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Optimal procurement strategy for uncertain demand situation and imperfect quality by genetic algorithm

Md. Sanowar Hossain*, Nur-E-Zannat*, Umme Aftahaune Mohana* and Md. Mosharraf Hossain*
*Department of Industrial and Production Engineering
Rajshahi University of Engineering and Technology, Rajshahi 6204, Bangladesh
E-mail: sanowar_ruet05@yahoo.com

Abstract

This paper determines an optimal procurement strategy as the demand over a finite planning horizon is known. This study considers the scenario of supply chain with multiple products and multiple suppliers, all of which have limited capacity. It is assumed that the received items from suppliers are not of perfect quality. Items of imperfect quality, not necessarily defective, could be used in another inventory situation. Imperfect items are sold as a single batch, prior to receiving the next shipment, at a discounted price. Some critical parameters for determining optimal procurement strategies like maximum storage space for the buyer, standard deviation of demand during lead time the corresponding product dependent compensation cost are also considered here. The whole mathematical model is structured and represented as linear programming model and was solved by an efficient meta-heuristic algorithm (Genetic Algorithm). Some computational studies were also carried on to prove its acceptance in the real world.

Keywords: Supply Chain Management, Inventory control, Genetic algorithm, Integer linear programming, optimal procurement strategy, Supplier selection.

1. Introduction

For a multi-objective optimization problem, a complete optimal solution seldom exists, and a Pareto-optimal solution is usually used. A number of methods, such as the weighting method, assigning priorities to the objectives and setting aspiration levels for the objectives are used to derive a compromised solution. In general, an inventory model involves ''fuzziness" since shortage constraint and demands are not always known exactly. Furthermore a DM often has vague goals such as ''This profit and ROII objective functions should be larger than or equal to a certain value." For such cases, fuzzy set theory and fuzzy mathematical programming methods should be used [16]. Again some researcher proposed an interactive fuzzy method for multi-objective non-convex programming problems using genetic algorithms.

Classical inventory models generally deal with a single-item. But in real world situations, a single-item inventory seldom occurs and multi-item inventory is common. In a multi-item inventory system, the companies or the retailers are required to maximize/minimize two or more objectives simultaneously over a given set of decision variables. This leads to the idea of a multi-objective mathematical programming problem. Toroslu and Arslanoglu [14] researched a genetic algorithm for the personnel assignment problem with multiple objectives. While modeling an inventory problem, inventory costs, purchasing and selling prices in the objectives and constraints are defined to be confirmed. However, it is seldom so in the real-life. For example, holding cost for an item is supposed to be dependent on the amount put in the storage. Similarly, set-up cost also depends upon the total quantity to be produced in a scheduling period.

During the last two decades, many researchers have given considerable attention to the area of inventory of deteriorating/defective/perishable items, since the life time of an item is not infinite while it is in storage and/or all units can't be produced exactly as per the prescribed specifications. Recently, Goyal and Giri [7] have presented a review article on the recent trends in modeling with deteriorating items listing all important publications in this area. The application of control theory in production inventory control analysis is now-a-days gradually increasing due to its dynamic behavior. Many research papers [Bounkel et al. [4] Kleber et al. [9] etc.] have been published in this regard. Later many researchers utilized optimal control theory to obtain optimal production policy for production inventory systems where items are deteriorating at a constant rate. Optimal control problems usually deal with both objective function and the constraints. The objective function is the cost function that needs to be minimized with respect to time, fuel, energy, etc. The constraints are usually the system dynamics, the limits of the system states and the control effort.

The traditional economic order quantity (EOQ) models cannot be applied to solve these types of production problems. Wang et al. [13] discussed an economic production plan under chaotic demands to minimize overall cost. There have been numerous publications on EOQ models with fixed cost per unit. Recently, however, several papers relaxed the assumption of the fixed cost per unit for the EOQ models. Supplier selection problem has gained great attention in the business management literature and Under the business environment of global sourcing, core-competence outsourcing strategy, supply base reduction, strategic buyer–supplier relationship, cross functional purchasing program, Internet and e-commerce and so forth, the supplier selection decision is becoming ever important and complicated decision.

Basnet and Leung [2] presented a model for optimal procurement lot-sizing with supplier selection. Multi-period models also offer the opportunity to change suppliers for a product from one period to the next. Many supplier selection models are single period models. Benson [3] by introducing capacities for the suppliers, considered a supply chain with multiple suppliers, all of which have limited capacity and determined an optimal procurement strategy for this multi-period horizon. Rezaei & Davoodi [11] provided a deterministic multi-item inventory model with supplier selection and imperfect quality. O. Jadidi et al [10] propose models the problem of supplier selection as a multi-objective optimization problem (MOOP) where minimization of price, rejects and lead-time are considered as three objectives.

