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A Comparative Analysis of Genetic Algorithm and LINGO for an Inbound Transportation Model

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Abstract Supply chain management (SCM) has become a topic of critical importance for both companies and researchers today. Supply chain optimization problems are formulated as linear programing problems with costs of transportation that arise in several real-life applications. While optimizing supply chain problems, inbound logistic segment has been considered as one of the most neglected area in SCM. Very few studies have focused on utilizing optimization model on SCM that only accounts for inbound logistic system. This study has identified the research gap and proposed method attempts to minimize the total transportation costs of inbound logistic system with reference to available resources at the plants, as well as at each depot. Genetic algorithm and Lingo were approached to help the top management in ascertaining how many units of a particular product should be transported from plant to each depot so that the total prevailing demand for the company's products satisfied, while at the same time the total transportation costs are minimized. Finally, a case study involving a Bangladeshi renowned retail super shop is used to validate the performance of the algorithm. In order to evaluate the performance of the proposed genetic algorithm, the obtained result was compared with the outputs of LINGO 17.0. Computational analysis shows that the GA has result very close to optimal solution in very large-sized problems, and in case of small problems, LINGO that means exact method works better than heuristics.

Keywords: *supply chain, genetic algorithm, LINGO, inbound transportation cost*

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1. Introduction

Supply chain management is a field of growing interest for both companies and researchers. Supply chain management (SCM) definition varies from one enterprise to another. This chain is concerned with two distinct flows: a forward flow of materials and backward flow of information. At its highest level, a supply chain is comprised of two basic, integrated process: (1) The Production Planning and Inventory Control Process and (2) The Distribution and Logistic Process. The aim of logistics activities, as a bridge between manufacturers and customers, is to bring the right product to the right place in the right quantity at the right time [1]. Inbound and outbound logistics combine within the field of supply-chain management, as managers seek to maximize the reliability and efficiency of distribution networks while minimizing transport and storage costs. Inbound logistics refers to the transport, storage and delivery of goods coming into a business whereas outbound logistics refers to the same for goods going out of a business. According to Ali Naimi Sadigh [2] supply chain is an interrelating network of suppliers, manufacturers, distributors, and customers, plays an important role in competitive markets to satisfy customer demands. Recently it has been found that product delivery to customers in a suitable time with desirable quality and minimum cost is a complicated process that needs several internal and external organizational transactions. Since efficiency and responsiveness are two generic strategies for supply chain network design, coordination of these transactions is an important issue. The reason behind transportation's having a prime role in supply chain management is because products are never produced and consumed in the same place. According to the studies of [3], Genetic Algorithms work better where the traditional search and optimization algorithms fail to avail the goal performance. Genetic algorithm is the most popular algorithm that has been used to select optimal route. Many researchers are working on it to optimize routes in supply chain networks using Genetic algorithm. In this research GA was approached to get the total optimized cost and allocation of truckloads and prioritized further.

Our proposed model is composed of single objective function to minimize the total transportation costs between plant & depot and as well as to determine the best optimal truck load that to be transported from plant to depot.

The remainder of this paper is as follows. In Section 2, literature review of the approached problem is presented. Section 3 presents a descriptive idea about linear programing. The ordinary Genetic Algorithm is introduced in

Section 4. Section 5 presents the mathematical formulation for the transportation costs of truckloads. The solution procedure is explained in section 6. Section 7 represents the performance and comparison between GA and exact method by solving some numerical examples. Finally, conclusions and the future research points are drawn in Section 8.

