A Genetic Algorithmic Approach for Optimizing Supply Chain Network Designs for Retail Distribution Networks

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Abstract

The modern industries are compelled to become more competitive for providing the quality product at a minimum cost. In particular, companies have to analyze the efficiency of their logistic operations and need to adopt a holistic view of the entire supply chain network. The network design optimization attempt to optimize the flows of goods traverse among the main entities of the supply chain, not limited to the suppliers, warehouses, distribution centers, retailers and customers. In this study, Network Optimization (NO) will be carried from the perspective of the Retail Supply Chain (RSC) and study proposes a Genetic Algorithm (GA) for optimizing a novel mathematical model of the retail SCND. Most of the real world scenarios involve multi-source, multi-stage and multi-product with large instances. Therefore, the developed GA is more beneficial for real world scenarios strategic decisions such as location and allocation decisions and also to perform powerful 'what if' analyses. The authors have elaborated the GA with numerical examples and compared the results. The outcome of the study proposes the GA approach to reduce the distribution network design cost and the most appropriate number of facilities to minimize total supply chain costs to match the organization's service goals.

Keywords: *Genetic Algorithm (GA), Mixed Integer Linear Programming (MILP), Network Optimization (NO), Retail Distribution, Supply Chain Network Design (SCND), Supply Chain Performance*

1. Introduction

A world-class transformational supply chain begins with a network that employs an all-encompassing view of the various business areas that manage the delivery of products to customers. The result is significant capital, operational, and tax savings while achieving optimal customer satisfaction. The result is significant capital, operational, and tax savings while achieving optimal customer satisfaction.

As customer service requirements become more complex, supply chain optimization studies have become the foundation for some of the most successful companies' logistics and fulfillment operations. Thus, world-class organizations now realize that non-integrated manufacturing processes, non-integrated distribution processes and poor relationships with suppliers and customers are inadequate for their success [4]. The network design problem is one of the most comprehensive strategic decision problems that need to be addressed for a long-term efficient operation of the entire supply chain. The SCND provides an optimal platform for efficient and effective supply chain management [8] and also determines the number, location, capacity and type of plants, warehouses and DCs to be used [2].

Due to the complexity of Location Routing Problem (LRP), the exact methods have been used for solving small sized instances, and only for two-index formulations [6]. Three-index formulations, a more versatile but more complex, have not been solved optimally. Therefore, multi-stage formulation is realistic as well as a timely research which has a significant practical importance. Many of studies have focused only a two-stage supply chain network design with multi-product and/or multi-source scenarios. Therefore, in this study, authors consider the multiproduct, multi-source, multi-stage nature of the SCND. The multi-stage formulation has more advantages as opposed to the single SCND formulation. Furthermore, the proposed GA considered six stages on SCND and the Network Optimization (NO) will be carried from the perspective of Retail Supply Chains (RSC) and study proposes a Genetic Algorithm (GA) for optimizing the MILP. Most of the real world problems deal with large instances consisting multi-source, multi-stage and multi-products. Therefore, the developed model is more beneficial for real world strategic decision making such as location and allocation decisions. The authors have developed the new GA to optimize the retail SCND and has validated the solutions with the CPLEX optimization, which was developed by [15].

2. Literature Review on SCND Optimization

The authors report a rigorous literature survey with the approaches gaps and applicability of existing literature related to the network design optimization of supply chain network. The review process is carried out by extending the published review literature from [12] and [10], which consists articles up to 2016.

Network design is the basis for the efficient operation of the supply chain and consequently one of the most important problems a supply chain manager is called to solve. During the past decades, there have been some interesting studies in the literature concerning the network design problem [12]. Review of the SCND problems are depicted in Table 1 with application areas and solving techniques.

As the review, most of the studies are in related to the production-distribution planning. A few of the studies focused with on the distribution network planning. The authors have reviewed the literature across the production-distribution and distribution network planning studies to enhance the understanding of problem formulation and applicability of the proposed model. There are two studies, which have concerned about supply chain network design optimization. One of the studies have solved by using empirical test cases, whereas the other one has solved by using CPLEX. The CPLEX approach cannot be used for large instances and only one study has used GA with a single source approach. Therefore, there is an open research area for the SCND optimization with GA for multi-source and multi products context.

