PREEMPTIVE AND NON-PREEMPTIVE GOAL PROGRAMMING APPROACH TO INVENTORY OPTIMIZATION OF THE CENTRAL STERILE SUPPLY DEPARTMENT, UNIVERSITY COLLEGE HOSPITAL, IBADAN, NIGERIA

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Abstract: This research applied a multi-criteria optimization technique to analyse the inventory system of a Central Sterile Supply Department (CSSD) through preemptive and non-preemptive goal programming. Data on six raw materials and four finished products were collected, in addition to their costs, demand rates, shelf lives, and available capital. The developed objective function of the non-preemptive model combined four goals: inventory cost optimization (highest priority), inventory turnover, service level, and delivery lead time. The implemented model guaranteed zero stock-outs, reduced wait times between productions, timely product sales, and the elimination of unnecessary overall costs.

Keywords: goal programming, inventory system, multi-criteria optimization, optimum, sterile

1. INTRODUCTION

Companies face difficulties trying to match customers' varying demands with available production. An organization's capacity to manage this challenge significantly impacts profitability [1-2]. A business aims to make goods available to meet demand by holding a certain inventory level. Inventory is described as a stock of goods or raw materials having monetary value held by an organization in anticipation of future demand [3-4]. The level of inventory holding by an organization influences revenue availability and directly impact on profit maximization [5]. Some organizations cannot function effectively unless they keep some level of inventory on hand to act as buffers during periods of unpredictable demands. Keeping a minimum ordering level is critical to maximizing available stock [6-7]. Raw materials, component parts, work-in-process, and finished goods are typical inventories in a production setting [8, 9]. As a result, in business operations, inventory refers to resources held in storage by organization for future sales or production of additional goods [10].

These organizations must however, deal with overstocking or understocking materials and component part delivery delays [11]. To address the conditions of holding too little or too much inventory, there is the need for the development of an effective and well-coordinated inventory management system. A good inventory management process ensures a sufficient level of holding stock by, for instance, accommodating an acceptable level of available demand while minimizing the associated holding stock to meet such demands [12]. This principle ensures that stocks are properly managed, stored, and accessible to ensure adequate supplies of required items without

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unnecessary oversupply or undersupply [13]. This management approach combines purchasing, manufacturing, and distribution functions to balance marketing and organizational needs in product distribution based on identified need [14]. As a result, the company's goal is to maintain an optimal level of inventory that meets their immediate needs without incurring any shortages or excess inventory [15]. The organization strives to keep inventories under control at the lowest possible cost in order to ensure a sufficient and consistent supply of resources, resulting in the proper and timely distribution of products at a reasonable cost [16]. This has an impact on manufacturers' ability to meet customers' demands on the spur of the moment, as measured by the level of responsiveness to unexpected needs without incurring excessive costs. This indicates improved customer service, increased profitability, and increased competitiveness [16]. Customer service level may imply an organization's tendency to not run out of stock during an upcoming replenishment cycle. This monitored inventory system process provides the convenience of easily tracking product expiry dates [17]. Tracking inventory turnover is critical for successful planning when a firm's significant assets are tied up as inventory [3]. Inventory costs are as follows: (1) holding cost, (2) ordering cost, and (3) shortage cost [17-18].

The goal of a proper inventory management technique is to ensure the availability of the right materials at the right time, with a focus on minimizing storage costs and investment. An inventory management optimization technique is the determination of the best combination of parameters relating to stock availability to achieve the best measurable performance of the system under given constraints [19]. Inventory optimization is critical in many organizations because managers are under pressure to maintain a high level of service while lowering costs [20-21]. In inventory optimization, common practice involves considering a single objective of cost minimization or profit maximization and using linear programming models to obtain an optimal solution [22]. The linear programming approach, on the other hand, has some limitations. It is focused on a single goal. Real-world decision problems frequently have competing and multiple objectives [20]. Another significant limitation of this approach is in its assumptions. The parameters are generally assumed to be constant, but in practice, these parameters are not constant and unknown [23]. In reality, there are numerous objectives to consider in inventory optimization problems, such as reducing inventory cost, lead time, quality loss, stock out, and increasing service level and inventory turnover ratio, among others [20]. In many cases, these objectives are defined in incomparable units that conflict with one another, necessitating the use of multi-criteria optimization models [24].

