buying was opportunistic and the behaviour predatory. This distorted distribution dynamics operating through a multi-tiered complex web of channel players resulted in value dissipation.

In order to streamline distribution Network, organisation under study adapted Fast Moving Consumer Good (FMCG) framework. Organisation appointed set of distributors all over India and assigned specific territory for distribution of its products. The retail products basically retailed were Galvanised Plain (GP) /Galvanised Corrugated (GC), Re-bars, Wire rods, Galvanised Iron (GI) Wires. The distribution network of GI Wire and Wire product had 40 large distributors all over the country who were exclusive to steel company and operated in well demarcated territories for different product segments. The challenge before organisation was to optimise the current the distribution network so that retailer reach is increased, inventory is optimised and transportation costs are reduced to serve the natural markets well to increase market share.

In view of the above, the challenge for steel company was to recognize the change in emphasis from brand value to customer value and re-design a channel for the products that could create and capture value for steel retail products. As the steel industry did not have an existing retail business optimisation model that could be followed, strategic team studied the best practices outside organisation and zeroed in on the Fast-Moving Consumer Good (FMCG) Model. An application of the retail supply chain optimisation models for dispensing steel products to growing network of retail stores was studied for improving reach. It was observed that pharmaceutical, oil & gas and FMCG organisations are following inventory distribution models for improvement of their retail supply chain. But steel industry was found to be slow in adapting it. This was observed in literature too as there is hardly any literature available on optimisation of steel retail supply chain.

2. Literature Review

Retail distribution as we see in Fast Moving Consumer Good (FMCG) is evolved over the years and comparatively better than the steel hardware retail distribution. The steel branding and organised retail distribution was first introduced in India in 2000 by Tata Steel Ltd. Previously it was pure trading. The traders who used to buy material through tenders issued by steel businesses time to time depending upon unsold inventory accumulated over the period. There is hardly any literature available on integrated steel retail channel optimisation however literature is available on retail supply chain optimisation for other industrial retail products viz. Pharmaceutical, Oil & Gas and FMCG. Following part of this section highlights some of the relevant literature available in other product categories.

Literature on optimisation of retail supply chain in other product categories, other than steel, showed ample potential for improvement of steel retail supply chain. Ref. [7] refers to an integrated multi-echelon distribution inventory supply chain model using genetic algorithm and particle swarm optimization for a tyre and a plastic goods manufacturer in the southern part of India. Ref. [18] in their research deliberated on in how supply chain management helps in distributing goods and services to the client for 7- Eleven retail shops in Thailand. Ref. [14] showed how simulation and optimization models can be utilised for solving integrated supply chain network design problems by analysing supply chain costs.

Ref. [3] is about discrete-event simulation model for redesigning the fast-moving consumer goods (FMCG) supply chain intended at quantitatively evaluating the properties of dissimilar supply configurations bearing in mind entire supply chain costs and bullwhip effect. Ref [15] talks about pharma company distribution network using a nonlinear mixed-integer programming model by curtailing the total delivery expenses and enhancing the client service levels. Ref. [10] used differential evolution algorithm with an improved constraint treatment technique to explain model on localising facilities and assigning product flows in a reverse logistics. Ref. [5] utilised a multi-objective genetic algorithm (MOGA) and simulation approach to addresses the design of production-delivery networks for supply chain configuration and order splitting, transportation distribution and inventory control decisions. Ref. [12] presented the solution for integrated multi-plant, multi-retailer, multi-item, and multi-period production and delivery planning and examined the efficacy of their integration in an environment where the goal was to make best use of the total net return.

