

Development of Vendor Management Inventory (VMI) Model for Single Vendor Single Retailer Using Imperialist Competitive Algorithm

Ferdous Sarwar

Department of Industrial & Production Engineering
Bangladesh University of Engineering & Technology
Dhaka, Bangladesh
ferdoussarwar@ipe.buet.ac.bd,

Mahmudul Hasan Porag

Mechanical and Industrial Engineering Department
Ahsanullah University of Science and Technology
Dhaka, Bangladesh
porag024.@gmail.com

Abstract

This paper develops a single-vendor single-retailer supply chain for multi-product. The proposed model is based on Vendor Managed Inventory (VMI) approach and vendor uses the retailer's data for better decision making. Number of orders and available capital are the constraints of the model. In this system, shortages are backordered; therefore, the vendor's warehouse capacity is another limitation of the problem. After the model formulation, an Integer Nonlinear Programming problem will be provided; hence, a metaheuristic algorithm called Imperialist Competitive Algorithm has been used to solve the model. Consequently, order quantities, number of shipments received by a retailer and maximum backorder levels for products have been determined with regard to cost consideration. Then, a numerical example is presented to describe the sufficiency of the proposed strategy. Furthermore, the model is also solved using Particle Swarm Optimization (PSO) and compared with the Imperialist Competitive Algorithm (ICA).

Keywords

Vendor Management Inventory, Supply Chain Management, Back Order, Warehouse, Inventory Cost

1. Introduction

Supply Chain Management (SCM) concerns the integrated and process-oriented approach to the design, management, and control of the SC, with the aim of producing value for the end customer, by both improving customer service and lowering cost. Each stage in the supply chain need to perform many activities and must interact with all other stages in supply chain. The primary purpose of a supply chain is to satisfy the needs of the customer as well as generating profits. Nowadays, inventory management plays an important role in reducing total costs of supply chains (SC). Supply chain management (SCM) techniques with the aim of coordinating all parts of SC from supplying raw materials to delivering and/or resumption of products, tries to minimize total costs with respect to existing conflicts among the chain partners. An example of these conflicts is the interrelation between the sale department desiring to have higher inventory levels to fulfill demands and the warehouse for which lower inventories are desired to reduce holding costs. Due to the uncertainty involved in demand, unbalancing (shortage or surplus) has always been one of the main problems in demand predictions, especially at lower echelons of SC, namely retailer and supplier. As a result, several approaches or policies were proposed in the literature to manage and control inventory levels in retailer-supplier partnerships. The most well-known policies are: Continuous replenishment policy, Periodic Replenishment Policy, Quick Response Policy, Vendor Managed Inventory Policy. Among them, VMI, sometimes called vendor-managed replenishment (VMR), is the most popular approach based

on which both suppliers and retailers' benefit. For instance, popular suppliers such as Wal-Mart and J.C. Penny reduced their costs by the implementation of the VMI policy.

The VMI model is a cooperative communication innovation where suppliers are permitted to manage the retailer's inventory. Vendors can manage retailer's orders and total inventory data between retailers by utilizing of information technologies such as Electronic Data Interchange (EDI) on a real time basis (Yao et al., 2007). The VMI is a business model in which the vendor is a responder to control the retailer's inventory levels and then determines the retailer's order quantity and time. The possible advantages of the VMI models include a reduction of inventory costs for the supplier and the retailer and improvement of customer service levels (Achabal et al., 2000). Successful retailers and suppliers such as Kmart, Dillard Department Stores, JcPenney and WalMart achieved these advantages (Dong&Xu, 2002). In other words, in these models, the supplier determines quantity of replenishment for a retailer in the specified time horizon, with regard to the minimum total inventory cost in the supply chain. According to the cost reduction, determination of the amount of orders is one of the important decisions that suppliers are involved in the supply chain. Two general models of economic order quantity (EOQ) and economic production quantity (EPQ) are frequently used. The order size, which minimizes the total inventory cost, is known as the EOQ. The EPQ model applies the logic of EOQ to parts that are made, as opposed to those purchased from an outside vendor. The EOQ is one of the most popular and successful optimization models in SCM, due to its simplicity of using, simplicity of concept, and robustness (Axsäter, 2010). All of the mentioned models have been developed based on some basic assumptions, with regard to their applications in the real situations. In this paper, research is concentrated on this scenario: there is a single vendor who supplies multi products for a single retailer and the model has been completed by multi-constraint. These constraints have an important influence on the conformity of model with inventory systems in the real world. In this model, shortages are backordered. In addition, the vendor's warehouse is limited by an upper bound for available inventory or maximum inventory. Constraints like number of orders, available capital, and average inventory have an important role in the inventory systems, so that they have been considered in the proposed model.