There is no single optimum method for selecting a better solution when using multi-objective optimization [25]. However, it is customary for the decision maker to select a desired solution from a group of practical alternatives that are closest to the ideal. This implies that multi-objective optimization issues include more than just finding the best solution according to an objective function, but also the best solutions that are closest to the ideal [24-26]. There are several ways for solving multi-objective issues, such as goal programming, compromise programming, linear combination of objectives, weighted sum scalarisation, and so on [27]. The goal programming optimization technique was used in this research to solve multi-objective optimization problems in inventory management, to find sufficient solutions to conflicting objectives that are closer to the ideal. The sole focus of goal programming is to optimize numerous goals at the same time by minimizing measured deviations from the desired targets for each of the objectives based on what is possible in relation to specified targets [29]. There are two strategies for solving the goal programming problem, both of which are based on a single objective function representing numerous objectives [26]. Weights provided to deviational variables in the non-preemptive or weights technique are used to stress the importance and attractiveness of deviations from certain goals [28]. However, the proactive strategy requires the decision-maker to rank the goals into distinct priority levels, each of which contains multiple goals [29-30].

The association between total inventory cost, inventory service level, and system constraints such as storage space and inventory balance has been established in the literature with extensive findings [31, 32]. However, little emphasis has been placed on the items' shelf life, the available lead time for materials, and the inventory system's turnover ratio. For example, observation revealed that only cost was deemed to be optimized in the inventory system of the production room in the Central Sterile Supply Department of the University College Hospital, Ibadan, Nigeria. Other goals, such as lead time, quality loss, stock out, service level, and inventory turnover rate, must be optimized to ensure that the total inventory system is performing optimally. There was also an obvious shelf-life constraint on the completed product inventory. To avoid loss, the final products have to be sold before the expiration date. As a result, this work focused on the application of multi-criteria approaches to optimize the inventory system of a healthcare production room, such that all objectives are optimized all at once. The purpose of this study is to utilize the goal programming preemptive and non-preemptive procedures to solve the inventory problem in the production room at University College Hospital's Central Sterile Supply Department. The study's specific objectives were to analyse the establishment's current inventory system, create preemptive and non-preemptive goal programming, and then solve the established preemptive and non-preemptive models using the optimization tools Lingo 17.0 and TORA to compare the outcomes.

2. METHODOLOGY

2.1. Studying and observing the present inventory system

The Central Sterile Supply Department inventory system was studied and observed using the following methods:

1. Interviews with members of staff and personnel: The nurses, storekeeper, accountant and the biomedical engineers were interacted with and their responses recorded using pen and paper. Data gathered from the interviews include bill of materials, list of products, inventory costs and lead time;
2. Record checking: Daily inventory record for two years (2018-2019) was gathered for each of the 6 raw materials and 4 finished products. The daily inventory record contained cost per unit for each day, amount of finished goods supplied, inventory level, amount of raw material ordered, capital available and usage requirements;
3. Personal observations: The storeroom of the Central Sterile Supply Department was visited a number of times to study the production process, the storage capacity of each raw material and the material re-order rate.

The study and observation of the system led to an insight on the following about the inventory system: List of products; Inventory cost; List of suppliers; Storage capacity; Bill of materials; Usage requirements; Delivery lead time; Product shelf life; Delivery lead time; and Capital available necessary for data collection.

2.2. Developing a preemptive and non-preemptive goal programming model

Preemptive and non-preemptive goal programming models were adopted for this work [30]. They are goal programming models to solve problems with multi-criteria scenarios, subject to a set of particular goal constraints [24]. The model was then solved using Lingo 17.0.

a. Model assumptions

The following assumptions for typical inventory system hold [5]:

1. The ordering cost is fixed and known;
2. There is a fixed maximum amount of backordering for each item;
3. Lead times are predictable and reliable;
4. Each item's demand rate is predictable and constant;
5. The holding cost is set and understood;
6. The rate of production required for each material is predictable and constant;
7. The buying price for each component and finished good is fixed;
8. Storage space is limited for both raw materials and completed goods;
9. The FIFO rule is the foundation for inventory transactions.

