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Particle Swarm Optimization Based Genetic Algorithm for Two-Stage Transportation Supply Chain

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Abstract**—**Supply chain consists of all stages involved, directly or indirectly, includes all functions involved in fulfilling a customer demand. In two stage transportation supply chain problem, transportation costs are of a significant proportion of final product costs. It is often crucial for successful decisions making approaches in two stage supply chain to explicit account for non-linear transportation costs. In this paper, deterministic demand and finite supply of products was considered. The optimized distribution level and the routing structure from the manufacturing plants to the distribution centres and to the end customers is determined using developed mathematical model and solved by proposed particle swarm optimization based genetic algorithm. Numerical analysis of the case study is carried out to validate the model.

Keywords**—**Genetic Algorithm, Particle Swarm Optimization, Production, Remanufacturing

I. Introduction

THE primary purpose for existence of any supply chain is to satisfy customer needs, in the process generating profits for itself. Supply chain activities begin with a customer order and end when a satisfied customer has paid for his or her purchase. The term supply chain conjures up images of product, or supply, moving from suppliers to manufacturers to distributors to retailers to customers along a chain. A typical supply chain may involve a variety of stages like customers, retailers, wholesalers/distributors, manufacturers, component/ raw material suppliers. Objective of every supply chain is to maximize the overall value generated. Supply chain success should be measured in terms of supply chain profitability and not in terms of profits at an individual stage. Successful supply chain management requires several decisions relating to the flow of information, product, and funds. These decisions fall into three categories or phases, supply chain strategy or design, supply chain planning and supply chain operation, depending on the frequency of each decision and time frame over which a decision phase has an impact.

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Supply Chain Management (SCM) is defined as "Maximizing added value and reducing total cost across the entire trading process through focusing on speed and certainty of response to the market." It is the term used to describe the management of the flow of materials, information, and funds across the entire supply chain, from suppliers to component producers to final assemblers to distribution (warehouses and retailers), and ultimately to the consumer. SCM has become a necessity especially for manufacturing industry when it comes to deliver products at a competitive cost and at a higher quality than their competitors. SCM has allowed business nowadays to not just have productivity advantage alone but also on value advantage. Mass manufacturing offers productivity advantage but through effective supply chain management, mass customization can be achieved. With mass customization, customers are given the value advantage through flexible manufacturing and customized adaptation. In this paper, the investigation of supply chain configuration has been done using a single product two-stage transportation model with a focus on the capacity of the plants, capacity of the distribution centers, demand at the end customers, fixed cost and transportation cost between plants to distribution centers and distribution centers to the end customers. We proposed particle swarm optimization based genetic algorithm is applied to solve the problem.

II. Literature Review and Methodology

A two-level mathematical model for supplier selection in developing a supply chain network to minimize the end customer’s level of dissatisfaction by making a trade off between price and delivery lead time by assuming that there is a defined set of potential suppliers at each stage of the supply chain [1]. Supply chain scheduling has the complexities of the two aspects initiated respectively by MC and supply chain environment at the same time [2]. To provide a topology of the field of supply chain management as an aid to both the classification of research in the field, and as a means of providing a framework for the identification of the key content of the subject [3]. A mathematical model for the two-stage supply chain fixed charge distribution problem is formulated and solved using a GA-based heuristic method [4]. A steady-state genetic algorithm (SSGA) for the single-source multi-product multi-stage supply chain network design problem, which is a NP-hard problem, a new encoding structure to represent a solution for the problem and new greedy heuristics to generate initial population were employed [5]. The decisions related to the development of a SCN are strategic in nature. The approach presented here is to facilitate the decision-making process and not to force the decision. As the solution depends on the set of data, the objective functions with different sets of data will be different [6]. Moreover, the characteristics that a facility location model should have been identified to adequately address SCM planning needs [7]. The main conclusion that can be drawn from this review is that finding a growing stream of research aiming at the integration of strategic and tactical/operational decisions in supply chain planning. A five- tiered network and the variation inequality formulation of governing equilibrium condition utilized in order to obtain qualitative properties as well as the computation of the equilibrium flows and prices by making some assumptions [8]. A large-scale model for the supply chain planning problems arising at a pulp company by combining the rolling planning horizon and the Lagrangian decomposition is discussed. They generated several candidate solutions by starting from different dual solution by applying the rolling horizon heuristic. In addition, it do generate bounds which are better than the LP relaxation value [9].