2. Literature Review:

A substantial amount of work has already been done on inventory control model in different researches. Determination of when and how much to order is the aim of an inventory control system. The most well-known inventory control model is the classical EOQ formula. The first EOQ formula was presented by Harris (1913), but Wilson (1934) was also recognized in connection with this model (Axsäter, 2010, Tersine, 1993). Then, the model was extended to EPQ in which production rate was considered in the model. The EOQ and EPQ inventory systems have been used in many practical applications, because these inventory models are simple and easy to implement in organizations, but the EOQ and EPQ inventory models have several assumptions that are very restrictive (Cárdenas&Leopoldo, 2009). Since the EOQ and the EPQ are obtained with some assumptions and conditions that their applications are limited in real issues, some researchers such as Goyal (1985), Chung (1998) have tried to develop formulated inventory models for more real issues.

Goyal (Goyal, 1985), Chung (1998) worked on "The optimal inventory policies under permissible delay in payments depending on the ordering quantity". This paper dealt with the problem of determining the economic order quantity under conditions of permissible delay in payments. The delay in payments depends on the quantity ordered. When the order quantity is less than the quantity at which the delay in payments is permitted, the payment for the item must be made immediately. Otherwise, the fixed trade credit period is permitted. The minimization of the total variable cost per unit of time is taken as the objective function. An algorithm to determine the economic order quantity was developed. The results obtained in this paper generalized some already published results.

A summary of different studies on inventory control or Vendor Managed Inventory is tabulated here :

Table 1: Some Studies on VMI model

Study	Retailer	Demand	Backorder	Discount	Algorithm	Policy	Constraint
Hill	Single	No	No	No	Heuristic	EPQ	No
Bragila and Zavanella	Single	No	No	No	Optimal Solution	EPQ	No

Nachiappan and jawhar	Multi	No	No	No	GA	EOQ	Storage, Sales Quantity
Yao	Single	No	No	No	Optimal Solution	EOQ	No
Zavanella and Zanoni	Multi	No	No	No	Optimal Solution	EPQ	No
Lin, et al	Single	Fuzzy	No	No	GA	Production	No
Darwish and Odah	Multi	No	No	No	Heuristic	EOQ	Overstock Penalty
Yu and Huang	Multi	No	No	Yes	Mixed GA	Production	Resource
Pasandideh, et al	Single	No	Yes	No	GA	EOQ	Storage, Number of Orders

3. Mathematical Model:

We have considered a single-vendor single-retailer supply chain consists of m products according to previous mentioned assumptions for the proposed model. It is assumed that, inventory level is available inventory with respect to three constraints: available capital, vendor's warehouse capacity and average inventory. An important point must be considered if the model is the EPQ, or encounters with shortages as backordered, the maximum inventory must use for applying warehouse capacity and available capital constraints (Axsäter, 2010, Tersine, 1993). Under VMI system policy, the vendor manages the holding and ordering costs and forwards cost to the retailer. When the retailer's inventory level goes down to reorder point R , a batch quantity of size q is ordered. Moreover, exceeding demand will be repaid and any surplus shipment is not allowed. Furthermore, it is assumed that retailer sells all of products received from the vendor. Thus, annual demand for the vendor and retailer is the same and is deterministic. Under the VMI strategy, a retailer's order cost is smaller than the retailer's order cost in case of no-VMI strategy (Yao et al., 2007)

