Multi-Suppliers Procurement Model with Optimal Service Level Tailored for Egyptian Industrial Sector

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Abstract—Figuring out the appropriate procurement model that fits certain business environment is a challenge due to the diversity of procurement models’ configurations. The literature was surveyed to identify the anatomy of procurement model. After that, a questionnaire was conducted with a number of procurement specialties in the Egyptian industrial sector in order to characterize the model that fits them the best. Then, in order to achieve the questionnaire result, a constrained mathematical model is developed to optimize the total cost including procurement, holding, ordering and shortage costs. This model includes several factors affect the optimum order quantity and the suppliers’ share factor. Finally, a series of simulation experiments are conducted in order to validate the proposed model under various system configurations.

Keywords—Procurement models; inventory control systems; suppliers’ selection; payment term; orders’ quantity; orders quality; Egyptian enterprises.

I. INTRODUCTION

Procurement is considered a cornerstone for many organizations [1]. Thus, the procurement department plays a key role in improving the organization’s efficiency and effectiveness because its decisions have a direct effect on cost reduction, profitability and flexibility. Procurement is defined as the acquisition of goods or services at the lowest possible total ownership cost with right quantity and quality, at the right time and the right place and from the right source. Handling these multi-criteria concurrently require a structured approach. Configuring the procurement model to fit the business environment is a challenge due to the diversity of the business environments in different countries and different industries [2]. The procurement literature introduced a number of procurement models addressing a wide spectrum of business needs and business environments [3][4][5][6][7][8][9][10][11][12]. Therefore, there may be a challenge to select appropriate procurement model for a specific business environment in a specific country. In order to address this challenge, a survey was conducted through a questionnaire to characterize the procurement problems in the Egyptian industrial sector. The next section introduces a brief background of the different aspects of procurement models, followed by the survey design. After that, the questionnaire result is presented and a statistical analysis is performed, before the final model was mathematically concluded and tested with real industry data.

II. BACKGROUND

The procurement problem has two dimensions, which are the suppliers’ selection that answers the "who question" and orders’ quantity that answers the "what question" [3].

There are various models addressing the suppliers’ selection problems [4][5][6][13][14][15][16][17]. In addition, Minnergave an extensive review on this issue; he reviewed 92 papers, which were classified based on supplier’s selection criteria. The classification criteria were prices (net prices, discounts and payment conditions), quality, contracts and supplier service (delivery time, lead time, flexibility, variability and reliability) [18].

Kawtummachai and Hop introduced a suppliers’ selection model with order allocation procedures and multiple prices while maintaining a specified service level [4]. Qi added supplier capacity and fixed order cost to Kawtummachai and Hop’s model [5]. The former procurement models implicitly assume that all receiving items are perfect; although procurement models, which consider the quality of the purchased items, are closer to real-world problems [17]. Liaoa and Rittscher addressed this issue by introducing a model in which the defect units are refunded to their supplier [13]. On the other hand, Rezaei and Davoodi developed a constrained model with supplier’s limited capacities [14]. They assumed that imperfect items could be used at a discounted price; their model objective is to maximize the total profit of sold good and defect items after subtracting them from total cost of purchasing, transaction and screening cost. Wahab and Jaber[15] and Chang [16] developed a model involving imperfect items with discount price; in addition, Chang’s
model adopted lot splitting shipment policy and ordering cost variation. Zhang and Zhang [6] addressed a model similar to Qi’s model while considering suppliers’ minimum order quantity (MOQ) constraints and supplier selection cost.

Consequently, it is clear that there are many models handling the suppliers’ selection that consider multiple aspects as order splitting among suppliers, suppliers’ capacity, minimum order quantity required by suppliers, handling different unit prices, ordering cost variations, and purchased items quality including multiple aspects as receiving inspection, accepting order with defect units and refusing the defect units. Moreover, availability of supplier credit facility, which allows the procurement department to delay payment for a certain time, was neglected by the mentioned researchers. In Table I, the previously described suppliers’ selection policies are summarized.

The order’s quantity dimension was also heavily investigated by many inventory researchers [7] [8] [20][21] [10] [9] [22] [23] [11] [24] [12][25].