A new HGA approach both with a local search technique and adaptive local search scheme has been proposed in this study using a hill climbing method for local search method [10]. An online system that can reduce the bullwhip effect dramatically along supply chains by applying computational intelligence techniques is proposed [12]. The proposed algorithm is inspired by the particle swarm optimization technique [13]. A group (swarm) of virtual particles is moving in discrete intervals through the search space. Particles represent solution instances in the search space. Each particle keeps track of the best solution (location) it encountered in its path (pbest, particle's best) and the best location encountered by all particles (gbest, global best). The next move of each particle is controlled by a velocity vector that is influenced by both pbest and gbest. Kennedy and Spears have concluded through rigorous experimentation that PSO is able to accomplish the same goal as GA optimization in a new and a faster way [14]. A hybrid algorithm in which a population of genetic algorithm is taken, when the improvement began to level off, and used as the starting population of the particle swarm optimization algorithm [15].

The investigation of supply chain configuration has been done using a single product two-stage transportation model with a focus on the capacity of the plants, capacity of the distribution centers, demand at the end customers, fixed cost and transportation cost between plants to distribution centers and distribution centers to the end customers. The three entities plants, distribution centers, end customers are considered in this supply chain model. The model is generalized by considerations of 'I' number of plants, 'J' number of distribution centers and 'K' number of customers. The total number of products manufactured at plants depends on demand of the end customers. The cost level in transporting the products between plants and the end customers depends on the logistic flow structure from the plants to the end customers. So the cost factor may come in accordance with optimal transportation root. In designing the model three sub systems need to be analysed.

- The capacities of plants and distribution centers demand at the end customers.
- Route between which the product is transported from plants to the customers.
- The quantity of product transporter through the corresponding routes.

A synthesis of these sub systems is used to minimize the total cost of the supply chain. The purpose of two stage transportation model is to develop a network of flow of products from plants to distribution centers and then to the customers by minimizing the transportation cost of the entire supply chain. The minimum cost is achieved by following the most efficient way of transporting the manufactured products from plants to distribution centers and from distribution centers to the end customers. The processes of analysis and selection of the best transportation method is done by using genetic algorithm. Details of the methodology are given in Appendix I

III. Particle Swarm-based Genetic Algorithm

Conceptually, particle swarm optimization technique seems to lie somewhere between genetic algorithms and evolutionary programming. It is highly dependent on stochastic processes, like evolutionary programming. The adjustments toward pbest (local best) and gbest (global best) by the particle swarm optimizer are conceptually similar to the crossover operation utilized by genetic algorithm. It uses the concept of fitness, as do evolutionary computation paradigms. In this proposed approach, the chromosomes in the initial genetic algorithm population are treated as particles in a swarm and crossover operator of GA is done in two steps. In the first step, a particle is crossing with its local best and one of new child particle is crossing with its (parent particle) global best. Mutation operator of GA is not considered in this proposed approach.

Priority-based encoding structure is considered for genetic representation in GA. The priority-based encoding is applied to a single-product transportation problem, a chromosome consists of priorities of sources and depots and its length equals to total number of sources ($|K|$) and depots ($|J|$), i.e. $|K| + |J|$. Depending on the selected source (depot), a depot (source) is determined considering minimum transportation cost and an arc between them is added to corresponding network. In the algorithm, while the chromosome is defined as $v(t)$, b_j, a_k, f_{kj} are the demand on depot j for product, capacity of source k, space requirement of product on a source and shipment amount of product between source k and depot j, respectively. Decoding of the chromosomes is given in Appendix I. The initial population is generated randomly and evaluation aims to associate each individual with a fitness value so that it can reflect the goodness of fit for an individual. In this proposed approach, the objective function has been taken as fitness function. Two parents are selected from the population by the binary tournament selection mechanism in every generation. The crossover is done to explore new solution space and the crossover operator corresponds to the exchanging parts of the strings between selected parents.