The following set of notations will be used in this research:

A_i	Vendors order cost for ith product
a_i	Vendors order cost for ith product for retailer
D_i	Demand rate for ith product
p_i	Annual holding cost as a fraction of unit cost for retailer
p	Annual holding cost as a fraction of unit cost for vendor
u_i	Purchase cost for ith product
α	Fixed backorder cost per unit in each period
λ	Fixed backorder cost per unit
V_i	Space required to store one unit of ith product
W	Maximum utilization of vendors warehouse space
X	Total number of vendors order
O	Maximum available capital for vendor
Z	Upper limit for vendors average inventory level
n	Number of shipments received by a retailer
q_i	Quantity of ith product dispatched to retailer
b_i	Maximum backorder level of ith product for vendor

Q_i	Order quantity of i th product for vendor
T	Vendor cycle time
T_i	Cycle time for the i th product
TR	Common cycle time for products
TCR	Total retailers cost in case of VMI system
TCV	Total vendors cost in case of VMI system
TC_{vmi}	Total cost incurred by VMI system

As it is assumed, the vendor dispatches products at the same time, i.e. $T_i = T_j = TR$. It is logical in VMI policy because the vendor selects the best alternative for relationships between the time and volume of replenishment (Darwish&Odash, 2010). Therefore, the vendor a lot of size Q_i to a retailer transferred that takes n shipments each of size q_i . Following equations represent the relationship between the delivered products to the retailer:

$$\frac{q_i}{D_i} = \frac{q_j}{D_j}$$

So,

$$\frac{q_1}{D_1} = \frac{q_i}{D_i}$$

And

$$Q_i = nq_i$$

Finally, the specifications of the supply chain in which vendor and retailer cooperate are defined as follows:

- Vendor decides for the timings and the quantities of production considering inventory cost that is the total cost of the VMI system.
- Shortages are allowed and backordered.
- Lead-time is zero and inventory system follows immediately replenishment.
- All of costs are fixed.
- The rate of production for all products is infinite (EOQ model).
- Vendor's warehouse capacity is fixed and pre-determined.
- Available inventory has an upper bound.
- Number of vendor's order is limited.
- Available capital is finite.

3.1 Defining the mathematical model:

In this section, the mathematical model is defined with respect to the aforementioned assumptions for the VMI system where intends to minimize the total inventory cost in a supply chain per unit time T . The model involves costs such as holding, ordering and shortage cost as well as the purchase cost. According to the assumptions, total retailer's cost is calculated as follows:

$$TCR = \sum_{i=0}^m \frac{p_i q_i}{2}$$

Although the order cost involved TCR , but it belongs to the vendor's cost in the VMI system. Based on previous assumptions following equations will be provided:

$$Q_i = \frac{D_i q_1 n}{D_1}$$

$$q_i = \frac{D_i q_1}{D_1}$$

As a result, the total vendor's cost has been calculated here:

$$TCv = \sum_{i=0}^m \left(\frac{A_i D_i}{Q_i} + \frac{a_i D_i}{q_i} + p_i \frac{(Q_i - b_i)^2}{2Q_i} + \frac{a b_i^2}{2Q_i} + \frac{\lambda b_i D_i}{Q_i} + D_i u_i \right)$$

Therefore, the total cost for the whole system is:

$$TC_{vmi} = TC_r + TC_v$$

Total cost incurred by the VMI system, can be determined as follows.

$$TC_{vmi}(b, q_1, n) = \sum_{i=0}^m \left(\frac{A_i D_i}{n q_1} + \frac{a_i D_i D_1}{D_i q_1} + \frac{D_i p_{ui} q_1}{2 D_1} \right) + \sum_{i=0}^m \left(p_{ui} \frac{\left(\frac{D_i q_1 n}{D_1} - b_i \right)^2}{2 \frac{D_i q_1 n}{D_1}} \right) + \sum_{i=0}^m \left(\frac{D_1 \alpha b_i^2}{2 D_i q_1 n} + \frac{\lambda b_i D_i D_1}{D_i q_1 n} + D_{iui} \right)$$