b. Basic notations and terms include

1. C_t = Budgeted resource allocated at a particular period of concern;
2. h_k= cost of holding one-unit item “k”;
3. I_{kt}^{+}= total number of items available in inventory period “t”;
4. I_{kt-1}^{+} = total number of items available in inventory period “t-1”;
5. Z_{kt} =ordering period binary decision variable for item “k”;
6. S_{kt} = fixed ordering cost for unit item “k” in period “t”;
7. C_k = cost of unit item “k”;
8. Y_{kt}= decision variable for quantity of item “k” to order in period “t”;
9. π_k= shortage cost for a unit of item “k”;
10. I_{kt}^{-} = total number of backorders of item “k” at period “t”;
11. I_{kt-1}^{-}= total number of backorders of item “k” at period “t-1”;
12. e_{jk} = distribution cost per unit to customer “j” for item “k”;

13. x_{jkt} = decision variable for quantity of item "k" to distribute to customer "j" in period "t";
14. D_{jkt} = quantity demand for item "k" by customer "j" in period "t";
15. L_{kt} = minimum service level;
16. I_{k0}^{+} = total number of items in inventory at period "0";
17. I_{kT}^{+} = total number of items in inventory at period "T";
18. L_t = available lead time to order material "k";
19. T_r = desirable inventory turnover;
20. R_t = receiving time of material "k";
21. O_t = ordering time of material "k";
22. T = number of periods in planning horizon;
23. t_k= the item's cycle time;
24. m= number of items;
25. n= number of customers;
26. r_k= the ratio of item's demand rate to production rate;
27. I_i= post-production shelf life;
28. $I_{k,t}$ = inventory position decision variable of item "k" in period "t";
29. $I_{k,t-1}$ =inventory position decision variable of item "k" in period "t-1";
30. M = maximum quantity of item that can be ordered in period "t".

c. Problem solving steps

The steps involved include [24]:

1. Identification of the goals and constraints imposed by the level of available resources which may limit achieving the goals.
2. Determination of each goal's associated priority.
3. Ranking of the different goals by weights.
4. Definition of the decision variables.
5. Definition of the deviational variables for each of the goals.
6. Formulation of the system constraints
7. Development of the objective function by minimizing the prioritized function for the deviational variables.
8. Resulting goal program was then solved.
9. Implementation and interpretation of the resulting solution.

2.3. Model development

The objective function of the non-preemptive and preemptive goal programming model is given below:

Non-preemptive:

$$\text{Minimize G} = W_1 d_1^{+} + W_2 \sum_{k=1}^{m} \sum_{t=1}^{T} d_{2kt}^{-} + W_3 d_3^{-} + W_4 d_4^{+} \tag{1}$$

Preemptive:

$$\text{Minimize G} = P_1 d_1^{+} + P_2 \sum_{k=1}^{m} \sum_{t=1}^{T} d_{2kt}^{-} + P_3 d_3^{-} + P_4 d_4^{+} \tag{2}$$

The constraints of the model are as follow:

Goal constraints

1. Minimization of total inventory cost:

$$\sum_{k=1}^{m} \sum_{t=1}^{T} \left\{ h_k \left(\frac{I_{kt}^{+} + I_{k,t-1}^{+}}{2} \right) + \left(Z_{kt} S_{kt} + C_k Y_{kt} \right) + \pi_k \left(\frac{I_{kt}^{-} + I_{k,t-1}^{-}}{2} \right) + \left(e_{jk} x_{jkt} \right) \right\} \leq C_t \tag{3}$$

2. Maximization of service level,

$$\left[1-\left(\frac{I_{kt}^{-}}{\sum_{j=1}^{n} D_{jkt}}\right)\right] \geq \quad L_{kt} \tag{4}$$

3. Maximization of inventory turnover rate,

$$\sum_{j=1}^{n}\sum_{k=1}^{m}\sum_{t=1}^{T}\left\{\frac{C_k D_{jkt}}{\frac{1}{T}\sum_{k=1}^{m}\sum_{t=1}^{T-1} C_k\left(\left(\frac{I_{k0}^{+}+I_{kT}^{+}}{2}\right)+I_{kt}^{+}\right)}\right\} \geq T_r \tag{5}$$