Ref. [6] minimised distribution cost using a non-linear integer location-inventory model. Stochastic transportation-inventory network model was extended to Non-standard demand distributions [16]. Ref. [9] formulated an integrated model seeing the effects of facility location, distribution, and inventory issues which included conflicting objectives such as cost, customer service level (order fill rate) and flexibility (responsiveness level). Ref. [15] developed a supply chain design model for number and locations of the distribution centres (DCs) with safety stock at certain service level for the customers facing stochastic demand. Ref. [1] adapted structure-based approach for location decision in multiple retailer environments and used “Theory of Constraints” specifically for managing the inventory. They used particle swarm optimization approach to find the location of the warehouse. Ref. [11] developed an integrated optimisation model based on existing retail distribution processes with multiple warehouses, multiple products, multiple retailers and multiple stages and reduced distribution cost by finding out optimal number of warehouses at right location for GI wire organisation.

This paper follows similar approach as recognised by Ref. [1] and [11], for multi-echelon, multi-product, multi-warehouse, multi-retailer environment using different algorithm "TDEA" and different distributor territory.

3. Problem Environment

The problem undertaken here is from one of the GI wire manufacturing plants in India which route its products to warehouse to distributor to Distribution Centres (DCs) and finally to retailers. This problem necessitates constructing a supply chain distribution network structure, where a manufacturing unit with regional warehouse, distributor with a set of DCs distributed in a territory to allocate different goods to different retailers. DCs are intermediary amenities between the plant and the retailers to enable the product delivery between the two levels. Similar kinds of distribution network normally exist for FMCG, Pharmaceutical and Oil and Gas organization in which location of DC is fixed. In such networks it is important to have right warehouse location so that all the retailers are optimally allocated the goods. When solving such a model, the common problem faced is; demand at each warehouse is not known before the actual assignment of retailers to the warehouse.

4. Solution Methodology

The organisation desires to restructure the supply chain in a manner that it will support the inventory refill activities of its retailers under stochastic demand environment at definite service levels and at the lowermost potential cost. The problem we are dealing with is multi-objective, multi-product which deals with the restructuring multi- level supply chains network, as depicted in Figure 1.

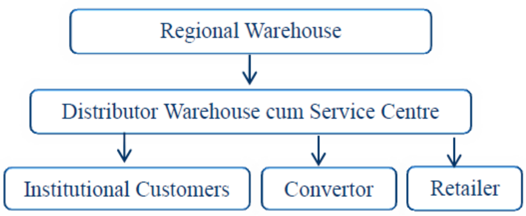

Figure-1: Multi-echelon distribution network problem

TDEA provides optimal solution by utilising the territory defining property to arrive at pereto frontier by converging the solution well dispersed in the polulation. The algorithm is different and superior to other algorithms as it doesn't need explicit diversity preservation operator and as such has computational advantage. This is comparable to idea of [8] where target space is split into hyper packages of the same size. TDEA algorithm has two kinds of populaces; archive and regular. The archieve populace is comparatively nondominated. Updation of archieve populace needs that the territory to be defined around the individual which is most closure to the offspring. Offspring could be rejected based on its position. If it is outside we reject else we accept. TDEA algorithm is as per Figure 2.

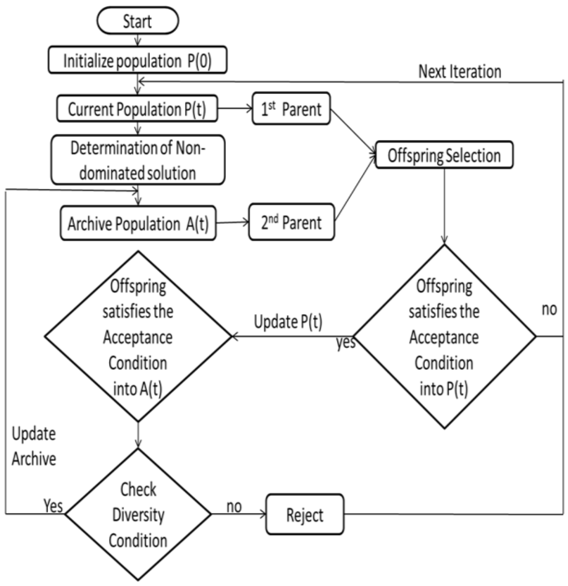

Figure-2: Computational flow of the proposed TDEA technique.