According to the previous statements, the aim of this research is to calculate synchronous order quantities, number of shipments received by a retailer and maximum backorder levels for each product in a cycle time with respect to the vendor's warehouse capacity; W as follows:

$$\sum_{i=0}^m V_i (Q_i - b_i) \leq W$$

In addition, the amount of available capital is O ,

$$\sum_{i=0}^m u_i (Q_i - b_i) \leq O$$

And Z is upper bound of vendor's available inventory,

$$\sum_{i=0}^m \frac{(Q_i - b_i)^2}{2 Q_i} \leq Z$$

Finally, number of vendor's order is bounded to X ,

$$\sum_{i=0}^m \frac{D_i}{Q_i} \leq X$$

Hence, the mathematical model can be set out as follows:

$$\begin{aligned} & \text{Min } TC_{vmi}(b, q_1, n) \\ & = \sum_{i=0}^m \left(\frac{A_i D_i}{n q_1} + \frac{a_i D_i D_1}{D_i q_1} + \frac{D_i p_{ui} q_1}{2 D_1} \right) + \sum_{i=0}^m \left(p_{ui} \frac{\left(\frac{D_i q_1 n}{D_1} - b_i \right)^2}{2 \frac{D_i q_1 n}{D_1}} \right) + \sum_{i=0}^m \left(\frac{D_1 \alpha b_i^2}{2 D_i q_1 n} + \frac{\lambda b_i D_i D_1}{D_i q_1 n} + D_{iui} \right) \end{aligned}$$

Subject to,

$$\sum_{i=0}^m V_i (Q_i - b_i) \leq W$$

$$\sum_{i=0}^m u_i (Q_i - b_i) \leq O$$

$$\sum_{i=0}^m \frac{(Q_i - b_i)^2}{2Q_i} \leq Z$$

$$\sum_{i=0}^m \frac{D_i}{Q_i} \leq X$$

$$\sum_{i=0}^m b_i \leq Q_i$$

$b_i, q_i, n > 0$ integer

$i=1, 2, 3, \dots, m$.

Where $b_i \leq Q_i$ means that backorder levels cannot be bigger than order quantity. In next section, a proposed ICA (Imperialist Competitive Algorithm) will be presented to solve the obtained model.

4. The Proposed Algorithm

In this research Imperialist competitive algorithm (ICA) is used. The purpose of using this algorithm is its simplicity. It is easy to implement and has the ability to deal with multiple conflicting objectives.

4.1 Imperialist Competitive Algorithm (ICA)

Imperialist competitive algorithm (ICA) is a computational method that is used to solve optimization problems of different types. Like most of the methods in the area of evolutionary computation, ICA does not need the gradient of the function in its optimization process. From a specific point of view, ICA can be thought of as the social counterpart of genetic algorithms (GAs). ICA is the mathematical model and the computer simulation of human social evolution, while GAs are based on the biological evolution of species. Imperialist Competitive algorithm for global optimization is inspired by imperialistic competition. All the countries are divided into two types: imperialist states and colonies. Imperialistic competition is the main part of proposed algorithm and hopefully causes the colonies to converge to the global minimum of the cost function.

4.2 Generating Initial Empires

The goal of optimization is to find an optimal solution in terms of the variables of the problem. An array of variable values is formed to be optimized. In GA terminology, this array is called “chromosome”, but here the term “country” is used for this array. In an $Nvar$ – dimensional optimization problem, a country is a $1 \times Nvar$ array. This array is defined by

$$\text{Country} = [p_1, p_2, p_3, \dots, p_{Nvar}]$$

The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function f at the variables $(p_1, p_2, p_3, \dots, p_{Nvar})$

$$\text{Cost} = f(\text{country}) = f(p_1, p_2, p_3, \dots, p_{Nvar})$$

To start the optimization algorithm, we generate the initial population of size pop $Npop$. We select $Nimpof$ of the most powerful countries to form the empires. The remaining $Ncol$ of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; imperialist and colony.