In this paper, a multi-item inventory model is discussed having demand uncertainty/lumpiness as well as imperfect quality items. The demand uncertainty is expressed in terms of the demand variation in the lead time which eventually causes the cost of compensation for the organization concerned. Later, a way for determining optimal procuring quantities from supplier along with the selection of suppliers in a particular period is formulated as an integer programming model. Then the model is solved with Genetic Algorithm.

2. Problem formulation

The model which is considered here consists of multiple products and multiple suppliers having capacity limitation (fig.1). It is assumed that the products or materials that would be purchased from the supplier are all not of perfect quality. That means some of them may be of imperfect quality, not necessarily defective and would be used in another inventory situation. These imperfect quality products will be sold as single batch at a discounted price prior to receiving the next shipment. In fig.1, it is shown that each of the suppliers is providing each of the products. After receiving the products, screening takes place to sort out the imperfect quality items. Then production is carried out and demand is fulfilled with the inventories of currently produced ones along with the inventories from the previous period. Imperfect quality items are also sold prior to the next shipment. Eventually, the unsold products remain in the inventory for use in next period. The demand over a finite planning horizon is considered to be known and what needs to be determined is the optimal procurement strategy for this multi period horizon. A supplier-dependent transaction cost applies for each period in which an order is placed on a supplier. A product-dependent holding cost per period applies for each product in the inventory that is carried across a period in the planning horizon. A product-dependent compensation cost applies for each type of product due to the variation of demand during lead time.

Also a maximum storage space for the buyer in each period is considered. In order to maximize the total profit, the decision maker, the buyer, needs to decide what products to order, in what quantities, with which suppliers, and in which periods (x_{ijt}). Since multiple products, multiple suppliers, multiple periods are considered; solving such a large optimal problem using conventional methods is quite impossible. In order to obtain a population of solutions a GA approach is proposed to solve the problem.

Assumptions & notations

Some assumptions & notations are adopted to develop the model-

O_j	Transaction cost for supplier j does not depend on the variety and quantity of products involved
H_i	Holding cost of product i per period is product-dependent
D_{it}	Demand of product i in period t is known over a planning horizon
P_{ij}	Each lot of product i received from supplier j contains an average percentage of defective items
b_{ij}	Purchasing price of product i from supplier j
S_{gi}	Good-quality items i have a selling price per unit
S_{di}	Discounted price of defective items i are sold as a single batch
v_i	screening cost of product I,
W	Available total storage space
w_i	Product i needs a storage space
σ_L	Standard deviation of demand during lead time
C_i	Corresponding compensation cost for this variation is considered to be of product i

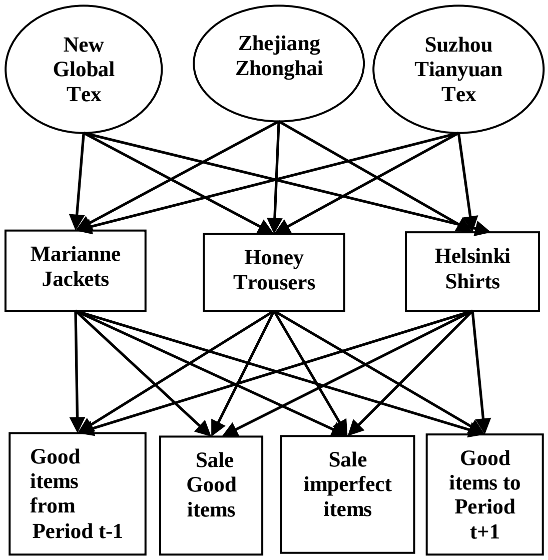

Fig. 1: Behavior of the model in period t

The assumptions are

- 100% screening process of the lot is conducted.
- Items received, are not of perfect quality, not necessarily defective, kept in stock and sold prior to the next period as a single batch.
- Each supplier has a limited capacity.
- All requirements must be fulfilled in the period in which they occur: shortage or backordering is not allowed.
- Also $S_{gi}>S_{di}$

Now, the revenue & cost terms of the model can be stated as below-

Total revenue (TR) = revenue of selling good quality products + revenue of selling imperfect quality products.

$$TR = \sum_i \sum_j \sum_t X_{ijt}(1-P_{ij})S_{gi} + \sum_i \sum_j \sum_t X_{ijt}P_{ij}S_{di} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Total cost (TC) = purchase cost of products + transaction cost for the suppliers + screening costs of the products + holding cost for remaining inventory in each period + compensation cost

$$TC= \sum_i \sum_j \sum_t X_{ijt}b_{ij} + \sum_j \sum_t O_j Y_{jt} + \sum_i \sum_j \sum_t X_{ijt}V_i +$$

$$\sum_i \sum_t H_i (\sum_{k=1}^{t} \sum X_{ijt}(1-P_{ij}) - \sum_{k=1}^{t} D_{ik} + \sum_i \sum_j \sum_t X_{ijt}\sigma_L C_i \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