Ouyang and Yao, and Chang et al. developed a mixed inventory model for a single SKU (product) involving ordering, holding, product shortage resulting in backorder (B) and lost sales (L), and lead time crashing cost; they compensated clients in case of shortage[7] [8] [9]. Yang et al. added the reorder point under the effectiveness of time value regarding money to the former model [10]. Lin formulated a similar model as change et al. [9] but with a periodic review [22]. Chandraa and Grabise developed a procurement model involving ordering, holding, shortage with fully backorder, and procurement cost in order to find the optimal solution of lead time, order quantity and safety factor[23]. Bera et al. reformulated Yang et al.’s model for multi-item to find the optimal order quantity and the optimal value of safety stock under the budget constraint and random lead time [11]; in addition, full inventory backorder was considered. Taliezadeh et al. developed a procurement model based on uncertain demand and random time between replenishments to minimize the total cost of purchasing, holding and shortage of backorder and lost sales under limited storage space constraint [25].

The previous models implicitly assumed that there was no delayed payment. However, delayed payment reduces the capital amount invested in inventory during the credit time. Suppliers usually offer payment delay period in order to encourage buyers to increase their lot size. Huang proposed a procurement model considering payment delay period and the integrated supply chain cost[12].

It is clear that there are many models handling the orders’ quantity, which consider multiple aspects as the interdependence between different SKU, allowable shortage, backorder, handling penalty cost, partial replacement in case of shortage, fixed reorder point for each SKU, holding cost variation, limited budget allocation for each SKU, various lead time and payments terms. Despite the availability of many other procurement models offering different solution techniques, not all of those models are considered. The reason for not considering those models is that the objective of this research is limited to find the assumptions and parameters in the appropriate model for Egyptian industrial sector and not the solution techniques or model structure. Table II summarizes the previously described orders’ quantity policies.

**TABLE I. FACTORS AFFECTING SUPPLIERS’ SELECTION.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Order Splitting</th>
<th>MOQ</th>
<th>Supplier capacity</th>
<th>Quality inspection</th>
<th>different unit prices</th>
<th>Ordering cost variation</th>
<th>Other consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kawtummachai and Hop [4]</td>
<td>✔</td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td>Service level</td>
</tr>
<tr>
<td>Qi [5]</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td>Shipping cost and carrier selection</td>
</tr>
<tr>
<td>Liao and Rittscher [13]</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td>Transaction, screening cost and storage space constraint</td>
</tr>
<tr>
<td>Rezaei and Davoodi [14]</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td>Screening cost</td>
</tr>
<tr>
<td>Wahab and Jaber [15]</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Selection cost</td>
</tr>
<tr>
<td>Zhang and Zhang [6]</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td>Screening cost</td>
</tr>
<tr>
<td>Chang [16]</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE II. FACTORS AFFECTING ORDERS’ QUANTITY.

<table>
<thead>
<tr>
<th>Author</th>
<th>Ordering</th>
<th>Holding</th>
<th>shortage</th>
<th>procurement</th>
<th>Lead time</th>
<th>Decision variable</th>
<th>other consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ouyang and Yao [7]</td>
<td></td>
<td>✔</td>
<td>B and L</td>
<td></td>
<td>✔</td>
<td>Lead time and order quantity</td>
<td>Uncertain demand</td>
</tr>
<tr>
<td>Chang et al. [8][9]</td>
<td>✔</td>
<td>✔</td>
<td>B and L</td>
<td></td>
<td>✔</td>
<td>Lead time and order quantity</td>
<td>Variable lead time and uncertain backorder</td>
</tr>
<tr>
<td>Yang et al. [10]</td>
<td>✔</td>
<td>✔</td>
<td>B and L</td>
<td></td>
<td>✔</td>
<td>Order quantity, and reorder point</td>
<td>Demand and lead time follow normal distribution, studied the effect of time value of money</td>
</tr>
<tr>
<td>Lin [22]</td>
<td>✔</td>
<td>✔</td>
<td>B and L</td>
<td></td>
<td>✔</td>
<td>Lead time</td>
<td>Periodic review and crashing cost</td>
</tr>
<tr>
<td>Chandraa and Grabise [23]</td>
<td>✔</td>
<td>✔</td>
<td>B</td>
<td>✔</td>
<td>✔</td>
<td>Lead time, order quantity, and safety factor</td>
<td>Safety and lead time, Interdependency among SKUs, and limited budget</td>
</tr>
<tr>
<td>Bera et al. [11]</td>
<td>✔</td>
<td>✔</td>
<td>B</td>
<td></td>
<td></td>
<td>Safety stock and order quantity</td>
<td>Safety and lead time, Interdependency among SKUs, and limited budget</td>
</tr>
<tr>
<td>Huang[12]</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td>Order quantity</td>
<td>Transportation cost, Payment condition and integrated supply chain between buyer cost and vendor cost.</td>
</tr>
<tr>
<td>Taleizadeh et al. [25]</td>
<td>✔</td>
<td>✔</td>
<td>B and L</td>
<td>✔</td>
<td>✔</td>
<td>Maximum inventory level</td>
<td>Uncertain demand and random time between two replenishment</td>
</tr>
</tbody>
</table>

