# Optimization of Supply Chain System in Multi-Product, Multi-Supplier Scenario Using Teaching-Learning-Based Optimization Algorithm

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## Abstract

This paper presents the multi-objective optimization aspects of a supply chain with multi-product, multi-supplier system. The three objectives considered in this work are: minimization of the total cost of the supply chain, maximization of total quality level of supply chain, and maximization of service level of supply chain through optimum allocation of the order quantity of each product to each buyer. Various practical constraints such as product demand, shortage prevention, supply capacity of the supplier, and available storage space of the supplier are also considered. The optimization is carried out using a recently developed optimization method known as teaching-learning-based optimization (TLBO). The results of optimization are compared with those obtained by genetic algorithm (GA).

**Keywords** Supply chain, Teaching-Learning-Based Optimization (TLBO)

## 1. Introduction

The operational issues of a supply chain include determination of sales quantity, transportation cost, quantity discount, production capacity, storage capacity, starting-operation quantity, total service level, total quality level, and the system costs including purchasing cost, holding cost, and cost due to shortages. To assure that customer demand can be satisfied without delays, it is necessary to keep inventory in the supply chain, which helps to absorb the impact of random events. A stream of research has emerged in recent years aiming at the coordination of inventory replenishment decisions among individual companies to benefit the entire supply network by reducing the total cost of the system. The integrated supply chain models used to coordinate the supply chain system with multiple buyers and multiple vendors is usually a multi-objective mixed integer nonlinear programming problems. Due to the complex nature of this problem and to overcome the drawbacks of traditional optimization methods, researchers are employing various meta-heuristics such as genetic algorithm (Liao and Rittscher, 2007; Pasandideh, 2010; Liao and Lai, 2011), particle swarm optimization (Yang and Lin, 2010; Sue-Anna et al., 2012; Taleizadeh et al., 2012; Che, 2012; Kedadevaramath et al. 2012; ), ant colony optimization (Arora et al., 2010; Hong et al., 2018), memetic algorithm (Pishvaee et al., 2010), bacterial foraging optimization (Niu et al., 2019; Sinha and Anand, 2019), artificial bee colony algorithm (Zhang et al., 2019), biogeography based optimization (Yang et al., 2015; Yang and Liu, 2017), harmony search algorithm (Pawar and Nandurkar, 2018), firefly algorithm (Khalifehzadeh and Fakhrzad, 2019) to solve this problem.

However, the major difficulty in application of these algorithms lies in their selection of appropriate algorithm-specific parameters such as crossover probability, mutation probability, scaling function, selection function, etc. in case of GA; inertia coefficient and acceleration coefficients in case of PSO; and harmony memory consideration rate and pitch adjusting rate in case of HS algorithm etc. The performance of all the above mentioned algorithms is greatly influenced by their respective algorithm-specific parameters in addition to the common control parameters such as population size and number of generations. Selection of suitable values of these algorithm-specific parameters for a particular application is itself is a complex optimization problem. To overcome this drawback of existing advanced optimization algorithms, an optimization algorithm known as teaching-learning-based optimization (TLBO) algorithm. TLBO requires only common controlling parameters like population size and number of generations for its working. In this way TLBO can be said as an algorithm-specific parameter-less algorithm. Hence the same algorithm is used to solve the supply chain problem presented in this work. The next section briefly presents the working of TLBO algorithm.

## 2. Teaching learning based optimization algorithm

Teaching-learning-based optimization algorithm (TLBO) is a teaching-learning process inspired algorithm proposed by Rao et al. (2011) which is based on the effect of influence of a teacher on the output of learners in a class. The algorithm mimics the teaching-learning ability of teacher and learners in a class room. Teacher and learners are the two vital components of the algorithm and describes two basic modes of the learning, through teacher (known as teacher phase) and interacting with the other learners (known as learner phase).