Table 1. Summary Of The Literature Review

Study	Application Area	Solving Technique
[19]	Production- distribution, Facility location-allocation	Heuristic procedure with the aid of Lagrangian relaxation
[23]	SCND optimization, production-distribution planning	Lagrangian heuristic and GA
[1]	Capacitated location-allocation	MILP and Spanning tree based genetic algorithm (GA)
[22]	production–distribution model with consideration bills of materials (BOM)	MILP problem solved using LINDO
[24]	Production-distribution	Heuristics
[25]	Facility location-allocation problem	Non-linear integer program and propose a Lagrangian-relaxation solution algorithm
[2]	Facility location-allocation problem	Non-linear integer program and propose a GA
[3]	Production-distribution planning	MILP and heuristics
[13]	Transportation planning	Non-linear integer program and propose a spanning tree-based GA
[9]	design task involves the choice of facilities (plants and distribution centers (DCs)) to be opened and the distribution network design to satisfy the customer demand	GA and result compared with CPLEX, Lagrangian heuristic, hybrid genetic and simulated annealing algorithms
[16]	Facility location	Non-dominated sorting algorithm (NSGA II)
[18]	Distribution network planning	MIP and heuristics
[20]	Distribution allocation	A mathematical model is formulated as an integer-programming and the model is solved using GA-based heuristic
[17]	Production-distribution	MILP and particle swarm optimization heuristic algorithm
[10]	Production-distribution planning	Heuristics based on Tabu Search (TS)
[14]	Supply chain network design optimization	Empirical test cases
[15]	Supply chain network design optimization	Simulation and optimization based approach. Optimization has performed with CPLEX

3. Formulation of the GA

The Genetic Algorithm (GAs) using the Darwinian concept was first introduced by Holland (1975). GA is useful when a large search space with little knowledge of the solution is presented, and has been successful in providing near optimal solution for many diverse and difficult problems [10]. Overall GA procedure is depicted in Figure 1.

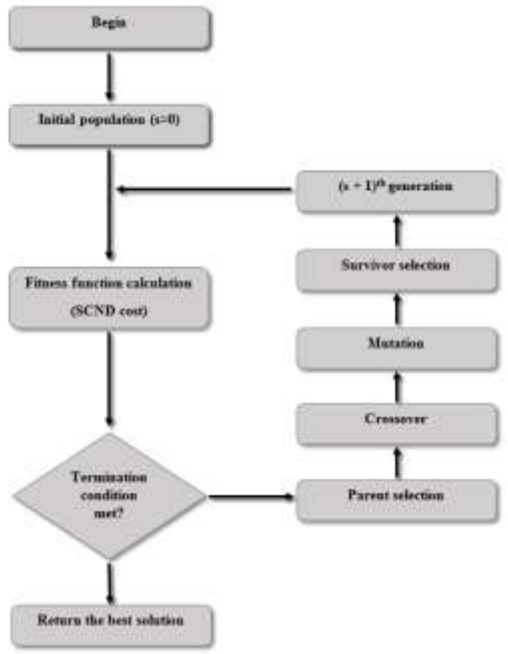

Figure1. Overall GA Procedure

A. *Chromosome Representation*

Literature suggests to use the flexible multi logistics network (fMLN) with vertex based encoding GA solution to find the best route for delivering the product to each customer when the network is single source [11]. In our approach to depict the multi product, multi-source SCND nature. The chromosome is represented as an edge based. The formulation has a SCND with six different delivery routes along with multiple products as supplier to warehouse, warehouse to DC, DC to retailer, supplier to DC, supplier to retailer and warehouse to retailer. Therefore, the length of every chromosome is equal to:

$$X \times (I(J + K + L) + J(K + L) + K(L)) \quad (1)$$

Where;
X: Number of Products
I: Number of Suppliers
J: Number of Warehouses
K: Number of DCs
L: Number of Retailers

There are six different types of decision variables as $Q1_{xij}$, $Q2_{xjk}$, $Q3_{xkl}$, $Q4_{xil}$, $Q5_{xik}$ and $Q6_{xjl}$ and they are depended on the number of suppliers, warehouses, DCs, retailers, and products. Every gene represents the product amount shipped between different facilities. Figure 2 is depicted the proposed chromosome representation to solve the multi-product, multi-source SCND problem.