III. QUESTIONNAIRE DESIGN

The previous survey introduced eighteen different factors that can be used to characterize procurement models. Ranking the importance of these factors for the Egyptian industrial sector is addressed through a questionnaire. Fifteen of the previous factors are addressed with one question and five factors are addressed with two questions. Therefore, the questionnaire consists of twenty-five classification questions divided in two sections; each section addresses one of the former dimensions. The questionnaire starts by assessing the need for multiple suppliers. This factor is addressed through two questions about the number of SKUs that are supplied from more than one supplier and the maximum number of suppliers for the same SKU. Then, one question about the top three factors affecting suppliers’ selection. The need for order splitting among suppliers is assessed through two questions about the importance of having a tool to optimize the order size and to split the order among suppliers for the same SKU. Then, MOQ and limited suppliers’ capacity are addressed by three questions, followed by three questions about quality addressing receiving inspection, accepting orders with defect units and handling defect units. The Twelfth question is about the order receiving duration. Handling multiple prices is addressed through two questions inquiring about the need to handle different unit prices and multiple order costs.

The first factor of the second dimension, which is the holding cost, is addressed through two questions about having different holding cost for different SKUs and handling limited inventory budget, followed by four questions about product shortage addressing allowing shortage, allowing backorder in case of shortage, compensating customer in case of shortage and replacing the out of stock SKU by another SKU. Lead-time is addressed through two questions about lead-time consistency among different SKUs and different suppliers. Reorder point is addressed through one question. Finally, payment term consistency among different SKUs and different suppliers is addressed by two questions. A pilot test of questionnaire was performed with one procurement specialist. Based on his feedback, some questions were restated in order to be clearer and more understandable.

IV. QUESTIONNAIRE DISTRIBUTION

The appropriate questionnaire subjects are procurement specialists working in the Egyptian industrial sector. Two cities were arbitrarily selected to represent the Egyptian industrial sector, which were 10TH of Ramadan city representing the new industrial regions and Mit-Gamer city representing the traditional industrial regions. The data of the industrial companies of each city was obtained from the relevant chamber of commerce. After that, the questionnaire was sent to all the industrial companies of the two cities via email; unfortunately, very low response was obtained. Therefore, companies were contacted to discuss the possibility of conducting personal visit in order to fill the questionnaire. Thirty-two companies responded positively; twenty-four companies of them from 10th of Rodman city and eight companies from Mit-Gamer city. This sample size was considered enough to achieve the goal of the research by getting a casual trend of procurement models that are suitable for Egyptian industrial sector. However, getting sharp and quantifiable results about the sector procurement
preferences could be an interesting point for further research. Fortunately, filling the questionnaire through direct discussion (interviews) allowed the research team to obtain deeper understanding of a complicated problem such as the one under investigation. Direct contact questionnaire filling for complex problems was supported by some researchers as Varnas et al. [26]