4. Minimization of lead time,

$$R_t - O_t \leq L_t \tag{6}$$

System constraints

1. Shelf-life constraint,

$$t_k(1-r_k)\frac{\pi_k}{h_K+\pi_K} \qquad \leq l_i \tag{7}$$

2. Inventory balance constraints,

$$I_{kt} = I_{k,t-1} + Y_{kt} - \sum_{k}^{m} D_{kt} \tag{8}$$

$$I_{kt} = I_{kt}^{+} - I_{kt}^{-} \tag{9}$$

3. Storage constraint

$$Y_{kt} \leq MZ_{kt} \tag{10}$$

$$I_{kt} \leq M \tag{11}$$

Non-negativity constraint,

$$Y_{kt}, I_{kt}^{+}, I_{kt}^{-}, d_i^{-}, d_i^{+}, R_t, O_t \geq 0 \tag{12}$$

Binary variable constraint,

$$Z_{kt} = 0,1 \tag{13}$$

2.3.1. Non-preemptive model summary
The model is presented thus [31]:

$$\text{Minimize G} = W_1 d_1^{+} + W_2\sum_{k=1}^{m}\sum_{t=1}^{T} d_{2kt}^{-} + W_3 d_3^{-} + W_4 d_4^{+} \tag{14}$$

Subject to:

$$\sum_{k=1}^{m}\sum_{t=1}^{T}\left\{hk\left(\frac{I_{kt}^{+}+I_{k,t-1}^{-}}{2}\right) + (Z_{kt}S_{kt} + C_k Y_{kt}) + \pi k\ \left(\frac{I_{kt}^{-}+I_{k,t-1}^{-}}{2}\right)\ +\ \left(e_{jk}x_{jkt}\right)\right\} + d_1^{-} - d_1^{+} = C_t \tag{15}$$

$$\left[1-\ \left(\frac{I_{kt}^{-}}{\sum_{j=1}^{n} D_{jkt}}\right)\right] + d_{2kt}^{-} - d_{2kt}^{+} = L_{kt} \tag{16}$$

$$\sum_{j=1}^{n}\sum_{k=1}^{m}\sum_{t=1}^{T}\left\{\frac{C_k D_{jkt}}{\frac{1}{T}\sum_{k=1}^{m}\sum_{t=1}^{T-1} C_k\left(\left(\frac{I_{k0}^{+}+I_{kT}^{+}}{2}\right)+I_{kt}^{+}\right)}\right\} + d_3^- - d_3^+ = T_r \tag{17}$$

$$R_t - O_t + d_4^- - d_4^+ = L_t \tag{18}$$

$$t_k(1-r_k)\frac{\pi_k}{h_K+\pi_K} \le l_i \tag{19}$$

$$I_{kt} = I_{k,t-1} + Y_{kt} - \sum_k^m D_{kt} \tag{20}$$

$$I_{kt} = I_{kt}^+ - I_{kt}^- \tag{21}$$

$$Y_{kt} \le MZ_{kt} \tag{22}$$

$$I_{kt} \le M \tag{23}$$

$$Y_{kt}, I_{kt}^+, I_{kt}^-, d_i^-, d_i^+, R_t, O_t \ge 0 \tag{24}$$

$$Z_{kt} = 0,1 \tag{25}$$

2.3.2. Preemptive model summary
As adapted from [31]:

$$\text{Minimize G} = P_1 d_1^+ + P_2\sum_{k=1}^{m}\sum_{t=1}^{T} d_{2kt}^- + P_3 d_3^- + P_4 d_4^+ \tag{26}$$

Subject to:

$$\sum_{k=1}^{m}\sum_{t=1}^{T}\left\{hk\left(\frac{I_{kt}^{+}+I_{k,t-1}^{-}}{2}\right)+(Z_{kt}S_{kt}+C_kY_{kt})+\pi k\left(\frac{I_{kt}^{-}+I_{k.t-1}^{-}}{2}\right)+\left(e_{jk}x_{jkt}\right)\right\}+d_1^- - d_1^+ = C_t \tag{27}$$

$$\left[1-\left(\frac{I_{kt}^-}{\sum_{j=1}^{n} D_{jkt}}\right)\right] + d_{2kt}^- - d_{2kt}^+ = L_{kt} \tag{28}$$

$$\sum_{j=1}^{n}\sum_{k=1}^{m}\sum_{t=1}^{T}\left\{\frac{C_k D_{jkt}}{\frac{1}{T}\sum_{k=1}^{m}\sum_{t=1}^{T-1} C_k\left(\left(\frac{I_{k0}^{+}+I_{kT}^{+}}{2}\right)+I_{kt}^{+}\right)}\right\} + d_3^- - d_3^+ = T_r \tag{29}$$