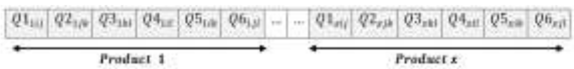

Figure 2. Chromosome Representation

B. *Initialization*

A random chromosome generation has been implemented to generate the initial population and the fitness of each chromosome is equal to the corresponding SCND cost, which is obtained by multiplying shipping quantity, unit shipping cost and distance. The first generated population is improved by applying crossover and mutation genetic operators.

The value for each gene is generated randomly within a defined and specific range. In this study, this specific range is defined by generating random value in between 0 and upper limit value. This upper limit value is defined by considering retailers demand values. Because, each SCND should be satisfied the retailer's demand.

The fitness of each chromosome equal to the corresponding SCND cost. Developed GA fitness function calculation is based on the model developed by [14] where the total supply chain network design cost is minimized. The overview of the proposed GA is depicted in Figure 3.

C. *Genetic Operators*

In order to enhance the ability of producing new solutions, this study is employed the cross over and mutation operators. Due to the different natures of the different products in the chromosome, crossover and mutation operations are performed in separately with each product.

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Procedure: GA for SCND optimization
  Input: Problem data
      initialize P(g) // population of chromosomes
  Output: Best Solution
      for g = 0 to G // g generation number
          GA capacitated constrained checking
          fitness evaluate P(g) // evaluation function is objective function
              while (termination criteria is reached) do
                  select C1 and C2 by tournament selection from P(g)
                  apply cross over to obtain C
                  apply mutation to C
                  // generate new offsprings
                  fitness evaluation of C
                   select P(g + 1) from P(g) and C by romoving the worst solution
                  g ← g + 1
              end while
      output : best solution
      end for
```

Figure3. Proposed GA

1) Crossover

This operator allows genetic material to be exchanged between two chromosomes with the aim of exploring new solution spaces [5]. Cross over operates on two parent chromosomes at a time.

It generates offspring by adding both chromosomes' features. A sample illustration of cross over operator is depicted in Figure 4, Figure 5 and this sample is illustrated for one supplier, one warehouse, one DC and one retailer for multi-product.

Step 1: generate a random split point from each product to cross over. (Figure 4)

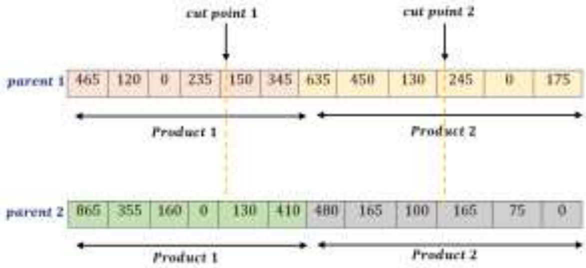

Figure 4. Step 1 Overview

Step 2: Exchange substrings between parents and generate new offspring. (Figure 5)

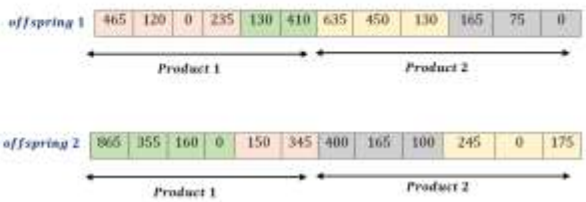

Figure5. Step 2 Overview

1) Mutation

This operator produces spontaneous random changes in one or more chromosomes of a population generation selected on a fitness basis [5]. In the proposed GA, a gene swapping mutation operator is executed. It randomly selects two genes from each product within a chromosome and exchange their positions each other. A sample illustration of mutation operator is depicted in Figure 6.

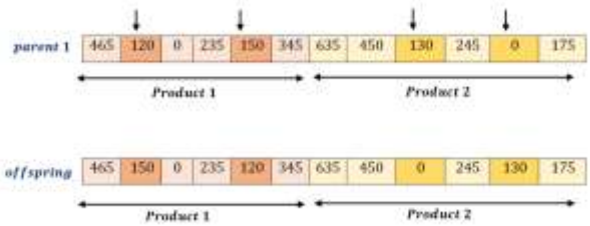

Figure 6. Mutation Overview