To form the initial empires, the colonies are divided among imperialists based on their power. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by

$$C_n = \frac{cn}{\max\{ci\}}$$

Where cn is the cost of n th imperialist and C_n is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by

$$P_n = \left| \frac{C_n}{\sum_{i=0}^{N_{imp}} C_i} \right|$$

From another point of view, the normalized power of an imperialist is the portion of colonies that should be possessed by that imperialist. Then the initial number of colonies of an empire will be

$$N.C_n = \text{round}(p_n, N_{col})$$

Where, $N.C_n$ is initial number of colonies of n th empire and N_{col} is the number of all colonies. To divide the colonies, for each imperialist we randomly choose $N.C_n$ of the colonies and give them to it. These colonies along with the imperialist will form n th empire.

5. Numerical Example

In this section a numerical example is presented to illustrate the solution process of the proposed vendor managed inventory model. The example is almost similar to the example provided by Sadeghi (2010). But as the model presented in the thesis is an improved version of their model, some new parameters are introduced in the example. Though the model is developed for multi products in this example we consider only two products for the simplification of the calculation. The demand for the first and second product is 420 and 360 units respectively. The annual holding cost as a fraction of unit cost for retailer is 0.4 whereas the annual holding cost as a fraction of unit cost for vendor is 0.3. Fixed backordering cost per unit is 0 Tk and fixed backordering cost per unit in each period is \$3. The vendor's ordering cost for the first product is \$4 and the second product is \$3. The vendor's ordering cost of the first product (per unit) for retailer is \$4 and the second product (per unit) is \$3. The purchase cost for first and second product is \$13 and \$30 respectively. The vendor is planning to use the model developed in this thesis for one retailer and one supplier. The maximum available capital for the vendor (O) is \$130000 and total number of vendor's order(X) is 8. The maximum utilization of vendor's warehouse space (W) is 18000 and the upper limit for vendor's average inventory level (Z) is 250. The optimal values of the decision variables that will lower the value of the inventory cost. Table 2 provided below summarizes the values for the input parameter used in the model. From now on these values of the parameters are going to be used to gain insights about the solution methodology.

Table 2: Different Parameter Values for numerical example

Parameter	Value
D1	420
D2	360
u1	13
u2	30
A1	4
A2	3
a1	3
a2	2
p	0.3
p1	0.4
α	3

6. Result and Discussion

Thesis work is naturally theoretical. The model can be optimized for real time value of various parameters. For a hypothetical problem as described in the previous section the proposed model is optimized so that required four decision variables i.e. the maximum backorder level for first product(b_1), the maximum backorder level for second product(b_2), quantity of the product dispatched to retailer(q) and the number of shipments received by a retailer(n) can be determined. For this purpose, a computer programming code of the model has been generated in MATLAB

R2013a and Imperialist Competitive Algorithm (ICA) And Particle Swarm optimization (PSO) has been used to get the optimal value.

Imperialist Competitive Algorithm (ICA) And Particle Swarm optimization (PSO) are used to have the optimum values of decision variables that minimize the total inventory cost per unit time. The parameters used for ICA and PSO are listed in the following tables.

Table 3: Different Parameters for Imperialist Competitive Algorithm (ICA)

Parameters for ICA	Value
Population Size (N_{pop})	25
Maximum Number of Iterations (It)	60
Number of Empires/Imperialists(N_{emp})	10
Selection Pressure (α)	1
Assimilation Coefficient (β)	1.5
Revolution Probability	0.05
Revolution Rate	0.1
Colonies Mean Cost Coefficient	0.2

Table 4: Different Parameters for Particle Swarm Optimization (PSO)

Parameters for PSO	Value
Number of particle (N_p)	25
Number of iteration (It)	150
First coefficient related to acceleration($C1$)	2
Second coefficient related to acceleration($C2$)	2
Inertia weight (maximum)	0.9
Inertia weight (minimum)	0.4

There are some results summarized in the following table which are obtained through ICA algorithm. Iteration and population size have been changed to have better view of the result. The convergence paths of points in the domain in ICA are shown in the following figures. From the table it has been observed that for iteration 60 all the cost for different population sizes are less than that for iteration 50. On the other hand, as the population size increases from 10 through 25 the cost is decreased both for 50 and 60 iterations. After 60 iterations and for 25 population sizes the solution path converges. So, it can be decided that with the increase in population size and iteration number the chance of having optimal result can be ensured more effectively.