The stages of TDEA technique are defined below:

Stage 1: create an early populace (i.e. regular populace, P (0)) and construct the empty archive populace A (0).

Stage 2: revise archive populace, A, as below:

Duplicate the nondominated entities of P (0) into A (0) to custom the initial records populace.

Established t ← t + 1. Select a parent from every populaces P(t) and A(t). Combine parents to make a fresh child and go for mutation.

Verify if the child fulfils the acceptance situation for P(t). If yes, inset into P(t) and follow next stage. Else, follow Stage 5.

Verify if the child fulfils the acceptance situation for A(t). If yes, inset into A(t).

While t = T, discontinue and report the archive populace. Else follow Stage 2.

Stage 3: Choosing Parent: Choose two entities s1 and s2 out of regular populace and parent p1 is decided based on next process.

Check for supremacy amid s1 and s2. If one takes over another, designate the leading entity as the parent p1.

In case of no domination, choose arbitrarily amongst s1 and s2.

Another parent p2 is arbitrarily archive populace.

Stage 4: Scaling: The scales of the objectives differ considerably in multi-objective optimization problems. The dissimilarities in objectives may cause Multi Objective Evolutionary Algorithms to be prejudiced. In order to take care of this issue, scaling practises as suggested by Ref. [17] could be used. The objective values may be scaled as [0, 1]. The values are otherwise, those amid the ideal (f^*) and the base point (f^n) and those outside the base point. We use liner scaling for earlier interval and sigmoid function for the later interval. With this, the values in the nondominated choice are scaled into large portion of [0, 1].

Stage 5: Updating Population: The child c is assessed first for its acceptance in regular population as per following procedure.

Examine c alongside every entity s_i ∈P (t) for supremacy. Spot the dominated entity as c. When c is dominated by s_i, c is rejected. If not, follow next stage.
Arbitrarily take out one of the marked individuals from P (t). If no entities are marked, select and eliminate an entity arbitrarily from P (t).

Add c into P (t) and check its acceptability in A (t).

Examine c in contrast to each entity s_i ∈A(t) for supremacy. Spot the entities dominated by c. When c is dominated by s_i, c is reject. If not, follow next stage.

Eliminate all noticeable entities from A(t).

When A(t) becomes empty, add c into A(t) and stop. If not, go to next stage.

Term f_{ij} as scaled value of entity i in objective j. Compute the rectilinear distance $d_{ci} = \sum_{j=1}^{m} | f_{cj} - f_{ij} |$ of c for every entity s_i ∈A(t).

Find out $i^* = \arg\min_i(d_{ci})$, that is, the individual s_{i^*} most close to c.

Calculate the maximum scaled absolute objective difference between c and s_{i^*}. That is, find $\delta = \max_{j=1.....m} |f_{cj} - f_{ij}|$

In TDEA algorithm, τ describes the territory size, if $\delta \geq \tau$, add c into A(t). If not, discard c.

5. Results and Discussion

Organisation under study has extensive retail distribution network with distributors spread all over the country in India. The distributors are assigned specific territory to serve the retail market. However, some of the distributors are unable to serve the natural market. The distributor under study is assigned one of the largest territory by the steel company.
However, based on existing retail database and sales report, it was observed that this distributor is unable to cover part of the territory assigned and there is gap in accounted category volume and retailer reach. Therefore, in order to improve accounted category volume and retailer reach, organisation and distributor has taken following goals:

a) Optimal DC locations for distributor warehousing.
b) Optimal mapping of retailers to DC to reduce transportation cost.
c) Optimal inventory level (i.e. Normal and safety stock) at each of the facility to ensure desired service level
d) Minimum inventory holding cost.

Company thinks that if all the above objectives are fulfilled, it will result in improvement of market share, improve service level and reduce distribution cost.
This is required because in existing situation,

a) There was no fixed inventory policy followed by the distributor and retailers.
b) There was judgement-based stocking pattern followed by the distributor and retailers.
c) Distributor had convenience-based location for warehouse which was inefficient in providing the better services to the customer and reaching to all the retailers in territory.
d) There were higher distribution costs in the territory.