In this proposed algorithm, new generation is created by crossing each particle (here the chromosome is treated as the particle in a swarm) with its local best solution and the global best solution. In PSO, each solution is adjusted based on the best chromosome in its search path through the generations (pbest) and the best chromosome generated up to that point (gbest). A chromosome is first crossed with pbest resulting in two children from that one is chosen randomly. The chosen chromosome is then crossed with gbest using the same operator. Again, one of the resulting two children is chosen randomly and copied to the new generation. Therefore, the outcome of a crossover operator assumes a location in the search space in the average space that includes the parent particle, the best solution in its search path and the best solution found over the whole population. Procedure adopted is given in Appendix III.

IV. Results and Discussions

The proposed Particle Swarm-based GA is tested with the actual data obtained from a company which is one of the producers of plastic which is planning to produce plastic profile which is used in buildings (vinyl sidings, doors, windows, fences, etc.), pipe lines and consumer materials. The company intends to establish new plants at three potential locations which were determined depend on the some specific considerations. The company is planning to open at most six DCs as the demand densities of 63 customer zones to be served and access time from DCs to customer zones. The company intends to establish supply chain network that satisfying the company objectives for the product and to meet customer demands from DCs. The input values given in Table I and II.

TABLE I
Capacities and Demands of Plants, DC's and Customers

Plants		Distribution Centre (DC)		Customers Demand		Fixed Cost of DC's ($)
No.	Capacity	No.	Capacity	No.	Demand	
1	500	1	590	1	350	24.0
2	490	2	400	2	340	26.0
3	500	3	130	3	360	24.6
		4	370	4	440	25.4

This example problem is optimised by using genetic algorithm by random generation of the initial solution and then optimizing the total cost taken. The desired heuristic method was incorporated in the form of program based on the algorithm developed by using MATLAB software. The program developed was tested with numerous randomly generated problems. The minimum total cost for the product for plant to distribution centers and from distribution centers to customers was 741$. The flow of products is shown in the tables III and IV.

TABLE II
Transportation costs between different nodes

Commodity	From plant to DC	Cost ($)	From DC to customer	Cost ($)
Transportation cost for unit product	1-1	0.68	1- 1	0.30
	1-2	0.58	1-2	0.36
	1-3	0.76	1-3	0.32
	1-4	0.58	1-4	0.38
	2-1	0.46	2-1	0.34
	2-2	0.68	2-2	0.40
	2-3	0.60	2-3	0.24
	2-4	0.54	2-4	0.36
	3-1	0.70	3-1	0.50
	3-2	0.62	3-2	0.46
	3-3	0.64	3-3	0.30
	3-4	0.60	3-4	0.42
			4-1	0.40
			4-2	0.32
			4-3	0.26
			4-4	0.28

TABLE III
Product quantity from plant to DC

		Distribution Centers (DC)			
		1	2	3	4
Plants	1	100	400	0	0
	2	490	0	0	100
	3	0	0	130	370

TABLE IV
Product quantity from DC to Customers

		Customers			
		1	2	3	4
Distribution Centers	1	350	10	230	0
	2	490	0	0	400
	3	0	0	130	370
	4	0	370	0	40

V. Conclusions

A network for solving two-stage transportation problem in supply chain management has been developed which is an attempt to address some shortcomings such as improvement of initial solution. An attempt was made to solve the problem using priority-based encoded for chromosome representation and crossing each particle (chromosome) with its local best solution and the global best solution in genetic algorithm. The developed network is tested with a numerical example generated randomly. MATLAB was used as the platform for developing the program using which the problem was solved. Scope for further research can be done by extending the findings to more complicated problems such as multi-product, multi-stage supply chain problems.

Appendix I

A. *Mathematical Formulation*

We do a programming formulation to the single-product, multi-stage SCN design problem. This problem is to determine the subsets of plants and DCs to be opened and to design the distribution network strategy that will satisfy all capacities and demand requirement for each product imposed by customers with minimum cost. The assumptions used in this problem are:

- The number of customers and their demand capacities are known.
- The number of potential plants, DC's and their maximum capacities are known.
- Customers are supplied products from a single DC.