2. Literature Review

In 1941 Hitchcock first developed the transportation model. Then the simplex method on the transportation problem as the primal simplex transportation method used by Dantzig [4]. The modified distribution method is useful in finding the optimal solution for the transportation problem. Whenever there is a physical movement of goods from the point of manufacture to the final consumers through a variety of channels of distribution (wholesalers, retailers, distributors etc.), there is need to minimize the cost of transportation (such as maintenance cost, personnel cost, fuel cost, and loading/offloading cost) so as to increase the profit on sales. Transportation problems arise in all such cases. It aims at providing assistance to top management in ascertaining how many units of a particular product should be transported from plant to each depot to that the total prevailing demand for the company's product is satisfied, while at the same time the total transportation costs are minimized [5]. According to Ali et. al. transportation criteria (for example costs and mode of transportation) play an important role in achieving sustainability across a supply chain, as well as enhancing supply chain performance [6]. Prichanont et. al. used discrete-event simulation to demonstrate that the number of trucks for harvested corps and processing mill should be drastically reduced in order to avoid excess supplies [7]. Emphasize has been given on creation of value that can only be achieved through internal and external organizational supply chain collaboration [3,8]. Hong and Liu [9] applied the knowledge-based view to the information process and knowledge development in organizational supply chain performance. They could describe the substantial variance in cycle time of organizational supply chain performance using knowledge-based view. This shows the relevance of sharing of knowledge in achieving supply chain performance in an organization. The relevance of this theory with regard to the objective of this study is that it demonstrates the use of strategic inbound transportation management practices as a resource that leads the organization to reduction of transport and communication costs and thus contributes to supply chain performance [10]. Strategic inbound transportation management practices are intangible resources that firms might utilize as part of the organizational capabilities to gain a competitive advantage by integrating strategic inbound management practices to suite customer needs. Strategic inbound transportation practices are the best practices that are used in transportation to ensure that manufacturers optimize cost [11]. These are those methods or techniques found to be the most effective and practical means in achieving transportation objectives such as low costs, timely delivery of transportation related information to the rest of the enterprise and to customers, increase transportation velocity while making optimum use of the firm's resources [12]. A well-run inbound transportation program can reduce costs, improve service, minimize delays, reduce confusion, and raise performance. It can drive efficiencies across the entire supply chain. Lack of optimization is another gap where suppliers at times just want to get product shipped not for client's benefits to get it out of their way. This can be corrected through optimization of orders and consolidation of loads so that weights on trucks are maximized before being sent. It should be noted that highlighted challenges can be minimized through optimization, planning, automation, and collaboration that facilitates control of transportation costs, embracing Omni channel, being compliant and adherent to set standards and multi-enterprise requirements; and utilization of data to improve operations [13].

According to the studies of Tiwari and J. Mehnen. [14], Genetic Algorithms work better where the traditional search and optimization Algorithms fail to avail the goal performance. Lawrynowicz et al also assert that GAs are efficient tools for solving complex optimization problems, highlighting the problem of minimizing the total cost for a distribution network, which presents some similar features to the problem addressed in this paper [15]. Wen et. al. proposed a Genetic Algorithm, using an integer encoding to represent the cargo item sequence to be delivered in order to solve the problem of logistics scheduling problem and optimize the total cost for a location-routing-inventory problem [16].

The main goal of a supply chain is to deliver the right supplies in the right quantities to the right locations at the right time and the strategic goal in logistics is to reduce costs, improve efficiency and increase customer value and satisfaction.

That's why we proposed a fulfilled supply chain network with minimum possible inbound transportation cost and number of truck loads to be delivered with Genetic Algorithm.

3. Linear Programming

Linear programming (**LP**; also called **linear optimization**) is a method to achieve the best outcome (such as maximum profit or lowest cost) in a mathematical model whose requirements are represented by linear relationships. Linear programming is a special case of mathematical programming (mathematical optimization). More formally, linear programming is a technique for the optimization of a linear objective function, subject to linear equality and constraints. Its feasible region is a convex polytope, which is a set defined as the intersection of finitely many half spaces, each of which is defined by a linear inequality. Its objective function is a real-valued affine (linear) function defined on this polyhedron. A linear programming algorithm finds a point in the polyhedron where this function has the smallest (or largest) value if such a point exists. Linear programs are problems that can be expressed in canonical form as

maximize $c^T x$

subject to

$Ax \leq b$

and $x \geq 0$

Where **x** represents the vector of variables (to be determined), **c** and **b** are vectors of (known) coefficients, A is a (known) matrix of coefficients, and $(\cdot)^T$ is the matrix transpose. The expression to be maximized or minimized is called the *objective function* ($\mathbf{c}^T\mathbf{x}$ in this case). The inequalities $A\mathbf{x} \le \mathbf{b}$ and $\mathbf{x} \ge \mathbf{0}$ are the constraints which specify a convex polytope over which the objective function is to be optimized. In this context, two vectors are comparable when they have the same dimensions. If every entry in the first is less-than or equal to the corresponding entry in the second, then we can say the first vector is less-than or equal to the second vector.