$$R_t - O_t + d_4^- - d_4^+ = L_t \tag{30}$$

$$t_k(1-r_k)\frac{\pi_k}{h_K+\pi_K} \le l_i \tag{31}$$

$$I_{kt} = I_{k,t-1} + Y_{kt} - \sum_k^m D_{kt} \tag{32}$$

$$I_{kt} = I_{kt}^+ - I_{kt}^- \tag{33}$$

$$Y_{kt} \le MZ_{kt} \tag{34}$$

$$I_{kt} \le M \tag{35}$$

$$Y_{kt}, I_{kt}^{+}, I_{kt}^{-}, d_i^{-}, d_i^{+}, R_t, O_t \geq 0 \tag{36}$$

$$Z_{kt} = 0{,}1 \tag{37}$$

2.4. Ranking of goals

The weighted goal programming approach was utilized since it helps to make a thorough sensitivity analysis, whereby goals of equal importance assume the same priority.

The weight selections are: W_1 = weight for minimizing inventory cost; W_2 = weight for maximizing inventory service; W_3 = weight for maximizing inventory turnover ratio; and W_4 = weight for minimizing inventory lead time. The following are the deviational variables for each goal:
d_1^- = underachievement of total inventory cost;
d_1^+ = overachievement of total inventory cost;
d_{2kt}^- = underachievement of inventory service level for product k in period t;
d_{2kt}^+ = overachievement of inventory service level for product k in period t;
d_3^+ = underachievement of inventory turnover ratio;
d_3^+ = overachievement of inventory turnover ratio;
d_4^- = underachievement of delivery lead time;
d_4^+ = overachievement of delivery lead time.

2.5. Problem solution

The preemptive and non-preemptive goal programming models were solved using Lingo 17.0. Using Lingo 17.0's commands, the models were coded such that solutions could be found and discussed. To verify the outcomes of the problem-solving process using Lingo 17.0 software, TORA was also used. The derived solution was contrasted with the original and discussed.

3. Results and Discussions

3.1. Studying and observing the present inventory system

As described in section 2.1, the results from the outlined procedure obtained are as presented. The initial step is to gather relevant data in relation with the goals.

Table 1. Bill of materials.

S/N	Raw material
1	Cotton balls
2	Gauze
3	Brown paper
4	Gamgee
5	Indicator strips
6	Paper tape

Table 1 is a list on all raw materials in the firm used for production. A total of 6 raw materials are listed. Some of the raw materials are contained in the finished products and these are called direct raw materials while those not contained in the finished product are called indirect raw materials.

Table 2. List of products.

S/N (k)	Product
1	Major pack
2	Mini-moderate pack
3	Moderate pack
4	Cardio pack

Table 2 consists of the different products produced by the Central Sterile Supply Department. A total of four products are produced. The major pack is made up of three gamgee, fifteen gauzes and twenty-five cotton balls. It is the largest product being produced by the firm. The moderate pack contains one gamgee, six gauzes and eight cotton wool balls. The mini-moderate pack contains one gamgee, four gauzes and four cotton wool balls, while the cardio pack contains ten cotton balls and ten gauzes.

Table 3. Cost parameters for raw materials.

S/N	Raw material	Purchase cost (₦)	Fixed ordering cost (₦)	Holding cost (₦)	Shortage cost (₦)
1.	Cotton balls	1410	3	25	15
2.	Gauze	1850	2	25	15
3.	Brown paper	100	3	25	15
4.	Gamgee	1790	1	25	15
5.	Indicator strip	1300	1	25	15
6.	Paper tape	450	3	25	15

Table 3 shows the cost associated with the raw materials. The ordering cost is the sum of fixed order cost and purchase cost for a material. The shortage cost is incurred when the amount of demand exceeds available stock and the values for each raw material. The shortage and holding costs were determined from the interactions with the various distributors and through observations of the system.

Table 4. Cost parameters of finished products.

S/N	Raw material	Handling cost (₦)	Holding cost (₦)	Transportation cost (₦)	Shortage cost (₦)
1.	Major pack	4	25	11	15
2.	Mini-moderate pack	4	25	11	15
3.	Moderate pack	4	25	11	15
4.	Cardio pack	4	25	11	15

Table 4 shows the costs associated with the finished goods inventory. The distribution cost includes the cost of shipping the products from the production site (warehouse, stores) to distribution points plus cost of handling inventory. These costs were assumed to remain constant from period to period.

Table 5. Demand for each product.

S/N	Product	Demand (Kg)
1	Major pack	220
2	Mini-moderate pack	370
3	Moderate pack	260
4	Cardio pack	110

Table 5 shows the various demands for the feeds produced by the firm. The mini-moderate pack and moderate pack were noticed to have high demands while the major and cardio packs have low demands.