This case scenario consists of manufacturing unit, its regional warehouse, a distributor with service centre cum warehouse and multiple retailers spread across large part of the territory of India. Following data was considered for analysis

i. Retailers location, distributor warehouse, proposed distribution centres, regional warehouse.
ii. Type of finished goods including quantity, prices of individual product and transportation routes and modes
iii. Average monthly demand for each product by retailer
iv. Distance based actual transportation rates by each route and mode
v. Distribution Centre opening costs.
vi. Inventory carrying charges
vii. Truck capacity and number of orders by retailers in a month
viii. Ordering cost.
ix. Required customer service level in %.

The data was provided by the company from the distributor Management Information System(MIS).

i) Cost of transportation from manufacturing unit to DC and from DC to retailers as considered was on the basis of freight Table 2.

Table 2. Freight Table as per data base

Distance Travelled (Kilo-meter)	Freight Rate (Rs / Ton Kilo-meter)
>300	2.5
>150 to 300	3
<150	3.6

ii) The Order cost consists of
a) Administrative Cost:
- Amount paid for clerical work
- Accountant fees

b) Fixed handling Cost:
Amount paid to the person who look after the unloading material at warehouse.

iii) Holding Cost consists of cost incurred for holding material at any facility.
- Components of holding cost: →Storage → Security→ Handling → Obsolescence → Damage→ Administrative → Loss→ Insurance → Opportunity cost → Central Govt. taxes

iv) Regular Stock consists of
- Amount of inventory a facility should hold to meet its normal demand.
- Optimal amount computed by model based on EOQ formula.
- Regular stock cost is inventory cost incurred in holding this inventory.

ii) Safety cost consists of
- Amount of inventory a facility should hold to mitigate stock out.
- Calculated on the basis of past variation in demands and transportation lead time.
- Safety stock cost is inventory cost incurred in holding this extra inventory.

The distributor considered for distribution network model had 247 retailer counters. Distributor had warehouse in one of the largest territories of India. In order to keep confidentiality of company data and information, the distributor warehouse location is named as Warehouse1. Whereas other locations as identified for distribution of goods by organisation and distributor are based on market potential and existing logistic flow of goods are named as Warehouse 2, 3, 4. The demand data is taken from distributor MIS. The holding and ordering cost, transportation cost data as provided is taken from freight table of the organisation.

To distribute product within the existing territory, organisation identified the markets. In order to keep confidentiality of organisation's data, these markets are termed as market-1, market-2, market-3, market-4. Distributor presently operates through Warehouse-1. However, distributor is unable to serve retailers in all these markets and as a result there is retailer reach gap in the respective geographies. In order to take care of the gap identified, organisation wanted to experiment whether having Warehouses in different market locations would help. Hence organisation decided to test Warehouse-2, Warehouse-3 and Warehouse- 4 at 2, 3, 4 market locations in addition to existing Warehouse-1. In the existing system, distributor is facing stochastic demand situation from the retailers. In order to take care of that, distributor need to maintain minimum normal and safety stocks. Organisation wants to see the effect of opening or closing of new warehouses. Further, organisation also wanted to allocate retailers to individual warehouse. Moreover, organisation would like to see scientific management of regular and safety stock. Overall, organisation wanted to see the result of existing and optimised distribution system for four distinct warehouses 1, 2, 3 and 4 individually and for various combinations of warehouses.

Input parameters such as demand with standard deviation, product type, price, number of orders, ordering cost, inventory cost, lead time and warehouse type as shown in Table III has been used input data. In addition to these input parameters, order cost, inventory holding cost, distance from plant and service level as depicted in Table-4 was used as input data. Moreover, prices of product at each warehouse as shown in Table 5 was used another input data for analysis of the steel retail distribution system.