4. Genetic Algorithm

Genetic algorithms were developed by J. Holland in the 1970s to understand the adaptive processes of natural systems. Then, in the 1980s, he applied genetic algorithm (GA) for optimizing and machine learning problems. GA belongs to a very popular class of evolutionary algorithms that use crossover and mutation operators and a selection procedure to generate new population. In the new population, strong species have greater chance to pass their genes to future generations via reproduction. In recent years, there has been a growing interest in using genetic algorithms to solve many single and multi-objective problems that are mostly NP-hard and combinatorial. Each possible configuration was then evaluated with respect to the key performance indicators. The crossover and mutation operators are segment based and the selection mechanism is based on the number of parents and offspring in the current generation. According to T. Jones. [17], one of the most general heuristics used in optimization techniques is the idea that the value of solutions is to some extent correlated with how similar the solutions are; crudely, that a good solution is more likely to be found nearby to other good solutions than it is to be found nearby an arbitrary solution. Naturally, 'nearby' or 'similar' needs to be qualified. The simplest notion of similarity of solutions is their proximity as measured in the problem parameters given. But alternatively, we may define proximity in terms of the variation operators used by the search algorithm. In any case, the simplest way to use this heuristic is a hill-climbing algorithm: start with some random solution, try variations of this solution until a better solution (or at least, non-worse solution) is found, move to this new solution and try variations of this, and so on. But the actual success of a hill-climber requires a stronger assumption to be true: that from any point in the solution space there is a path through neighboring points to a global optimum that is monotonically increasing in value. If this is true then a hillclimber can find a global optimum - and, although a hill-climber can do better than random guessing on almost all practical problems we encounter, it usually does not find a global optimum. More likely, it gets stuck in a local optimum - a sub-optimal point or plateau that has no superior neighboring points.

5. Model Formulation

Considering a transportation problem faced by a local retail super market chain which have four major plants and five major districts depots in Bangladesh. Production capacities of the plants are adequate to satisfy their customers, but with limited available of number trucks. Given the company's present situation, the objective is to determine the number of truckloads to be transported via each depot from the plants that provides the minimum total transportation cost.

Parameters and decision variables of proposed model are as follows:

i Index of plants, i= 1…m

j Index of depot, j= 1…n

c_{ij} Transportation cost from i^{th} plant to j^{th} depot

s_i Average available truckloads for i^{th} plant.

d_j Average demand of truckloads for j^{th} depot

x_{ij} Number of truckload transport from i^{th} plant to j^{th} depot

The cost objective Function,

Minimize,

$$Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij} \quad (1)$$

Subject to:

1. Constraints on total available truckloads at each plant

$$\sum_{j=1}^{n} x_{ij} \le s_i \dots_i \quad (2)$$

2. Constraints on total truckloads needed at each depot

$$\sum_{i}^{m} x_{ij} = d_{j \dots j} \quad (3)$$

$$x_{ij} \ge 0_{i};_{j} \quad (4)$$

Here equation (1) gives the objective to minimize the total inbound cost. However, it is subjected to some constraints. While equation (1) defines the total inbound cost, equation (2) and (3) define the capacity constraint and equilibrium constraint of plant as well as depot respectively. Each plant has its own maximum available truckload capacity. Equation (2) ensures that the expected cumulative net quantity of truckload is always less than or equal to the available truckload capacity of the plant. Equation (3) represents that the total number of truckload leaving from plant should equal to the demand of truckload in depot causing equilibrium in supply and demand between plant and depot. Equation (4) imposed the non-negative restriction on decision variable.

6. Solution Procedure

6.1. Solution Representation

Each chromosome consists of several gens which represents a feasible solution. The chromosome is coded as an integer number and explains the truckloads from each plant to each depot.

6.2. Initial Population

The value of each chromosome is generated randomly in which all constraints (e.g., equilibrium of supply and demand between suppliers and customers) should be satisfied. The initial population of algorithm is feasible and made randomly.

6.3. Fitness Function

The objective value of each chromosome is calculated from the mathematical model which presented in Section 3. Objective function value of cost can be obtained by considering the constraints. Therefore, fitness function is the objective function value itself.