Table 6. Usage requirement.

S/N	Raw material	Usage requirement
1.	Cotton balls	80
2.	Gauze	80
3.	Brown paper	100
4.	Gamgee	80
5.	Indicator strip	3
6.	Paper tape	15

Table 6 shows the quantity of materials required for production. The material with the highest requirement rate is brown paper while indicator strip has the lowest requirement.

Table 7. Storage capacity.

S/N	Raw material	Usage requirement
1	Cotton balls	200
2	Gauze	200
3	Brown paper	150
4	Gamgee	200
5	Indicator strip	50
6	Paper tape	50

Table 7 contains a list of the storage threshold for each of the raw materials determined through interviews with the storekeepers and personal observation of the storage facility.

3.1.1 Shelf-life

The shelf-life of the product is 14 days before the products expires. All finished products become unfit for use after 14 days.

3.1.2 Target level for total inventory cost

The following target total inventory cost values were gathered in Table 8.

Table 8. The target level for total inventory cost.

S/N	Raw material/Product	Target total inventory cost (₦)
1.	Cotton balls	112800
2.	Gauze	148000
3.	Brown paper	10000
4.	Gamgee	143200
5.	Indicator strip	3900
6.	Paper tape	6750
7.	Major pack	8800
8.	Mini-moderate pack	14800
9.	Moderate pack	10400
10.	Cardio pack	4400

Table 8 shows the target level for inventory cost for each of the raw materials and finished products. This demonstrates the level of inventory cost of the raw material and finished product desired by the firm.

3.1.3. Target level for inventory service level

A target of 90 % was set for the production room inventory service level. This means that there is only a 10 % likelihood of stocking out.

3.1.4. Target level for inventory turnover ratio

A firm with a high inventory turnover indicates better sales of the product or an efficient production system. For a system to function at its best, the turnover ratio should be greater than or equal to one. For this study inventory turnover ratio of two was targeted at.

3.1.5. Target level for delivery lead time

Implementing the approach using equation (6), it has been discovered that most materials are made available before production. In this study, a maximum of two days was considered as the lead time available.

3.2. Developing a non-preemptive and preemptive goal programming model

The multi-objective optimization model formulation methods; preemptive and non-preemptive goal programming was used as discussed.

3.3. Model assumptions

The assumptions upon which the model was developed were described in section 2.3. The assumptions applied to all 6 raw materials and 4 finished products.

3.4 Model development

Following the steps as described under section 2.4, the resulting model is applied under section 3.4.

3.4.1 Non-preemptive model summary

! COTTON BALLS;
$MIN = 0.4 * D1P + 0.3 * D2N + 0.2 * D3N + 0.1 * D4P;$
$!SUBJECT\ TO;$
$!INVENTORY\ COST; H * ((I + IP)/2) + ((Z * S) + (C * Y)) + J * ((B + BP)/2) + D1N - D1P = 112800;$
$!SERVICE\ LEVEL; (1 - (B/Q)) + D2N - D2P = 0.9;$
$!INVENTORY\ TURNOVER\ RATIO; ((C * Q))/((1/T) * (C * ((V + G)/2) + I)) + D3N - D3P = 2;$
$!DELIVERY\ LEAD\ TIME; R - O + D4N - D4P = 2;$
$!INVENTORY\ BALANCE\ CONSTRAINTS; INV = INVP + Y - Q; INV = (I - B);$
$!STORAGE\ CAPACITY; Y <= 200 * Z; INV <= 200;$
$!DATA; H = 25; S = 3; C = 1410; J = 15; IP$ =0;BP = 0;Q = 80;V = 0;O = 0;INVP = 0;
!NON-NEGATIVITY CONSTRAINTS;Y>= 0;R >= 0;INV >= 0;B >= 0;I >= 0;T >= 0;G >=0;
@BIN(Z);
!INTEGER
CONSTRAINTS;@GIN(Y);@GIN(R);@GIN(INV);@GIN(B);@GIN(I);@GIN(G);@GIN(T);@GIN(D1P);@GIN(D2N);@GIN(D3N);@GIN(D4P);