### 2.1 Teacher phase

During this phase a teacher tries to increase the mean result of the class in the subject taught by him or her depending on his or her capability. At any iteration $i$, assume that there are '$m$' number of subjects (i.e. design variables), 'n' number of learners (i.e. population size, $k$=1,2,…,n) and $M_{j,i}$ be the mean result of the learners in a particular subject '$j$' ($j$=1,2,…,$m$) The best overall result $X_{total\text{-}kbest,i}$ considering all the subjects together obtained in the entire population of learners can be considered as the result of best learner *kbest*. However, as the teacher is usually considered as a highly learned person who trains learners so that they can have better results, the best learner identified is considered by the algorithm as the teacher. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by,

$$Difference\_Mean_{j,k,i} = r_i \, (X_{j,kbest,i} - T_F M_{j,i}) \quad (1)$$

Where, $X_{j,kbest,i}$ is the result of the best learner (i.e. teacher) in subject $j$. $T_F$ is the teaching factor which decides the value of mean to be changed, and $r_i$ is the random number in the range [0, 1]. Value of $T_F$ can be either 1 or 2. The value of $T_F$ is decided randomly with equal probability as,

$$T_F = round\,[1+rand(0,1)\{2\text{-}1\}] \quad (2)$$

$T_F$ is not a parameter of the TLBO algorithm. The value of $T_F$ is not given as an input to the algorithm and its value is randomly decided by the algorithm using Eq. (2). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of $T_F$ is between 1 and 2. However, the algorithm is found to perform much better if the value of TF is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria given by Eq.(2).
Based on the $Difference\_Mean_{j,k,i}$, the existing solution is updated in the teacher phase according to the following expression.

$$X'_{j,k,i} = X_{j,k,i} + Difference\_Mean_{j,k,i} \quad (3)$$

Where $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. Accept $X'_{j,k,i}$ if it gives better function value. All the accepted function values at the end of the teacher phase are maintained and these values become the input to the learner phase. The learner phase depends upon the teacher phase.

### 2.2 Learner phase

Learners increase their knowledge by interaction among themselves. A learner interacts randomly with other learners for enhancing his or her knowledge. A learner learns new things if the other learner has more knowledge than him or her. Considering a population size of '$n$', the learning phenomenon of this phase is expressed below.
Randomly select two learners P and Q such that $X'_{total\text{-}P,i} \neq X'_{total\text{-}Q,i}$ (where, $X'_{total\text{-}P,i}$ and $X'_{total\text{-}Q,i}$ are the updated values of $X_{total\text{-}P,i}$ and $X_{total\text{-}Q,i}$ respectively at the end of teacher phase)

$$X''_{j,P,i} = X'_{j,P,i} + r_i \, (X'_{j,P,i} - X'_{j,Q,i}), \text{ If } X'_{total\text{-}P,i} < X'_{total\text{-}Q,i} \quad (4)$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i \, (X'_{j,Q,i} - X'_{j,P,i}), \text{ If } X'_{total\text{-}Q,I} < X'_{total\text{-}P,i} \quad (5)$$

Accept $X''_{j,P,i}$ if it gives a better function value.

The optimization model of the supply chain with multi-product, multi-supplier system is discussed in the next section

## 3. Optimization model of supply chain with multi-product, multi-supplier system

This section presents multi-objective mixed-integer non- linear programming (MOMINLP) models without shortage as given by Rezaei and Davoodi (2011). In this model the main assumption is that the shortages are not allowed. The three objectives considered in this model are minimization of the total cost of the supply chain, maximization of total quality level of supply chain, and maximization of service level of supply chain as discussed below:

*Objective 1: Minimization of cost of supply chain ($Z_1$)*

The cost of the supply chain is sum of purchase cost, ordering cost, inventory holding cost, and transportation cost as given by Eq. (6).

$$Min\ Z_1 = \sum_i \sum_j \sum_t p_{ij} x_{ijt} + \sum_j \sum_t o_j e^{-\ _j \sum_{k=1}^{t} yjk} y_{jt} + \sum_i \sum_t h_i \left( \sum_{k=1}^{t} \sum_j x_{ijk} - \sum_j \left(1 - s_{ij0} e^{¥_{ij} t}\right) x_{ijt} - \sum_{k=1}^{t} d_{ik} \right)$$
$$+ \sum_j \sum_t g_j \left[ \frac{\sum_i w_i x_{ijt}}{v_j} \right] \quad (6)$$

Where, $p$ = net purchase cost, $o$ = ordering cost, $\beta$ = ordering cost reduction rate, $y$ =1 (if order is placed), $y$ = 0 (otherwise), $h$ = holding cost, $s$ = service level, ¥ = service level growth rate, $d$ = demand, $g$ = transportation cost per vehicle, $w$ = space occupied by product, $v$ = vehicle capacity.