6.4. Population Sorting

The population is sorted into non-dominated solution set based on the total weighted sum of the objective value of each chromosome. The first ten non-dominated solution individuals are selected from the population and defined as grade 1 first of all, and then, the second ten non-dominated solution individuals are defined as grade 2 and so on.

6.5. Crossover Operator

Crossover operator is defined as a random selection of two chromosomes from the population. It selects equal-sized assembly schemes from each selected chromosome and then swaps the position of the selected schemes.

6.6. Mutation Operator

A bi-level mutation operator is presented for this model. In the first level, a randomly selected number of truckloads from chromosome mutates the value of each gene in this selected scheme with the same ratio. In the second level, mutated genes in first level are randomly selected, and then, their values are mutated.

6.7. Stop Criterion

The stop condition is set as the generation number; it will stop when the number of new generations reaches the generation number.

7. Computational Result

In this section, some computational experiments are presented to illustrate the efficient performance of the proposed approach for supply chain decision. GA and exact method were used to determine and compare the objective function value and the number of truckloads to be sent to the depot.

Here, Taguchi classifies objective functions into three categories: the smaller-the-better type, the larger-the-better type, and the nominal-is-best type. As the objective function in cost minimization problem so the smaller-the-better type is used here.

Table 1. Factors Levels of Proposed Algorithm

Factor	Symbol	Level	Type
Pop. Size	A	4	A (1) = 100 A (2) = 200 A (3) = 300
Crossover fraction	B	4	B (1) = 0.7 B (2) = 0.8 B (3) = 0.9
Migration fraction	C	4	C (1) = 0.2 C (2) = 0.3 C (3) = 0.4
Generation	D	4	D (1) = 2000 D (2) = 3000 D (3) = 4000

As mentioned in the previous section, the factors are: the population size, the rate of crossover, migration fraction, and the number of generations. Different levels of these factors are shown in Table 1. We used L12 (3^4). Therefore, only 12 experiments for setting the parameters of proposed algorithm are needed. As indicated in Figure 1, the optimal level of the factors A, B, C, D, and E clearly becomes A (2), B (2), C (3), and D (2) respectively.

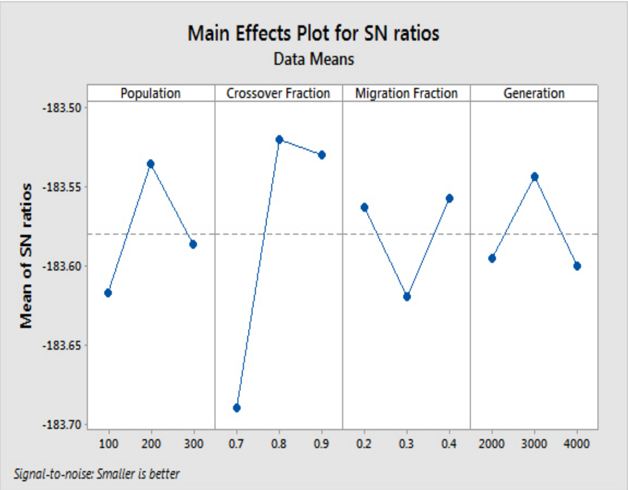

Figure 1. The mean S/N ratio plot for each level of factors

Considering the S/N ratio plot result, the best position of factors to determine the optimal cost are shown in Table 2.

Table 2. Factor Level from S/N Ratio Plot

Factors	**Symbol**	**Level**	**Type**
Population size	A	4	A (2) = 200
Crossover fraction	B	4	B (2) = 0.8
Migration fraction	C	4	C (3) = 0.4
Generation	D	4	D (2) = 3000

Figure 2 illustrates the minimum cost value using genetic algorithm considering the factors from S/N ratio plot.

Table 3 represents the comparison between the number of truckloads to be sent from each plant to each depot by approaching GA in MATLAB R2015a and run on Intel Core i3, 2.00GHz with 4.00GB of RAM. Results are compared to outputs of LINGO 17.0 software.