Table 3. Input Data

Retailer Name	Demand in Tons	Standard Devi-ation	Product Type	Price (Rs/t)	Number of Orders	Ordering Cost (Rs/t)	Inventory Holding Cost (%)	Lead Time Days	Ware-house Code
R1	1.65	1.01	4	65300	1	165.30	2.00	0.29	1
R2	1.38	0.64	4	65300	1	138.23	2.00	0.77	1
R3	0.50	0.00	4	65300	1	50.35	2.00	1.18	1
R4	0.25	0.01	4	65300	1	25.10	2.00	2.00	1
R5	0.67	0.31	4	65300	1	66.53	2.00	1.96	1
R6	1.40	0.79	4	65300	1	140.31	2.00	1.03	1
R7	0.81	0.35	4	65300	1	80.87	2.00	1.28	1
R8	0.49	0.18	4	65300	1	48.73	2.00	0.70	1
R9	0.93	0.67	4	65300	1	93.00	2.00	1.19	1
R10	1.02	0.49	4	65300	1	101.92	2.00	1.25	1
R11	0.76	0.38	4	65300	1	76.25	2.00	0.90	1
R12	0.51	0.01	4	65300	1	51.10	2.00	1.52	1
R13	0.67	0.29	4	65300	1	66.87	2.00	1.41	1
R14	0.61	0.50	4	65300	1	60.95	2.00	1.26	1
R15	0.51	0.23	4	65300	1	50.87	2.00	1.06	1
R16	0.84	0.15	4	65300	1	84.05	2.00	0.23	1
R17	1.16	1.09	4	65300	1	115.94	2.00	0.53	1
R18	0.29	0.03	4	65300	1	28.55	2.00	0.82	1

Table 4. Input Table for Order Cost, Holding Cost

Distributor Warehouse	Warehouse Code	Ordering Cost (Rs)	Holding Cost (%)	Distance from plant	Lead Time	Service Level
Warehouse 1	1	3000	1.5	1069.46	3.56	3.1
Warehouse 2	2	3000	1.5	897.979	2.99	3.1
Warehouse 3	3	3000	1.5	1144.86	3.82	3.1
Warehouse 4	4	3000	1.5	818.83	2.73	3.1

Table 5. – Price of the product

Warehouse Location	Warehouse Code	Code of Products Distributed	Price
All	1, 2, 3, 4	1	70387
		2	62500
		3	59500
		4	65300

One of the method applied for solving nonlinear programming problem is by Genetic Algorithm (GA). The usual approach for implementation of optimization is by means of formulation of multi-objective mathematical model considering location, production and distribution functions for any supply chain including steel retail. It involves coding and testing of multi-objective evolutionary optimisation model. In this case study, coding and testing is done using MATLAB for applying TDEA algorithm to solve integrated inventory allocation distribution network problem. TDEA technique applied has been described in stages below:

Stage 1: In the first stage a mathematical model has been developed taking into account all the activities with costs associated starting from production to its movement to regional warehouse and then to distributor and retailers with a constraint that a retailer would be served from defined single source (Warehouse) for all the products needed.

Stage 2: In second stage chromosomes are fixed for customer represented by m and warehouse location represented by r in Multi-objective Integrated Allocation Inventory Problem. The dimensional vector (m+1) represents schema. The values ranging from 1 to r is taken by each integer in the vector. Position vector represents warehouse allocation to customer whereas additional position vector represents maximum inventory at facility. One of the objective here is to minimise the maximum inventory at each stage.

Stage 3: Fitness values of all objective functions are defined based on gene evolution criteria's.

Stage 4: Initial populace of chromosomes as indicated stage 2.

Stage 5: This stage applies genetic operation. Genetic depiction of Multi-objective Integrated Allocation Inventory Problem is an integer permutation for 1st m – vector. Preceding vector is real coded. First m vectors are activated through n point cross over and n point mutation where n-vectors are chosen arbitrarily and their value is altered, [4]. Real coded Genetic Algorithm practises simulated binary crossover operator for crossover and mutation, [4], [2] and [13].