So, Profit, (π) = TR – TC

$$= \sum_i \sum_j \sum_t X_{ijt}(1-P_{ij})S_{gi} + \sum_i \sum_j \sum_t X_{ijt}P_{ij}S_{di} - \{ \sum_i \sum_j \sum_t X_{ijt}b_{ij} + \sum_j \sum_t O_j Y_{jt} +$$

$$\sum_i \sum_j \sum_t X_{ijt}V_i + \sum_i \sum_t H_i (\sum_{k=1}^{t} \sum X_{ijt}(1-P_{ij}) - \sum_{k=1}^{t} D_{ik}) + \sum_i \sum_j \sum_t X_{ijt}\sigma_L C_i \} \ldots\ldots\ldots\ldots(3)$$

The problem is to find the number of product i ordered from supplier j in period t so as to maximize the total profit function subject to restrictions and boundary conditions.

Objective function:

$$Max(\pi)=Max[\sum_i \sum_j \sum_t X_{ijt}(1-P_{ij})S_{gi} + \sum_i \sum_j \sum_t X_{ijt}P_{ij}S_{di} - \{ \sum_i \sum_j \sum_t X_{ijt}b_{ij} + \sum_j \sum_t O_j Y_{jt} + \sum_i \sum_j \sum_t X_{ijt}V_i$$

$$+ \sum_i \sum_t H_i (\sum_{k=1}^{t} \sum X_{ijt}(1-P_{ij}) - \sum_{k=1}^{t} D_{ik}) + \sum_i \sum_j \sum_t X_{ijt}\sigma_L C_i \}] \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Subject to:

$$\sum_{k=1}^{t}\sum X_{ijk}(1-P_{ij})-\sum_{k=1}^{t} D_{ik\backslash} \geq 0 \text{ for all i, t } \ldots\ldots(5)$$

$$\sum_{k=1}^{t} D_{ik\backslash} Y_{jt} - X_{ijt}(1-P_{ij}) \geq 0 \text{ for all i, j, t} \ldots\ldots (6)$$

$$\sum_{i} w_i \sum_{k=1}^{t}\sum_{j} X_{ijk}(1-P_{ij})-\sum_{k=1}^{t} D_{ik} \leq W \text{ for all t} \ldots\ldots (7)$$

$0 \leq X_{ijt}$ for all i, j, t……………………………………………………………..(8)

The constraints (5) indicate that all requirements must be fulfilled in the period in which they occur and shortage or backordering is not allowed. The constraints (6) represents that each Suppliers have limited capacities. The constraint (7) represents that the available total storage space is limited.

3. Results and discussions

To solve the model and to observe how profit is maximized, data are collected from one of the reputed garment industries in Bangladesh namely Talisman Ltd. which is a sub-company of FCI group and it's a UK-based company. Garments of different styles are usually produced by Talisman Ltd. each year. But considering all the styles will make the maximization problem more cumbersome and also the collection of such a huge data is quite arduous. Thus three particular styles namely Marianne jackets, Honey trousers and Helsinki shirts are taken into consideration. These products are supplied from each of the three suppliers i.e. **New Global Tex, Zhejiang Zhonghai Printing & Dyeing Co. Ltd. and Suzhou Tianyuan.**

In this paper, result is actually representing what products to order, in what quantities, with which suppliers and in which periods. That means the result is associated with the variables X_{ijt} and Y_{jt}. Thus for the two variables a nearly optimal outcome is reached such that it maximizes the profit. The MATLAB R2012a is used with genetic algorithm being the solver to solve the maximization problem. The options and codes that are used for running the problem are mentioned in appendix along with the other used & required details.

Table 1: Demand in pieces of three products over four periods

Products	Planning horizon (periods in four quarters of a year)			
	1st	2nd	3rd	4th
Marianne jackets	330	1594	357	1461
Honey trousers	320	1977	1886	426
Helsinki shirts	405	1925	2712	653

For that, the required data include demand, purchase price, transaction cost, average percentage of defective items, selling price of both the good & defective items, holding cost, screening cost, compensation cost for a variation in demand during lead time and warehouse space. Data of three products i.e. jackets, trousers, shirts are collected over a planning horizon of four periods. In this paper, data for only fabrics are considered since it incurs 95 % of the total cost. Demand in pieces of three products over four periods (Table 1).