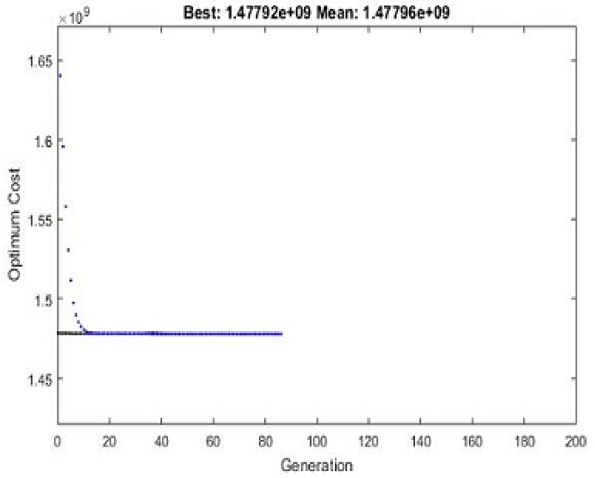

Figure 2. The objective function value considering the factors from S/N ratio plot

Table 3. Comparison of Decision Variables between GA and Exact Method

Variable	Decision Variable Value	
	GA	LINGO
X_{11}	360	576.0
X_{12}	215	864.0
X_{13}	181	0.0
X_{14}	252	0.0
X_{15}	143	0.0
X_{21}	361	432.0
X_{22}	217	0.0
X_{23}	465	1008.0
X_{24}	252	0.0
X_{25}	145	0.0
X_{31}	359	0.0
X_{32}	215	0.0
X_{33}	181	0.0
X_{34}	252	0.0
X_{35}	145	576.0
X_{41}	360	432.0
X_{42}	217	0.0
X_{43}	181	0.0
X_{44}	252	1008.0
X_{45}	143	0.0

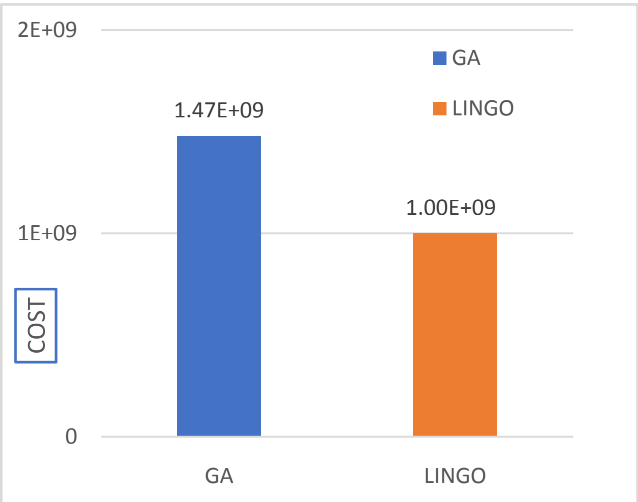

Figure 3. Comparison of the optimized cost between GA and LINGO

Figure 3 compares the results of GA and exact method where minimum monthly transportation cost for the company to transport its products from the four plants to the five depots are BDT 1.47E+09 and 1.00E+09 respectively.

8. Conclusion

Large scale firms that used strategic inbound transportation practices achieved reduced operational costs, reduced defects and minimized lead time which contributed to transportation performance. Furthermore, desired objectives have been considered and converted into costs for comparison and all related information from every function in the supply chain has been shared to create the process alignment and gain better communications which are the important characteristics of the responsive supply chain.

In this paper, authors have developed a mathematical model for a supply chain transportation network among two stages that minimizes the transportation costs and select optimum number of truckloads. The mathematical model was formulated as multi stage single-objective optimization problem. The research has used the Genetic Algorithm approach in a simple supply chain network model to find the optimized transportation cost in a Bangladeshi renowned retail super shop. To identify whether the proposed algorithm is effectively solving problems, the Taguchi method was applied to set parameters of genetic algorithm. To investigate the effectiveness of the proposed genetic algorithm, LINGO 17.0 was employed. A comparative analysis has been done between the obtained result from genetic algorithm and outputs of lingo 17.0. The indicators which considered in the comparison are: (1) the value of objective function and (2) Number of truckloads. Experimental results show that exact method (LINGO) generates better solutions than GA, but better performance is obtained in the large-scale problems in terms of quality of solutions and computation times in GA.

There are some key points for the future researches. In this paper, all parameters are certain, but considering the uncertainty of costs, new solution methodologies may be needed. Considering multi-period planning problems in developing mathematical models is also a potential aspect for future researches.

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