V. QUESTIONNAIRE RESULT

It is clear that procurement professionals depend on more than one supplier for sourcing the same SKU, as reported by 81% of the respondents. Concerning the acceptable maximum number of suppliers for the same SKU, half of the respondents stated that it should be three, while third of them reported that they can accommodate more than four suppliers for the same SKU. It can be concluded that although three is recommended as the maximum number of suppliers for the same SKU, the needed model should have no limitation for the number of suppliers. The respondents were asked to pick the top three factors affecting their suppliers’ selection, price (97%) and quality (84%) got the highest rank among all respondents; the lead-time was also highly ranked by 69%. Surprisingly, only 22% of the respondents considered the payment term as a significant factor for supplier selection. Other factors as minimum order quantity, ordering cost and long-term contracts were not highly ranked by the respondents as critical supplier selection criteria, as shown in Fig.1. Companies with limited number of suppliers per SKUs justified it by seeking to build a long-term supplier relationship in order to improve the service quality.

The need for a tool that optimizes the orders of the same SKU among multiple suppliers was enforced by 91% of respondents, while 86% described such tool “a must have” one. Moreover, 76% of respondents reported that they are used to split the same SKU orders among suppliers based on their quality and price. This result matches the research reported by Qi [5]. Therefore, it can be concluded that there is a need for a procurement model that can be used to optimize passing orders of the same SKU to more than one supplier.

More than three quarters (78%) of the respondents reported that the majority of their suppliers have unlimited capacity compared to their order size. Regarding the MOQ, two thirds of the respondents stated that their suppliers seldom force a minimum order quantity. It should be considered that the majority of the surveyed companies are medium and large enterprises, which usually ask for substantial quantities exceeding the suppliers’ MOQ. There is a significant correlation between respondents with limited capacity suppliers and those who reported the need for MOQ (r = 0.82). It is concluded that the surveyed companies aren’t restricted by suppliers’ MOQ, because their order size exceed the suppliers’ MOQ. Therefore, there is no need for procurement model that handles suppliers’ MOQ and supplier’s limited capacity.

About three quarters (72%) of the respondents stated that they receive their orders over a short period of time. Moreover, 28% of the respondents reported that they receive their order as one shipment. It is obvious that a procurement model with instantaneously replenishment can fit the need of the Egyptian industrial sector.

All of the respondents reported that they carry receiving inspection for some or all their SKUs. Two third of the respondents reported that they never accept to receive any defect units. Moreover, 60% of the respondents refunded only defect units to their suppliers. Therefore, it is quite beneficial to have a procurement model that considers the effect of returning defect units.

More than three quarters (78%) of the respondents reported that they source their SKUs with more than one price from more than one supplier at the same time. Moreover, about two thirds (62%) of the respondents reported that the order cost is not consistent among different SKUs even from the same supplier. There is a correlation between the respondents who reported different prices for the same SKU and those who reported different ordering cost of different SKUs from the same supplier (r = 0.71). It can be concluded that Egyptian industrial sector needs a procurement model that handles multiple prices and multiple ordering cost of the same SKU.

Majority of the respondents (78%) reported having different holding cost; moreover, about third of them (25%) reported different holding cost for almost all of their SKUs. Therefore, it might be quite beneficial to have a procurement model that considers different holding cost for different SKUs. The survey results showed that 72% of the respondents reported that it is the nature of business to limit the budget for the inventory value. Although, the remaining (28%) of the respondents reported that they didn’t allocate budget for inventory; it can be concluded that Egyptian industrial sector needs a procurement model that addresses the limited budget for inventory value.

It is clear that procurement professionals usually encounter shortage in some or even all SKUs, as reported by 72% of the respondents. The remaining 28% of the

![Figure 1. The factors affecting supplier selection.](image-url)
respondents reported that missing some SKUs might result in stopping their production lines, what would be too costly to afford. Regarding backorders, 87% of the respondents who encountered shortage, stated that they have backorders for some and almost all SKUs. The respondents were asked about compensating their clients in case of shortage; this hypothesis was supported by 61% of the respondents for some and all SKUs. It can be concluded that there is a need for a procurement model that implements shortage resulting in both of backorders and lost sales and accommodating shortage penalty cost.