Table 2: S_{gi}, S_{di}, C_i, H_i, V_i, σ_L, w_i for three products

parameter ↓	Products		
	1	2	3
S_{gi}	$ 16.15	$ 12.5	$ 10
S_{di}	$ 9.5	$ 6.8	$ 5.75
C_i	$ 0.80	$ 0.30	$ 0.10
H_i	$ 2.75	$ 2	$ 2.5
V_i	$ 0.20	$ .15	$ .18
σ_L	5 pcs	5 pcs	5 pcs
w_i	28.14 m^2	16 m^2	20.6 m^2

There are three suppliers and their prices and transaction cost and average percentage of the defective items are shown in Tables 2 and 3, respectively. In Table 4, selling price of good product i (S_{gi}), selling price of defective product i(S_{di}), storage space of product i (W_i), holding cost of product i per period (H_i) and screening cost of product i(v_i) are shown.

Table 3: Average percentage of defective items for three suppliers

Products	Average percentage of defective items		
	1	2	3
Marianne jackets	13	15	16
Honey trousers	12	11	14
Helsinki shirts	14	13	10

Total storage space, W = 3521.03 m^2

In this section the numerical example of the above model is solved by using a Real Parameter Genetic Algorithm. So, after running the problem in MATLAB software, the magnitudes of the variables X_{ijt} & Y_{jt} are obtained. The nearly optimal values of ordering frequency (X_{ijt}) of the three products i.e. jackets (Table 4), trousers (Table 5) & shirts (Table6) from each of the three suppliers at each quarter of a year is summarized. As the model has been formulated with vague parameters, the decision maker may choose that solution which suits him best with respect to resources. At the same time the standard deviation of lead time demand and the percentage of defective item supplied by supplier is considered.

Table 4: Ordering quantities for Marianne jackets

Jackets (i=1)		Periods (t)			
		1	2	3	4
Suppliers (j)	1	9688	55	9	55
	2	13	151	29	20
	3	9935	181	8	23

Table 5: Ordering quantities for Honey trousers

Trousers (i=2)		Periods (t)			
		1	2	3	4
Suppliers (j)	1	27	108	100	70
	2	323	1576	25	9597
	3	21	6498	337	9930

Table 6: Ordering quantities for Helsinki shirts

Shirts (i=3)		Periods (t)			
		1	2	3	4
Suppliers (j)	1	93	10001	139	9516
	2	122	9848	50	8169
	3	145	171	9963	24

Here uncertainty is incorporate to the analysis by the standard deviation of demand during lead time i.e. σ_L. For 5% standard deviation of demand during lead time i.e. σ_L the corresponding result is obtained the genetic algorithm. Since the suppliers have limited capacities, thus the quantities that the supplier can provide are also restrained. Depending on that restriction, the decision of which supplier is selected (Y_{jt}) in which quarter of a year that summarized in (Table 7). Also imperfect quality and compensation cost incorporated to the model to find the actual scenario of inventory control system.

In the table, the binary values represent yes/no decisions. 1 for yes and 0 for no i.e. 1 means to select the supplier where 0 indicates those suppliers that should not be selected for particular period of a year. Thus order should be received from supplier 1 in periods 2 and 4, from supplier 2 in periods 1 and 3, from supplier 3 in periods 1 and 2. The objective function value for the concerned problem is **282518.85,** which actually indicates the magnitude of annual profit of the concerned company. Thus the profit is determined to be $ 282518.85.

Table 7: Decision for the selection of suppliers

Periods → supplier ↓	1	2	3	4
1	0	1	0	1
2	1	0	1	0
3	1	1	0	0

For sensitivity analysis, the main parameter to be considered in this paper is the standard deviation of demand during lead time i.e. σ_L which is the indicator of uncertain demand. So, by both increasing and decreasing the values of σ_L will show how it has affected the result. For increased value of σ_L (σ_L=10 pcs) it is seen that the ordering quantities of each product has changed a lot. Not only that but also the supplier selection situation has also changed. The profit has decreased tremendously. For decreased value of σ_L (σ_L=1 pcs) it is seen that the ordering quantities of each product remain the same so do the supplier selection situation. The profit here has increased approximately by 42%. So, comparing the profit indicates that a little larger value of σ_L can cause a great loss to the concerned organization while keeping it as lower as possible can enlarge the profit.

4. Conclusions

A multiple-production-inventory model with multiple suppliers is considered in this paper. The current paper aims at providing a basis of planning and controlling the inventory in supply chain and unifying the selection of supplier for multi-products, period, and suppliers Backlogging compensation is one of the major considerations of this paper. They also face a great problem to decide appropriate suppliers from multiple suppliers what products to order, in what quantities, and in which periods. But it can be possible for the decision maker (DM) to apply this process to come to an overall verdict with fewer hurdles. Genetic Algorithm is used to solve the problem but Fuzzy Logic solver or other heuristic approaches can also be used to solve the problem. This study considers fabric cost of three products. So in future one may also consider accessories cost for as high number of products as possible.

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