3.5.2 Preemptive model summary

! COTTON BALLS;
! PRIORITY 1; MIN = D1P;
!SUBJECT TO;
$!INVENTORY\ COST; H * ((I + IP)/2) + ((Z * S) + (C * Y)) + J * ((B + BP)/2) + D1N - D1P = 112800;$
$!SERVICE\ LEVEL; (1 - (B/Q)) + D2N - D2P = 0.9;$
$!INVENTORY\ TURNOVER\ RATIO; ((C * Q))/((1/T) * (C * ((V + G)/2) + I)) + D3N - D3P = 2;$
$!DELIVERY\ LEAD\ TIME; R - O + D4N - D4P = 2;$
$!INVENTORY\ BALANCE\ CONSTRAINTS; INV = INVP + Y - Q;$
$INV = (I - B);$
$!STORAGE\ CAPACITY; Y <= 200 * Z;$
$INV <= 200;$
$!DATA; H = 25; S = 3; C = 1410; J = 15; IP = 0; BP = 0; Q = 80; V = 0; O = 0; INVP = 0;$
$!NON - NEGATIVITY\ CONSTRAINTS; Y >= 0; R >= 0; INV >= 0; B >= 0; I >= 0; T >= 0; G >= 0;$
$@BIN(Z);$
!INTEGER CONSTRAINTS; @GIN(Y); @GIN(R); @GIN(INV); @GIN(B); @GIN(I); @GIN(G); @GIN(T); @GIN(D1P); @GIN(D2N); @GIN(D3N); @GIN(D4P);

3.5. Ranking of goals

Two or more goals may be of equal importance. The non-preemptive goal program requires that the predefined goals are weighted and ranked. The individual deviational variables are assigned differential weights in the GP objective function using the identical priority factor. Based on the order of relative importance, the decision maker in the preemptive method ranks the goals of the problem. Given a situation comprising of *n* goals, the objectives of the problem can be written as follows:

$$Minimize\ G_1 = P_1(Highest\ priority)$$
$$\dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots$$
$$Minimize\ G_n = G_n(Lowest\ priority)$$

The preemptive method is designed such that a lower-priority solution never degrades a higher-priority solution.

Table 9. Ranking of goals and their respective weights.

Goal	Description	Rank	Weight
1.	Minimization of cost	4	0.4
2.	Maximization of service level	3	0.3
3.	Maximization of turnover ratio	2	0.2
4.	Minimization of Lead time	1	0.1

3.6. Problem Solution

3.6.1. Solving the problem using Lingo 17.0

The results obtained from using Lingo 17.0 for cotton balls are presented thus:

Lingo results for cotton balls (non-preemptive method)

```
Local optimal solution found.
  Objective value:                              1.200000
  Objective bound:                              1.200000
  Infeasibilities:                              0.000000
  Extended solver steps:                              21
  Total solver iterations:                           484
  Elapsed runtime seconds:                          0.09

Model Class:                                       MINLP

Total variables:                   16
Nonlinear variables:                3
Integer variables:                 12

Total constraints:                 16
Nonlinear constraints:              1

Total nonzeros:                    36
Nonlinear nonzeros:                 3

                   Variable           Value        Reduced Cost
                        D1P        3.000000           0.4000000
                        D2N        0.000000           0.3000000
                        D3N        0.000000           0.2000000
                        D4P        0.000000           0.1000000
                          H        25.00000            0.000000
                          I        0.000000            0.000000
                         IP        0.000000            0.000000
                          Z        1.000000            0.000000
                          S        3.000000            0.000000
                          C        1410.000            0.000000
                          Y        80.00000            0.000000
                          J        15.00000            0.000000
                          B        0.000000            0.000000
                         BP        0.000000            0.000000
                        D1N        0.000000            0.000000
                          Q        80.00000            0.000000
                        D2P       0.1000000            0.000000
                          T        1.000000            0.000000
                          V        0.000000            0.000000
                          G        35.00000            0.000000
                        D3P        2.571429            0.000000
                          R        0.000000            0.000000
                          O        0.000000            0.000000
                        D4N        2.000000            0.000000
                        INV        0.000000            0.000000
                       INVP        0.000000            0.000000
```

Lingo results for cotton balls (preemptive method)

```
Local optimal solution found.
Objective value:                              3.000000
Objective bound:                              3.000000
Infeasibilities:                              0.000000
Extended solver steps:                               2
Total solver iterations:                           187
Elapsed runtime seconds:                          0.06

Model Class:                                     MINLP

Total variables:                   16
Nonlinear variables:                3
Integer variables:                 12

Total constraints:                 16
Nonlinear constraints:              1
```

```
Total nonzeros:                33
Nonlinear nonzeros:             3
```