Table 5: Result analysis for different Iteration and different Population Size in ICA

Iteration	Population size	Cost
50	10	59260.67
50	15	59253.78
50	20	59248.23
50	25	59245.10
60	10	52381.74
60	15	52375.89
60	20	52370.63
60	25	52368

From above table we observed that the total cost is minimized for iteration 60 and population size 25. The optimized cost is \$52368 and the values of corresponding variables are 428, 306, 10, and 52. In the following section the graphs of different iteration and different population size are shown:

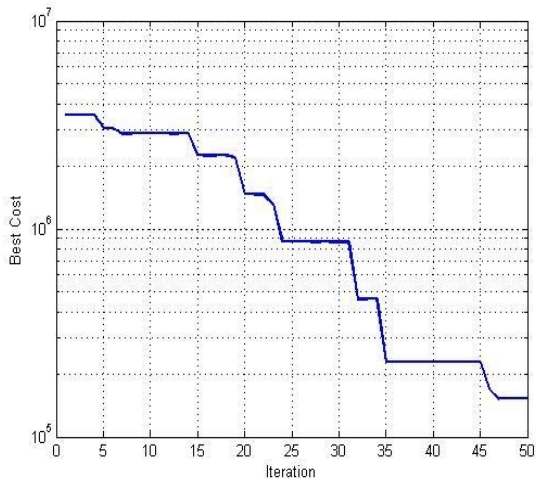


Figure 1 Graph for Population Size 10, Iteration 50

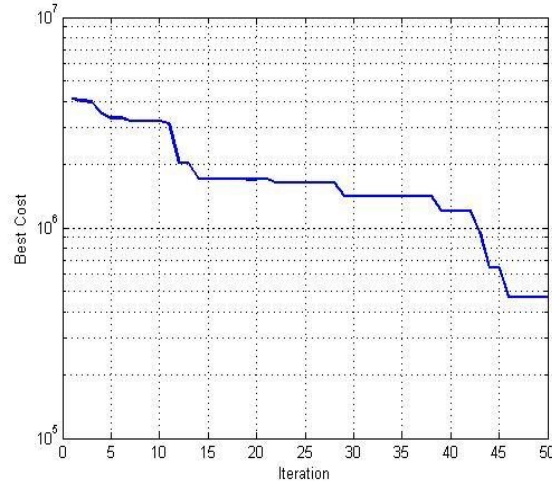


Figure 2 Graph for Population Size 15, Iteration 50

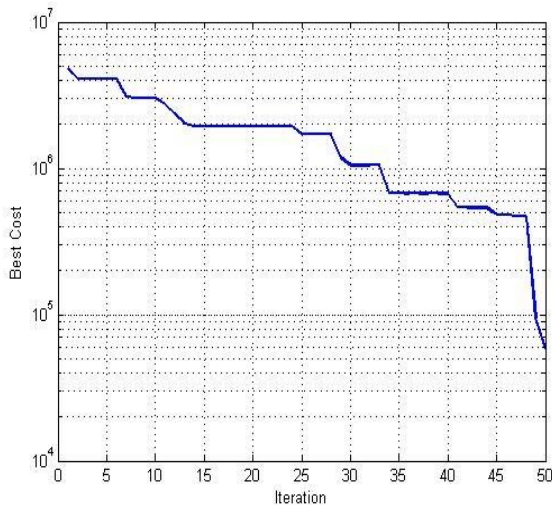


Figure 3 Graph for Population Size 20, Iteration 50

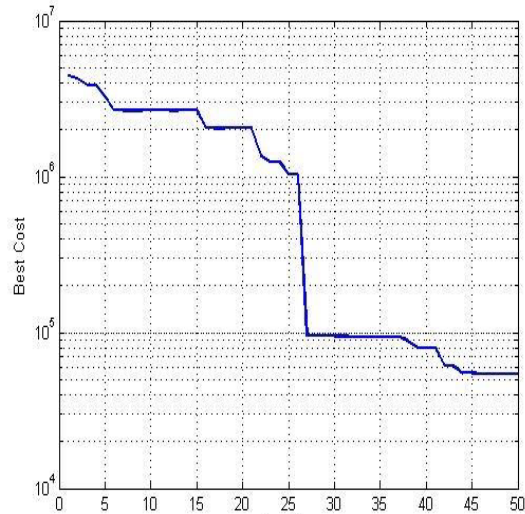


Figure 4 Graph for Population Size 25, Iteration 50

6.1 Comparison between PSO and ICA:

Table 6: Comparison between PSO and ICA

Characteristic	PSO	ICA
Total Cost	198760	52368
Convergence iteration	102	60
Execution time (second)	3.19	0.57

So, we can conclude that the cost function is best optimized in ICA compared to PSO. The increased iteration and increased population size give the best result. ICA is better than PSO with respect to total cost. Convergence iteration and execution time

7. Conclusion and recommendation for future work

In this paper, an inventory model was developed under conditions multi-product and multi constraint for the vendor managed inventory (VMI) system in a two-echelon supply chain. Moreover, it was assumed that shortages are backordered, so the vendor's warehouse capacity was limited by an upper bound for available inventory or maximum inventory. Since in inventory models, constraints like number of orders, available capital, and average inventory have an important role, these constraints were added to the model, too. The obtained model was an Integer Nonlinear Programming (INLP) problem; thus, the Imperialist Competitive algorithm (ICA) was proposed to solve it. Furthermore, Particle swarm Optimization (PSO) algorithm was also used to compare the results. Finally, a numerical example was presented to describe the sufficiency of the proposed strategy.