Stage 6: Run Genetic Algorithm procedure as defined by TDEA.

Extensive tests were carried out to find out a competent set of parameters for the TDEA. Five parameters values are needed for TDEA viz. size of populace, crossover points, perturbation mutation point, iterations and size of territory.

After having implemented the method and after following stages described above we got results for various combination of warehouses is summarised in Table 6.

Table 6. Parameter values of TDEA for case.

Warehouse option	Distribution Cost (Rs)	Regular stock (tons)	Safety stock (tons)	Total inventory (tons)
W1	2657193	31	247	277
W2	2470183	31	226	257
W3	2889922	31	256	286
W4	2376949	31	216	247
W12	2384969	44	234	278
W13	2615603	45	247	292
W14	2414957	45	231	275
W23	2564881	44	236	280
W24	2368207	41	217	258
W34	2489858	44	233	277
W123	2385735	54	234	288
W134	2436969	56	235	291
W234	2371199	55	215	270
W1234	2354006	63	228	290

From Table 6 and Figure 3, we can see that combination of warehouse 1,2,3,4 as optimal solution. However, there is 2nd option i.e. choosing Warehouse 4 as an alternate optimal solution. The solutions above will help decision maker to take right decision for organisation.

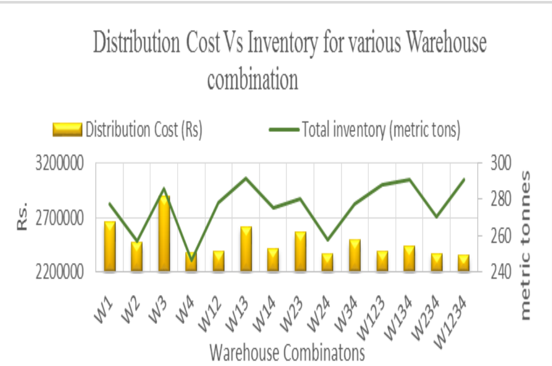

Figure-3: Distribution cost Vs Inventory for various combination of Warehouse

The analysis reflects the savings in overall distribution cost:

- Cost with Warehouse 1 as distribution centre = Rs. 2.657 Million per month
- Cost with Warehouse1, Warehouse2, Warehouse3 and Warehouse 4 as distribution centres = Rs. 2.354 Million per Month
- Savings over existing system Rs. 0.3 Millions /month
- Annual Savings Rs.3.6 Millions

The efficient frontier as shown Figure 4.

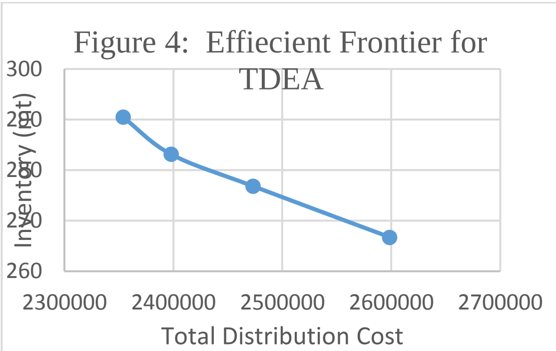

Figure 4: Efficient frontier for TDEA

The relationship of Warehouse combination with overall distribution cost and inventory in tons is shown below in Figure 5.

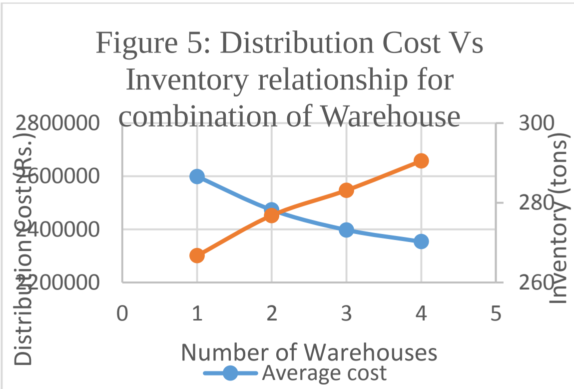

Figure 5: Distribution cost Vs Inventory in combination with No. of Warehouses

The existing distribution network is shown in Figure 6, whereas distribution network for 4 warehouse locations with allocation of retailers based on results of the model is shown in Figure 7.