*Objective 2: Maximization of total quality level ($Z_2$)*

The overall quality level of all the products ordered from all suppliers in all periods should be maximized. This model also takes into account the growth trend of quality level for each product offered by each supplier as an exponential time dependent function ($\lambda$) as given by Eq. (7).

$$Max\, Z_2 = \sum_i \sum_j \sum_t f_{ij0} e^{ª_{ijt}} x_{ijt} \quad (7)$$

Where, $f$ = product quality level, ª = quality level growth rate

*Objective 3: Maximization of total service level ($Z_3$)*

The overall service level of all the products ordered from all suppliers in all periods should be maximized. This model also takes into account the growth trend of service level for each product offered by each supplier as an exponential time dependent function ($\gamma$) as given by Eq. (8).

$$Max\, Z_3 = \sum_i \sum_j \sum_t s_{ij0} e^{¥_{ijt}} x_{ijt} \quad (8)$$

The above objectives are subjected to following five constraints:

1) Demand: The ordered quantity should be sufficient to meet demand in order to prevent shortages. This constraint is given by Eq. (9) below.

$$\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik} \geq \sum_j \left(1 - s_{ij0} e^{¥_{ij} t}\right) x_{ijt} \quad (9)$$

2) Charging ordering cost: This constraint is to ensure that the buyer can't place order without ordering cost. This constraint is given by Eq. (10) below.

$$\left( \sum_{k=1}^{T} d_{ik} \right) y_{jt} - x_{ijt} \geq 0 \quad (10)$$

3) End of planning inventory: This constraint is to ensure that the inventory level at the end should become zero. This constraint is given by Eq. (11) below.

$$\left(\sum_{k=1}^{T}\sum_{j} x_{ijk} - \sum_{j}\left(1 - s_{ij0}e^{¥_{ij}T}\right)x_{ijt} - \sum_{k=1}^{T} d_{ik}\right) = 0 \tag{11}$$

4) Storage capacity: This constraint is to ensure that the space occupied by total number of products should not exceed the storage capacity of a supplier. This constraint is given by Eq. (12) below.

$$\sum_{i} w_i\left(\sum_{k=1}^{t}\sum_{j} x_{ijk} - \sum_{j}\left(1 - s_{ij0}e^{¥_{ij}t}\right)x_{ijt} - \sum_{k=1}^{t} d_{ik}\right) \le W \tag{12}$$

$where, W = total\ storage\ capacity$

5) Supplier capacity: This constraint is to ensure that the number of products ordered to a supplier should not exceed his capacity. This constraint is given by Eq. (13) below.

$$x_{ijt} \le c_{ij} \tag{13}$$

Where, $c_{ij}$ is the supplier capacity.

The variables considered in this work are the quantities ordered for each product from each supplier in specified period ( $x_{ijt}$ ).

## 4. Example

Now, to demonstrate the effectiveness of proposed TLBO algorithm, an application example is considered for a supply chain with 3 products, and 5 suppliers with 4 replenishment periods. The product and supplier data is given in Tables 1 to 3 below.

**Table 1** Demand for three products in four periods

| | Product | Period (t) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| | 1 | 454 | 540 | 675 | 755 |
| $d_{it}$ | 2 | 327 | 320 | 290 | 285 |
| | 3 | 645 | 650 | 637 | 663 |

**Table 2** Holding cost, backordering cost, and occupied space of each product

| Product (*i*) | $h_i$ | $b_i$ | $w_i$ |
|---|---|---|---|
| 1 | 12 | 17 | 0.75 |
| 2 | 35 | 38 | 0.85 |
| 3 | 7 | 10 | 0.60 |