In this study, GA was developed to solve the SCND problem, which was formulated by [14], and performance comparison was carried through GA and CPLEX solution computed previously by the authors [15] lot of diversification in the solutions. Consequently, it is better to use an evolutionary algorithm like GA in this phase [7].

4. Discussions and Findings

The proposed GA chromosome representation, initialization, crossover and mutation have been explained in previous section. The algorithms were coded in C#.Net language and the parameters have been tuned for the proposed GA. Results of the proposed GA is depicted in Table 2.

A. Performance Comparison of Developed GA

With an approximation method like GA, it is not ensured the optimum solution is found.

Therefore, the solution obtained with the GA is compared with those obtained with CPLEX [15].

According to the results obtained in Table 2, it can be seen that as the number of generations increase, the solution quality enhances. From the GA, the minimum value is reached when the GA parameter of the generation size is fixed to five. In Figures 7 and 8 show this phenomenon.

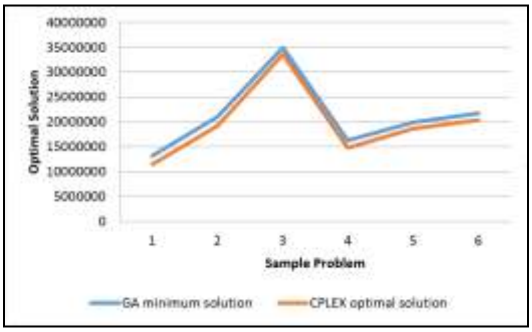

Figure 7. Performance comparison for first six sample problems

Table 1. GA solutions for sample problems

Sample Problem	Parameters tuning with varying size of the Generation size in the GA				
	1	2	3	4	5
01	13, 636, 420	13, 356, 785	13, 347, 360	13, 269, 780	13, 158, 690
02	21, 436, 450	21, 342, 830	21, 198, 760	21, 136, 960	21, 065, 490
03	35, 087, 960	34, 969, 520	34, 723, 695	34, 725, 875	34, 926, 650
04	16, 526, 555	16, 465, 452	16, 136, 450	16, 136, 985	16, 236, 895
05	20, 325, 645	20, 136, 540	20, 136, 525	19, 888, 995	19, 865, 750
06	22, 236, 450	22, 036, 980	22, 036, 475	21, 936, 210	21, 723, 920
07	17, 656, 980	17, 536, 565	17, 523, 325	17, 223, 680	17, 232, 640
08	27, 269, 545	27, 220, 075	27, 034, 895	26, 958, 750	26, 932, 125
09	49, 923, 695	49, 823, 680	49, 767, 855	49, 775, 660	49, 678, 930
10	28, 136, 450	27, 936, 495	27, 648, 750	27, 769, 840	27, 469, 780
11	34, 526, 985	34, 526, 970	34, 264, 450	33, 969, 785	33, 865, 210
12	36, 598, 750	36, 572, 655	36, 498, 760	36, 149, 320	36, 126, 695

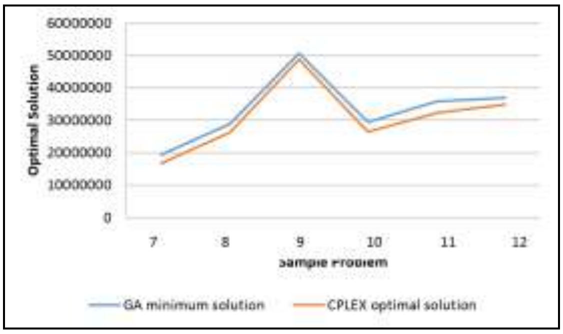

Figure 8. Performance comparison for last six sample problems

Since most of the real world scenarios are large cases, the model should be facilitated to reach optimal solution within a reasonable timeframe. To evaluate the accuracy, the authors have calculated a gap calculation between CPLEX and GA solutions for above 12 sample problems within 10 generations. Gap calculation are depicted in Table 3 and 4. It is facilitated to enhance the accuracy and fine function of the proposed model with GA.

$$\text{Gap} = \frac{\text{GA Minimum Solution} - \text{CPLEX Optimal Solution}}{\text{CPLEX Optimal Solution}} * 100 \quad (2)$$

This study has used the GA and CPLEX together for validation of the proposed approach using different scenarios and compared the outputs to demonstrate the quality of the performance [15]. By using the gap calculation, the authors concluded that the newly proposed GA is more suited for large-scale real world scenarios to optimize the SCND with minimum distribution cost.

6. Conclusion