Regarding partial replacement of one SKU by another SKU in case of shortage, only 3% of the respondents reported that almost all of their SKUs are replaceable. About 47% of the respondents reported that none of the SKUs is replaceable. However, 50% of the respondents reported that some SKUs are replaceable and some are not; therefore, no concrete conclusion can be drawn about the importance of accommodating such hypothesis in procurement models. It is suggested that a deeper investigation about the effect of products’ irreplaceability across different business sizes and different industries may be an interesting goal for future research.

Suppliers usually have different inventory, production and shipping policies resulting in different lead-time even for the same SKU; this hypothesis was supported by 72%. In addition, having different payment terms for different SKUs was supported by 84% of the respondents. On the other hand, 10% of the respondents reported that they succeeded to force the supplier to follow their payment conditions. Forcing the suppliers to follow the enterprise’s procurement conditions may not be applicable for small and medium ones, because they may not have enough buying power to control the market. Therefore, it might quite beneficial to have a procurement model that considered different lead-time for different suppliers and different SKUs and delayed payments diversity.

About 81% of the respondents reported that they use fixed reorder points for each of their SKUs even if it is ordered from more than one supplier. Therefore, it is clear that there is a need for a procurement model that considers a fixed reorder point.

VI. THE PROPOSED MODEL

Based on the results of the questionnaire, a constrained mathematical model is developed in order to minimize the total cost involving procurement, holding, ordering, and shortage costs while stratifying the given conditions. This model is consisted of a non-linear objective function and a number of bounding linear and nonlinear constraints and can be used to determine the optimal order quantity from the available suppliers and determine the suppliers’ share factor. The suppliers’ share factor is the percentage of supplier participation in the total demand of a single SKU per the cycle time.

The product procurement cost can be calculated using (1) [26].

\[ PC = C_p D \]  

(1)

Where

\( PC \): Total purchasing cost,

\( C_p \): Purchasing cost for one unit,

\( D \): Average demand per cycle.

To accommodate having different purchasing cost from different suppliers for the same SKU, the suppliers’ share factor used in order to calculate the total weighted purchasing cost as shown in (2).

\[ \omega_j PC = D \sum_{j=1}^{m} C_{pj} \]  

(2)

Where

\( C_{pj} \): Purchasing cost of one unit from supplier (j),

\( \omega_j \): Suppliers’ share factor (a decision variable),

\( m \): Number of available suppliers, \( j=1:m \).

According to Ouyang and Yao and Change et al., the expected average holding cost in the case of shortages involving back order and lost sales can be calculated as per (3).

\[ HC = C_h \left[ \frac{Q}{2} + SS_i + (1 - \alpha_i)E(x_i - r_i)^+ \right] \]  

(3)

Where

\( HC \): Total holding cost,

\( C_h \): Inventory holding cost per one unit,

\( Q \): Order quantity (a decision variable),

\( SS \): Safety factor,

\( \alpha \): Fraction of backordered demand during the stock-out period and \( 0 \leq \alpha_i \leq 1 \),

\( E(x_i - r_i)^+ \): Expected number of shortage, \( i=\text{SKU index} \).

Based on the questionnaire result, the received order is not totally accepted because it may contain a percentage of defects (p). The defect items are instantaneously removed from the received order and refunded to their suppliers. Therefore, the received order quantity is reduced by the factor \( (1 - p) \). Therefore, the suppliers’ share factor is used in order to calculate the total weighted average holding. Hence, (3) is reformulated in order to be applicable for the proposed model.

\[ HC = C_h \left[ \sum_{i=1}^{n} \frac{Q_i(1 - p_i)}{2} + SS_i(1 - \alpha)E(x_i - r_i)^+ \right] \]  

(4)

The safety stock is defined as the difference between the reorder point and the expected demand during the lead time [7] [21] [8] [9] [26] [11], and can be calculated as per equation (5).
Where:
- \( E(x) \): Expected demand during lead time,
- \( r \): Reorder point,
- \( k \): Safety factor,
- \( \sigma_x \): Standard deviation of lead time demand.