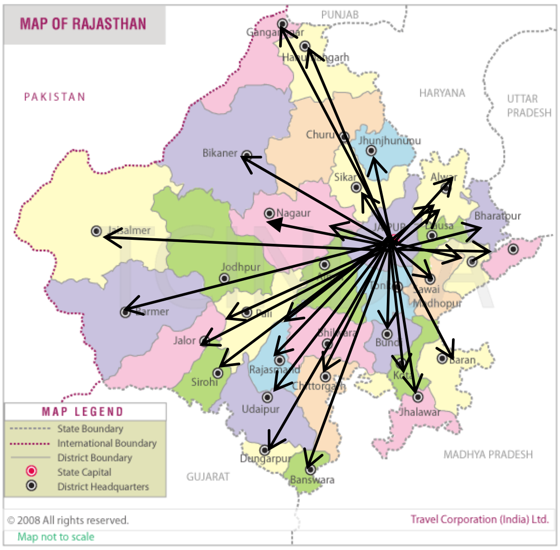

Figure-6: Distribution Network – Before

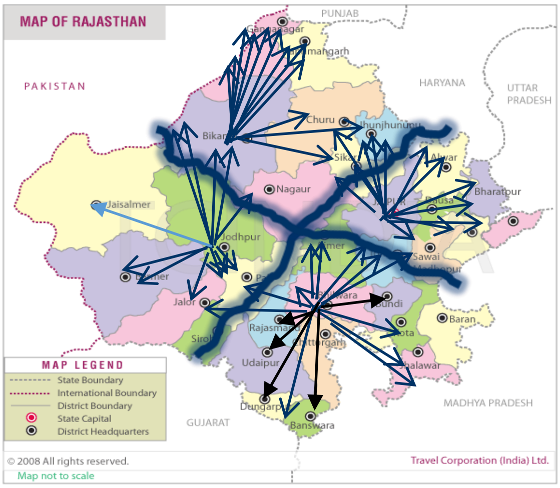

Figure 7: Distribution Network – After

6. Conclusion

The paper presented here is based on realistic situation of Indian steel wire manufacturer. The integrated steel retail supply chain is optimized based on actual data obtained from the organisation and its distributor. Territory Defined Evolutionary Algorithm (TDEA) is applied to solve non-linear formulation with stochastic demand characteristics from retailers. The input parameters considered for optimization are order cost, inventory carrying cost (for normal and safety stock), transportation cost for movement of from goods from one point to another point taking into account required service levels. Model produced Pareto front to make most prudent choice on number of warehouses required and to choose right location of warehouse to take care of already retailer reach deficit territories. The overall distribution cost designed is used for necessary evaluation as to which option would be better for future distribution network. The results obtained through model are used to allocate individual retailers to particular distribution center based on distance and overall distribution cost to avoid confusion as to which DC to serve which retailer. Moreover, results obtained through model are capable enough to derive managerial insights for necessary changes required in restructuring of the steel retail supply chain by increasing or decreasing level of input parameters.

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Abbreviations:

DC(s) : Distribution Centre(s).
EA : Evolutionary Algorithm.
TDEA : Territory Defined Evolutionary Algorithm
SCM : Supply chain management.
SCN : Supply chain network
GI : Galvanised Iron Wire
GP : Galvanised Plain Coil and Sheet
GC : Galvanised Corrugated Sheet
LRPC : Low Relaxation Pre-Stressed Concrete
OEM : Original Equipment Manufacturer
MOIAIP: Multi-Objective Integrated Allocation-Inventory Problem
MIS : Management Information System
FMCG : Fast Moving Consumer Good
NLP : Non-Linear Programming
IP : Integer Programming