In this study, initially a thorough systematic review has been carried out on SCND model approaches and problem formulations. Subsequently, the authors have considered the new MILP model for retail SCND by taking into account several factors such as transportation cost, capacity allocation and optimal facility location based on the study of [14]. The novelty of this study is carried out by considering distance from facility to facility with SCND and multi-echelon approach with new proposed GA. Therefore, the proposed GA is a new approach, which covers multi-product, multi-stage and multi-source scenarios together.

The solutions obtained have been compared solution with CPLEX optimal solution, which was obtained by [15]. Finally, the proposed GA is a more suitable approach for solving the SCND real world scenarios.

Furthermore, this study provides solutions for determining; the most profitable combination of supplier-warehouse-DC-retail mapping for product flows, locations of Distribution Centers (DCs) and, warehouses and locations for setting up new warehouse/DC, and capacities of DCs and warehouses.

Table 3. Gap Calculation for Sample Problems 01-06

Sample Problem	01	02	03	04	05	06
GA minimum solution	11, 708, 690	19, 465, 490	33, 626, 650	15, 036, 895	18, 865, 750	20, 543, 920
CPLEX optimal solution	11, 520, 880	19, 248, 380	33, 589, 850	14, 755, 220	18, 655, 860	20, 331, 350
Gap (%)	1.63	1.12	0.10	1.90	1.12	1.04

Table4. Gap Calculation for Sample Problems 07-12

Sample Problem	07	08	09	10	11	12
GA minimum solution	16, 932, 640	26, 332, 125	49, 078, 930	26, 669, 780	32, 565, 210	35, 326, 695
CPLEX optimal solution	16, 713, 430	26, 237, 330	48, 681, 050	26, 362, 970	32, 202, 610	34, 942, 930
Gap (%)	1.31	0.36	0.81	1.16	1.12	1.09

References

[1] Admi Syarif, YoungSu Yun, Mitsuo Gen, Study on multi-stage logistic chain network: a spanning tree-based genetic algorithm approach, *Computers and Industrial Engineering*, vol. 43, pp. 299-314, 2002.

[2] Altiparmak, F., Gen, M., Lin, L. and Paksoy, T., A genetic algorithm approach for multi-objective optimization of supply chain networks, *Computers & Industrial Engineering*, vol. 51, pp. 196-215, 2006

[3] Burcu B. Keskin and Halit Üster, "Meta-heuristic approaches with memory and evolution for a multi-product production/distribution system design problem," *European Journal of Operational Research*, vol. 182, no. 2, pp. 663–682, Oct. 2007

[4] Chandrasekaran Sowmya Danalakshmi and Gabriel Mohan Kumar, Optimization of Supply Chain Network Using Genetic Algorithm, *Manufacturing and Industrial Engineering*, Issue 3,pp. 30-35, 2010

[5] Costa, A., Celano, G., Fichera, S. and Trovato, E., A new efficient encoding/decoding procedure for the design of a supply chain network with genetic algorithms, *Computers and Industrial Engineering*, vol. 59, no. 4, pp. 986-999, 2010

[6] D. Ambrosino and M. Grazia Scutellà, "Distribution network design: New problems and related models," *European Journal of Operational Research*, vol. 165, no. 3, pp. 610–624, Sep. 2005

[7] Esmaeil Mehdizadeh and Fariborz Afrabandpei, Design of a Mathematical Model for Logistic Network in a Multi-Stage Multi-Product Supply Chain Network and Developing a Metaheuristic Algorithm, *Journal of Optimization in Industrial Engineering*, vol. 10, pp. 35-43, 2012

[8] F. Varasteh, "Using Genetic Algorithm for Supply Chain Network Optimization," pp. 01–06, 2007. Available.https://www.researchgate.net/publication/228551885_Using_Genetic_Algorithm_for_Supply_Chain_Network_Optimization