Indices and Parameters:

I set of plants (i to I)
J set of DCs (j to J)
K set of customers (k to K)
a_i capacity of plant i.
b_j capacity of DC j.
d_k demand of customer k.
W maximum number of DCs.
W maximum number of DCs.
g_j annual fixed cost for operating a DC j.
c_{jk} unit transportation cost from DC j to customer k.
t_{ij} unit transportation cost for product from plant i to DC j.
Decision Variables
z_j 1 if DC j is opened, 0 otherwise.
y_{jk} quantity of product shipped from DC j to customer k.
x_{ij} quantity of product shipped from plant i to DC j.

Objective Function

$$\min Z = \sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} c_{jk}y_{jk} + \sum_{j=1}^{J} g_j z_j \quad (1)$$

Term1: Total Transportation cost for product from Plant to DC.

Term2: Total Transportation cost for a product from DC to Customer.

Term3: Annual Fixed cost of a DC.

Subject to

$$\sum_{j=1}^{J} x_{ij} \le a_i, \quad \forall \text{ i} \quad (2)$$

$$\sum_{k=1}^{K} y_{jk} \le b_j z_j, \quad \forall \text{ j} \quad (3)$$

$$\sum_{j=1}^{J} z_j \le W, \quad (4)$$

$$\sum_{j=1}^{J} y_{jk} \ge d_k, \quad \forall \text{ k} \quad (5)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} = \sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk} \quad (6)$$

$$x_{ij}, y_{jk} \ge 0 \quad (7)$$

$$z_j = \{0, 1\} \quad (8)$$

Equation (2) and (3) ensure that the plant-capacity constraints and the distribution centre-capacity constraints, respectively. Constraint (4) satisfies the opened DCs do not exceed their upper limit. This constraint is very important when a manager has limited available capital. Constraint (5) ensure that all demand of customers are satisfied by opened DCs; Constraints (6) and (7) enforce the non-negativity restriction on the decision variables and the binary nature of the decision variables used in this model. Constraints (8) ensure that DC's are open or close.

APPENDIX II

Procedure: Decoding of the chromosome
Input: K : set of sources
J : set of depots
a_k : capacity of source k, $\forall$ k $\in$ K
c_{kj} : unit transportation cost of product from source k to depot j $\forall$ k$\in$K ; $\forall$ j$\in$J,
v (k+j) : chromosome, $\forall$ k$\in$K; $\forall$ j$\in$J,
Output: g_{kj} : quantity of product shipped from source k to depot j
step 1. g_{kj} ←0 , $\forall$ k$\in$K, $\forall$j $\in$J
step 2. l← arg max{v(t), t $\in$ |k|+|j|}; select a node
step 3. If l $\in$ K, then k*←l; select a source
j*←arg min{c_{kj} |v((j) $\neq$ 0, j $\in$ J}; select a depot with the lowest cost
else j*←l ; select a depot
k*←arg min {c_{kj} |v((k) $\neq$ 0,k $\in$K}; select a source with lowest cost
step 4. $g_{k^*j^*}$ ←min{a_k*/,b_j* }; assign available amount of units
Update availabilities on source k* and depot j*
a_k*=a_k* - $g_{k^*j^*}$; b_j*= b_j*- $g_{k^*j^*}$
step 5. If a_k*=0 then v(k*) = 0
If b_j*=0 then v(j*) =0
step 5. If v(k+j) =0, $\forall$ k$\in$K , $\forall$ j $\in$J, then calculate transportation cost and return
else go to step 1.

APPENDIX III

Procedure of the proposed Particle Swarm-based Genetic Algorithm
Input: Data, Parameters
Output: best solution
Begin
k 0;
initialize the population P(k);
evaluate P(k);
while not (termination condition) do
select P1 and P2 by binary tournament from P(k);
apply crossover to P1 and P2 using PSO
For each chromosome pi in P(k)
pbesti = pi
End
Denote the best chromosome in P as gbest
Repeat over all generations while termination is not reached
For all chromosomes pi in P(k)
c= outcome of crossover between pi and pbesti

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      pi = outcome of crossover between  c and gbesti
      If pi is better than pbesti
      pbesti = pi
      End if
      If  is better than gbest
         gbest = pi
      End if
      End for
      End repeat
      Evaluate pi
Update P(k) by deleting the worst solution and adding the pi
     End
     Output best solution
  End
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