**Table 3** Other data related to products and/or suppliers

| | Product (*i*) | Supplier (*j*) | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | 1 | 66 | 73 | 62 | 60 | 71 |
| $p_{ij}$ | 2 | 121 | 134 | 127 | 142 | 122 |
| | 3 | 28 | 26 | 29 | 25 | 23 |
| | 1 | 0.95 | 0.98 | 0.92 | 0.96 | 0.99 |
| $f_{ij0}$ | 2 | 0.89 | 0.92 | 0.95 | 0.90 | 0.91 |
| | 3 | 0.93 | 0.87 | 0..88 | 0.83 | 0.87 |
| | 1 | 0.95 | 0.97 | 0.94 | 0.99 | 0.98 |
| $S_{ij0}$ | 2 | 0.92 | 0.99 | 0.91 | 0.99 | 0.92 |
| | 3 | 0.99 | 0.98 | 0.99 | 0.97 | 0.99 |
| $c_{ij}$ | 1 | 550 | 480 | 420 | 890 | 790 |
| | 2 | 570 | 85 | 450 | 235 | 525 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 3 | 825 | 430 | 850 | 390 | 720 |
| | 1 | 0.001 | -0.002 | 0.0015 | -0.001 | -0.001 |
| $a_{ij}$ | 2 | 0 | 0.0015 | -0.001 | 0.002 | 0.002 |
| | 3 | -0.001 | 0.002 | 0.0015 | 0.0015 | 0.0012 |
| | 1 | 0.0013 | 0.0011 | -0.001 | 0.001 | -0.0011 |
| ¥$_{ij}$ | 2 | 0 | 0.0014 | 0.002 | 0.0015 | 0.002 |
| | 3 | -0.0011 | 0.0016 | -0.001 | -0.002 | 0.0011 |
| $\beta_j$ | | 0.08 | 0.1 | 0.09 | 0.12 | 0.09 |
| $o_j$ | | 45000 | 64500 | 37250 | 53400 | 42250 |
| $v_j$ | | 85 | 150 | 85 | 100 | 150 |
| $g_j$ | | 33500 | 55200 | 33500 | 38400 | 55200 |

$W$=150

## 5. Results and discussions

As TLBO algorithm is an algorithm-specific parameter-less algorithm, only population size and number of generations need to be specified to run the algorithm. Based on several trial runs, the population size decided for the present example is 10 and the number of generations is 115. Rezaei and Davoodi (2011) obtained set of Pareto optimal solution and declared the three solutions out of those as best solutions with respect to three objectives each. For comparison purpose, this problem is solved as single objective optimization problem considering each objective separately. The results of optimization using TLBO when $Z_1$, $Z_2$, and $Z_3$ are considered as sole objectives respectively are presented in Table 6. The objective function values using GA (Rezaei and Davoodi, 2011) and TLBO are presented in Table 5.

**Table 4** Results of single objective optimization for total cost

| Method | *For* $Z_1$ (to be minimized) | | | *For* $Z_2$ (To be maximized) | | | *For* $Z_3$ (To be maximized) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost | Quality Level | Service Level | Cost | Quality Level | Service Level | Cost | Quality Level | Service Level |
| GA | 3013904 | 5786.101 | 6076.555 | 3228229 | 5847.146 | 6113.339 | 3235358 | 5777.225 | 6120.463 |
| TLBO | **3007996** | **6822.87** | **7145.18** | **3191895** | **7055.78** | **7390.25** | **3134568** | **7054.79** | **7408.5** |

As shown in Table 4, using TLBO algorithm the best values of cost, quality level, and service level using 3007996, 7055.78, and 7408.5 respectively whereas those obtained using GA are 3013904, 5847.146, and 6120.463 respectively. Also all three results (for $Z_1$, $Z_2$, and $Z_3$) using TLBO algorithm are better than those obtained using GA for all three objectives.