Chopra and Meindl [27] calculated the safety stock for a single SKU as per (6).

\[ SS = \varepsilon^{-1}(CSL)\sigma_x \]  

Where:
- \( CSL \): Cycle service level,
- \( \varepsilon^{-1} \): The inverse of cumulative standard normal distribution.

Using equations (5) and (6), it can be concluded that the optimal safety factor should equal the inverse of cumulative standard normal distribution of optimal cycle service level:

\[ k = \varepsilon^{-1}(CSL) \]  

(7)

CSL is equal to the probability of having no stock out in a replenishment cycle [27] and the optimal CSL can be calculated as:

\[ CSL^* = \frac{C_u}{C_u + C_o} \]  

(8)

Where:
- \( C_{u} \): Under-stock cost,
- \( C_{o} \): Over-stock cost.

The cost of under-stocking is the margin lost by a firm for each lost sale (lost profit) because there is no inventory on hand [27].

\[ C_u = \text{sales price} - \text{purchasing cost} = S_p - C_p \]  

(9)

Where:
- \( S_p \): Selling price of one sold unit.

As previously mentioned, the purchasing cost should be multiplied with suppliers' share factor in order to calculate the total weighted average purchasing cost for the available suppliers. Then, the under-stock cost is calculated per (10).

\[ C_u = S_p - \sum_{j=1}^{m} C_{p,j} \beta_j \]  

(10)

The cost of over-stock is the loss occurred by a firm for each unsold unit at the end of the selling cycle [27].

\[ C_o = \text{holding cost on replenishment cycles} = \frac{\text{annual holding cost}}{\text{number of orders}} = \frac{C_h}{N} \]  

(11)

Where:
- \( N \): Total number of orders per cycle time.

The number of orders from each supplier \( j \) \((N_j)\) of a single SKU per the cycle time can be calculated per (12).

\[ N_j = \frac{D_j}{Q_j} \]  

(12)

The total number of orders for a single SKU from multi suppliers can be calculated per (13).

\[ N = \sum_{j=1}^{m} N_j \]  

(13)

From (12) and (13), the total number of orders as a function of \( D \) and \( Q \) is calculated per (17).

\[ N = \sum_{j=1}^{m} \frac{D_j}{Q_j} \]  

(15)

\[ D_j = D \cdot \beta_j \]  

(16)

\[ N = \frac{m}{D} \sum_{j=1}^{m} \frac{Q_j}{\beta_j} \]  

(17)

In order to calculate the appropriate over-stock cost for the proposed model, substitute by (17) in (11).

\[ C_o = \frac{C_h}{D} \sum_{j=1}^{m} \frac{Q_j}{\beta_j} \]  

(18)

Then, in order to calculate the optimal cycle service level, substitute by (10) and (18) in (8).

\[ CSL^* = \frac{C_u}{C_u + C_o} = \frac{S_p - \sum_{j=1}^{m} C_{p,j} \beta_j}{S_p - \sum_{j=1}^{m} C_{p,j} \beta_j + \frac{C_h}{D} \sum_{j=1}^{m} \frac{Q_j}{\beta_j}} \]  

(19)

Subsequently, the safety factor can be calculated per (20) after substituting by (19) in (7).

\[ k = \varepsilon^{-1}(CSL^*) = \varepsilon^{-1} \left( \frac{S_p - \sum_{j=1}^{m} C_{p,j} \beta_j + \frac{C_h}{D} \sum_{j=1}^{m} Q_j}{S_p - \sum_{j=1}^{m} C_{p,j} \beta_j} \right) \]  

(20)

According to Chopra and Meindl, the standard deviation of lead-time demand was calculated per (21)[27].

\[ \sigma_x = \sqrt{\left( \frac{L_j}{2} \right) \sigma^2 + D^2 \sigma_{x,j}^2} \]  

(21)

Where:
- \( L_j \): Lead time of supplier \( j \),
- \( \sigma^2 \): Variance of demand,
- \( \sigma_{x,j}^2 \): Variance of lead time.