Supply chain is a very complicated system. It includes many parameters and involvement of many people to run effectively (Krajewski and Ritzman, 2002). The vendor managed inventory model used here presents a simplification considering as one retailer has many products, many distributors and a number of retailers and suppliers. The real-life scenario is much more complex. Since the product considered here is supplied all over the country to a thousand of retailers, it is not possible to collect the data for the research in such extensive level with limitations like sources of information and cooperation. The more the members are included in the model, the more the realistic policy would be found with the help of genetic algorithm. Thus, by including more and more members and information of the supply chain, this limitation can be mitigated

For future work extensions, the followings are recommended for other researchers:

- 1.The lead-time effects can be considered.
- 2.Alternative meta-heuristic search algorithms such as Tabu search (TS) or simulated annealing (SA) can be used.
- 3.Other situations like variable costs and discounts can be considered.
- 4.Non-deterministic parameters such as fuzzy or stochastic demand can be considered.

Other cases of VMI system like the single-vendor multi-retailer, multi-vendor single-retailer and multi-vendor multi-retailer systems can be modeled.

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Biographies

Ferdous Sarwar received his B.Sc. (summa cum laude) and M.Sc. in Industrial & Production Engineering (IPE) from BUET and Ph.D. in Industrial & Manufacturing Engineering (IME) from North Dakota State University (NDSU), USA. He is an Associate Professor of Industrial and Production Engineering with BUET. His research interest includes optimization and supply chain management. He is a Member of the International Microelectronics and Packaging Society (IMAPS), the Surface Mount Technology Association (SMTA), and the Institute of Industrial Engineers (IIE).

Mahmudul Hasan Porag is a Lecturer in the Department of Mechanical & Industrial Production Engineering at the Ahsanullah University of Science and Technology Dhaka, Bangladesh. He earned B.S. in Industrial & Production Engineering from Bangladesh University of Engineering and Technology, Bangladesh. He worked at LafargeHolcim Bangladesh Limited as a Supply Chain Management Trainee. His research interests include Supply Chain, Logistics, Simulation, Optimization, Reliability, and Scheduling.