**Table 5** Optimum order quantities corresponding to results shown in Tables 4

| $x_{ijk}$ | For Min. $Z_1$ | For Max $Z_2$ | For max. $Z_3$ | $x_{ijk}$ | For Min. $Z_1$ | For Max $Z_2$ | For max. $Z_3$ |
|---|---|---|---|---|---|---|---|
| $x_{111}$ | 65 | 46 | 48 | $x_{233}$ | 112 | 112 | 112 |
| $x_{112}$ | 140 | 157 | 156 | $x_{234}$ | 104 | 99 | 99 |
| $x_{113}$ | 169 | 170 | 170 | $x_{241}$ | 0 | 87 | 87 |
| $x_{114}$ | 176 | 177 | 176 | $x_{242}$ | 0 | 59 | 59 |
| $x_{121}$ | 31 | 5 | 7 | $x_{243}$ | 19 | 52 | 52 |
| $x_{122}$ | 123 | 143 | 142 | $x_{244}$ | 10 | 38 | 38 |
| $x_{123}$ | 152 | 156 | 156 | $x_{251}$ | 174 | 121 | 120 |
| $x_{124}$ | 175 | 175 | 175 | $x_{252}$ | 126 | 121 | 120 |
| $x_{131}$ | 22 | 0 | 0 | $x_{253}$ | 117 | 113 | 113 |
| $x_{132}$ | 95 | 117 | 117 | $x_{254}$ | 109 | 100 | 100 |
| $x_{133}$ | 140 | 142 | 142 | $x_{311}$ | 198 | 177 | 177 |
| $x_{134}$ | 162 | 161 | 162 | $x_{312}$ | 205 | 177 | 177 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $x_{141}$ | 370 | 349 | 351 | $x_{313}$ | 203 | 177 | 177 |
| $x_{142}$ | 146 | 165 | 164 | $x_{314}$ | 201 | 177 | 177 |
| $x_{143}$ | 176 | 179 | 178 | $x_{321}$ | 107 | 107 | 107 |
| $x_{144}$ | 198 | 197 | 197 | $x_{322}$ | 107 | 108 | 108 |
| $x_{151}$ | 58 | 146 | 141 | $x_{323}$ | 104 | 108 | 108 |
| $x_{152}$ | 146 | 165 | 164 | $x_{324}$ | 112 | 108 | 108 |
| $x_{153}$ | 175 | 179 | 178 | $x_{331}$ | 120 | 177 | 177 |
| $x_{154}$ | 197 | 197 | 197 | $x_{332}$ | 119 | 177 | 177 |
| $x_{211}$ | 107 | 90 | 90 | $x_{333}$ | 116 | 177 | 177 |
| $x_{212}$ | 176 | 120 | 120 | $x_{334}$ | 124 | 177 | 177 |
| $x_{213}$ | 134 | 113 | 113 | $x_{341}$ | 97 | 97 | 97 |
| $x_{214}$ | 153 | 144 | 144 | $x_{342}$ | 97 | 98 | 98 |
| $x_{221}$ | 50 | 27 | 27 | $x_{343}$ | 94 | 98 | 98 |
| $x_{222}$ | 12 | 27 | 27 | $x_{344}$ | 102 | 98 | 98 |
| $x_{223}$ | 12 | 20 | 20 | $x_{351}$ | 180 | 176 | 177 |
| $x_{224}$ | 12 | 6 | 7 | $x_{352}$ | 179 | 176 | 177 |
| $x_{231}$ | 113 | 120 | 120 | $x_{353}$ | 177 | 176 | 177 |
| $x_{232}$ | 121 | 119 | 119 | $x_{354}$ | 184 | 176 | 177 |

It is observed from the results that all specified constraints are well satisfied by the results obtained by using TLBO. It can be seen from Table 5, that the quantity ordered for all products is more than their respective demands mentioned in Table 3. For example, for the first product the demand in period 1 is 454 and the quantity ordered for product 1 from all suppliers in period 1 is 544. Similarly the demand for product 2 in period 1 is 327 and quantity ordered for product 2 from all suppliers in period 1 is 442. Also since the service levels are less than 1, although the ordered quantities seems to be more than the actual demand, considering the specified service levels and service level growth rate, actual quantities received are exactly same as that of demand. For example, for product 1 in period 1, the demand is 454, the quantity ordered is 544 but considering the service levels and service level growth rate and using Eq. (11), the actual quality received is 454 only. Thus the inventory level for product 1 at the end is zero. Similar results can also be observed from Table 5 for all other products for each period of time. This clearly indicated that the constraint on end of planning inventory is well satisfied. Moreover, since the quantity received for each product in given period is exactly same as that of its demand for that period ($d_{it}$) as mentioned in Table 1, there is no shortage. Moreover, as the supply and demand are exactly matching, it is just in time strategy making the inventory holding cost and floor space requirement is also theoretically zero. The product-wise supplier capacity ($C_{ij}$) is provided in Table 3. For example, the supplier 1 can supply maximum 550 quantity of product 1, 570 of product 2, and 825 of product 3. It can be seen from Table 5 that the sum of all quantities ordered from supplier 1 during all 4 time periods for products 1, 2 and 3 are 549, 569, and 805 respectively, which are less than their supply capacities. Similar results are obtained for all other suppliers also. Thus, the constraint of supplier capacity is also well satisfied.

## 6. Conclusion

In the present work, optimization aspects of supply chain with multi-product, multi-supplier system are considered. The three objectives considered in this work are: minimization of the total cost of the supply chain, maximization of total quality level of supply chain, and maximization of service level of supply chain through optimum allocation of the order quantity of each product to each supplier while maintaining the constraints of product demand, shortage prevention, supply capacity of the supplier, and available storage space of the supplier. The mixed integer non-linear supply chain model is considered. It is observed that the results obtained by proposed TLBO algorithm are superior to those obtained using GA. This is mainly due to the fact that TLBO uses the best solution of the iteration to modify the existing solution as in PSO and it does not divide the population as in case of ABC.

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