[9] Fulya Altiparmak, Mitsuo Gen, Lin Lin, Ismail Karaoglan, A steady-state genetic algorithm for multi-product supply chain network design, *Computers & Industrial Engineering*, vol. 56, pp. 521-537, 2009

[10] Gabriel Machado Braido, Denis Borenstein, Gilmar D'Agostini Oliveira Casalinho, Supply chain network optimization using a Tabu Search based heuristic, São Carlos, vol. 23, no. 1, pp. 03–17, 2016

[11] Gen, M., Cheng, R. and Lin, L., Network Models and Optimization: Multiobjective Genetic Algorithm Approach, Springer-Verlag London Limited, 2008

[12] Kostis Taxakis and Chrissoleon Papadopoulos, A design model and a production–distribution and inventory planning model in multi-product supply chain networks, *International Journal of Production Research*, http://dx.doi.org/10.1080/00207543.2016.1158882, 2016

[13] Ming-Jong Yao and Hsin-Wei Hsu, A new spanning tree-based genetic algorithm for the design of multi-stage supply chain networks with nonlinear transportation costs, *Optim Eng*, vol. 10, pp. 219-237, 2009

[14] Munasinghe, I. and Rupasinghe, T. , A supply chain network design optimization model from the perspective of a retail distribution supply chain. In: *Manufacturing & Industrial Engineering Symposium* (MIES). Colombo: IEEE, 2016

[15] Munasinghe, I. & Rupasinghe, T., Simulation and Optimization-based Approaches to Assess the Behaviour of the Retail Supply Chain Network Designs. Colombo, *TIIKM*, pp. 17-29. , 2017

[16] Ranjan Bhattacharya and Susmita Bandyopadhyay, Solving conflicting bi-objective facility location problem by NSGA II evolutionary algorithm, *International Journal Advance Manufacturing Technology*, vol. 51, pp. 397-414, 2010

[17] Sasan Khalifehzadeh, Mehdi Seifbarghy, Bahman Naderi, A four-echelon supply chain network design with shortage:Mathematical modeling and solution methods, *Journal of Manufacturing Systems*, vol. 35, pp. 164-175, 2015

[18] V. Golmohammadi, H. Afshari, A. Hasanzadeh, and M. Rahimi, A heuristic approach for designing a distribution network in a supply chain system, *African Journal of Business Management*, vol. 4, no. 3, pp. 308–311, 2010

[19] Vaidyanathan Jayaraman and Hasan Pirkul, Planning and coordination of production and distribution facilities for multiple commodities, European *Journal of Operational Research*, vol. 133, pp. 394-408, 2001

[20] Vinay V. Panicker, R. Sridharan, B. Ebenezer, Three-stage supply chain allocation with fixed cost, *Journal of manufacturing technology management*, vol. 23, pp. 853-868, 2012

[21] Ronald G. Askin, Ilaria Baffo, Mingjun Xia, Multi-commodity warehouse location and distribution planning with inventory consideration, *International Journal of Production Research*, vol. 52, pp. 1897-1910, 2014

[22] Yan, H., Yu, Z., Cheng, E.T.C., A strategic model for supply chain design with logical constraints: Formulation and solution, *Computers & Operations Research*, vol. 30(14), pp. 2135–2155, 2003.

[23] Yang-Ja Jang, Seong-Yong Jang, Byung-Mann Chang, Jinwoo park, A combined model of network design and production/distribution planning for a supply network, *Computers and Industrial Engineering*, vol. 43, pp. 263-281,2002

[24] Y.B. Park, An integrated approach for production and distribution planning in supply chain management, *International Journal of Production Research*, vol. 43, pp. 1205–1224, 2005

[25] Zuo-Jun Max Shen, A multi-commodity supply chain design problem, IIE, vol. 37, pp. 753-762, 2005 http://dx.doi.org/10.1080/07408170590961120