The lead-times multiplied with suppliers' share factor in order to get the total weighted lead time of all the available suppliers to supply the same SKU.
Then, in order to calculate the safety stock for a single SKU from multi suppliers, substitute by (20) and (22) in (6).

\[ ss = \sqrt{\frac{1}{\sum_{j=1}^{m} \theta_j D_j + D \sum_{j=1}^{m} \theta_j^2}} \]  

(23)

According to Yang et al.; Chang and Lo; Annadurai and Uthayakumar and Chopra and Meindl, the expected shortage quantity at the end of the cycle was calculated as a function of safety factor per (24)[10][29][30][27].

\[ E(x - r)^+ = \sigma_k f_k(\frac{x}{\sigma_k}) - ss[1 - F_k(\frac{x}{\sigma_k})] \]  

(24)

Where:
\( f_k \) and \( F_k \), are the standard normal probability density function (pdf) and the cumulative distribution function (CDF) respectively. Those are originated in the standard normal distribution tables.

Then, substitute by (22), (20) and (23) in (24) to be appropriate in the proposed model

\[ E(x - r)^+ = \sqrt{\sum_{j=1}^{m} \sum_{j=1}^{m} \theta_j D_j + D \sum_{j=1}^{m} \theta_j^2} \left[ 1 - \left( \frac{s_p - \sum_{j=1}^{m} \theta_j D_j + D \sum_{j=1}^{m} \theta_j^2}{\sum_{j=1}^{m} \theta_j D_j + D \sum_{j=1}^{m} \theta_j^2} \right) \right] \]  

(25)

The order cost is the cost dealing with replenishing the inventory stock. It is normally evaluated as dollar amount per order. The order cost also depends on the number of orders per cycle [7] [8] [9] [26].

\[ OC = c_k \frac{D}{Q} \]  

(26)

Where:
\( OC \): Total ordering cost,
\( c_k \): Ordering cost per order.

In order to accommodate multi suppliers, equation (26) is reformulated as:

\[ \Delta OC = \frac{D}{Q} \sum_{j=1}^{m} \theta_j \]  

(27)

Some of the demand will not be satisfied due to insufficient inventory and intolerant customers. Therefore, shortage cost or stock-out cost is the total of all costs associated with shortage units. Ouyang and Yao; Chang et al.; Chang et al. and Lin accommodated the effect of backorder, lost sales and penalty cost as a result of inventory shortage. They calculated the shortage cost per (30)[7][8][9][21].

\[ SC = \frac{D}{Q} \left[ c_s + \pi (1 - \alpha) \right] E(x - r)^+ \]  

(28)

Where:
\( SC \): Total shortage cost,
\( c_s \): Penalty cost,
\( \pi \): Lost profit.

In order to consider multi suppliers sourcing, equation (28) is reformulated as follows:

\[ SC = \sum_{j=1}^{m} \frac{D \theta_j}{Q_j} \left[ c_s + \pi (1 - \alpha) \right] E(x - r)^+ \]  

(29)

\[ \alpha = \frac{s_p - \sum_{j=1}^{m} \theta_j D_j}{\sum_{j=1}^{m} \theta_j D_j} \]  

\[ \Delta SC = D \left[ c_s + \left( \frac{s_p - \sum_{j=1}^{m} \theta_j D_j}{\sum_{j=1}^{m} \theta_j D_j} \right) (1 - \alpha) \right] \sum_{j=1}^{m} \frac{\theta_j}{Q_j} E(x - r)^+ \]  

(30)

Since, the proposed model split the orders between the available suppliers. Moreover, it accumulates the percentage of quantities that are taken from the available suppliers for the same SKU per the cycle time. Therefore, the total suppliers share factor for a single SKU during the cycle time must be equal to 1.

\[ \sum_{j=1}^{m} \theta_j = 1 \]  

(31)

In order to keep the supplier active, some orders should be assigned to him during the cycle. Therefore, an arbitrary lower limit should be assigned to suppliers’ share factor, which should satisfy (32) in order to keep a feasible solution.

\[ \sum_{j=1}^{m} \theta_j < 1 \]  

(32)

Where:
\( \theta_j \): Lower-bound of suppliers’ share factor.

According to Bera et al., the budget constraint was formulated in which the total purchasing cost was less than or equal to the available budget [11].

\[ BC = \sum_{j=1}^{m} c_p (Q_j + \theta_j E(x_{i,j})) \leq B \]  

(33)

Where:
\( BC \): Budget constraint,
\( B \): Available budget.
Equation (33) is reformulated to consider multiple suppliers, defective goods return, sales during credit time, backorder and lost sales as follows:

\[ BC = C_p \left[ \delta_j \left(1 - p_j\right) - \varepsilon \left(z_j \right) \right] - \alpha z \left(x - \gamma^+ \right) + SS \]  

Therefore, the total cost can be minimized using (3), (4), (23), (25), (27), (30), (31), (32) and (34) as per the below model

\[ \text{Min } TC \left(= FC + HC + OC + SC \right) \]

S.T.

\[ \sum_{j=1}^{m} \delta_j = 1 \quad \forall j \]

\[ \sum_{j=1}^{m} \delta_j < 1 \quad \forall j \]

\[ BC \leq B \quad \forall j \]

\[ Q_j \geq 0 \quad \forall j \quad \text{and integer} \]

\[ \delta_j \in \left[ \delta_j, 1 \right] \quad \forall j \]

VII. CASE STUDY

In order to validate the proposed model, a set of MATLAB functions is developed to simulate the proposed model using MINLP (mixed integer nonlinear programing) and FMINCON solver. The model is tested using data obtained from a food manufacturing company in Cairo, Egypt. The company uses 17 main raw material items supplied from 24 suppliers. The company policy is to keep two active suppliers for each of its main raw material items. The company planning manager chooses 10% as the minimum order share a supplier can have in order to be considered as an active supplier for each item. Data obtained from the company is used to run the MATLAB functions to get the optimal supplier share and the optimal order cost of each of the 17 items, as shown in Table III. The model successfully selected the most economic suppliers and assigned them the largest feasible share of the item demand, while assigning the forced minimum share to the backup supplier. Then the system calculated all of the optimal order quantity, the optimal reorder point, the optimal safety stock and the optimal cycle service level. Comparing the actual costs in 2013 to the costs that would occur if the company used the data from the model revealed that the company would save 17.45% of its total inventory cost in 2013 by using the proposed model.

A second case study is created by doubling the lead-time of the main supplier, while keeping the lead-time of the backup supplier unchanged. The new data is re-used with the MATLAB functions to get the optimal procurement policies for each of the 17 items as shown in Table IV. Comparing Table III and Table IV shows that the model responded logically by getting higher optimal total cost when the lead-time lead was increased. Moreover, the model was able to alternate its selection of the main supplier when he became less economic than the back-up one (items number 5, 6, and 12).

Where:

#: supplier code,
%
: supplier share.

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<tr>
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<th>Backup supplier</th>
<th>Optimal total cost</th>
</tr>
</thead>
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VIII. 1. CONCLUSIONS

Suppliers' selection and orders' quantity models based on continuous inventory review were heavily addressed by procurement literature. This survey introduced eighteen different factors that can be used to characterize procurement models. Ranking the importance of these factors for the Egyptian industrial sector is addressed the conducted a questionnaire with the 32 procurement specialists in the sector. The questionnaire revealed some distinguished requirements for the procurement model that will address the needs of Egyptian industrial sector. Consequently, a constrained mathematical model is developed in order to minimize the total cost while stratifying the given conditions. This model is consisted of a non-linear objective function and a number of bounding linear and nonlinear constraints that address the following business needs:

- Manipulating orders from multiple suppliers for the same SKU with different purchasing prices, different ordering costs, different lead times and different payment terms
- Accommodating the effect of returning defective items to the suppliers
- Handling different holding cost for different SKUs.
- Accommodating the effect of backorder, lost sales and penalty cost as a result of inventory shortage.
- Using fixed reorder point
- Budgeting the maxim inventory value for some/all SKUs.

On the other hand, considering the effect of receiving time was neglected due to surveyed requirement of the Egyptian industrial sector.

References


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