Variable	Value	Reduced Cost
D1P	3.000000	1.000000
H	25.00000	0.000000
I	0.000000	0.000000
IP	0.000000	0.000000
Z	1.000000	0.000000
S	3.000000	0.000000
C	1410.000	0.000000
Y	80.00000	0.000000
J	15.00000	0.000000
B	0.000000	0.000000
BP	0.000000	0.000000
D1N	0.000000	0.000000
Q	80.00000	0.000000
D2N	0.000000	0.000000
D2P	0.1000000	0.000000
T	1.000000	0.000000
V	0.000000	0.000000
G	79.00000	0.000000
D3N	3.000000	0.000000
D3P	3.025316	0.000000
R	2.000000	0.000000
O	0.000000	0.000000
D4N	0.000000	0.000000
D4P	0.000000	0.000000
INV	0.000000	0.000000
INVP	0.000000	0.000000

3.6.2. Solving the problem using TORA

Only the results obtained for cotton balls are presented due to space limitation.

LINEAR PROGRAM—ORIGINAL DATA

Table 10. Title: COTTONBALLSNON-PREEMPTIVE

TORA Optimization System, Windows®-version2.00

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LINEARPROGRAMMINGOUTPUTSUMMARY

Title: COTTONBALLSN ON-PREEMPTIVE

Final Iteration No.: 10

Objective value 0.48

Table 11. Sensitivity analysis cotton balls non- preemptive.

Title:COTTONBALLSNON-PREEMPTIVE

	D1P x1	D2N x2	D3N x3	D4P x4	I x5	Y x6
Minimize	0.40	0.30	0.20	0.10	0.00	0.00
Subjectto						
(1)	-1.00	0.00	0.00	0.00	12.50	1410.00
(2)	0.00	1.00	0.00	0.00	0.00	0.00
(3)	0.00	0.00	1.00	0.00	-2820.00	0.00
(4)	0.00	0.00	0.00	-1.00	0.00	0.00
(5)	0.00	0.00	0.00	0.00	0.00	-1.00
(6)	0.00	0.00	0.00	0.00	1.00	0.00
(7)	0.00	0.00	0.00	0.00	0.00	1.00
(8)	0.00	0.00	0.00	0.00	0.00	0.00
LowerBound	0.00	0.00	0.00	0.00	0.00	0.00
UpperBound	infinity	infinity	infinity	infinity	infinity	infinity
Unrestr'd(y/n)?	n	n	n	n	n	n
	B x7	D1N x8	D2P x9	T x10	G x11	D3P x12
	0.00	0.00	0.00	0.00	0.00	0.00
(1)	7.50	1.00	0.00	0.00	0.00	0.00
(2)	-1.00	0.00	-1.00	0.00	0.00	0.00
(3)	0.00	0.00	0.00	112800.00	-1410.00	-1.00
(4)	0.00	0.00	0.00	0.00	0.00	0.00
(5)	0.00	0.00	0.00	0.00	0.00	0.00
(6)	-1.00	0.00	0.00	0.00	0.00	0.00
(7)	0.00	0.00	0.00	0.00	0.00	0.00
(8)	0.00	0.00	0.00	0.00	0.00	0.00
LowerBound	0.00	0.00	0.00	0.00	0.00	0.00
UpperBound	infinity	infinity	infinity	infinity	infinity	infinity
Unrestr'd(y/n)?	n	n	n	n	n	n
	R x13	D4N x14	INV x15	Z x16		
	0.00	0.00	0.00	0.00		
(1)	0.00	0.00	0.00	3.00	=	112800.00
(2)	0.00	0.00	0.00	0.00	=	-8.00
(3)	0.00	0.00	0.00	0.00	=	0.00
(4)	1.00	1.00	0.00	0.00	=	2.00
(5)	0.00	0.00	1.00	0.00	=	-80.00
(6)	0.00	0.00	-1.00	0.00	=	0.00
(7)	0.00	0.00	0.00	-200.00	<=	0.00
(8)	0.00	0.00	1.00	0.00	<=	200.00
LowerBound UpperBound Unrestr'd(y/n)?	0.00 infinity n	0.00 infinity n	0.00 infinity n	0.00 infinity n		

Variable	Current ObjCoeff	MinObjCoeff	MaxObjCoeff	ReducedCost
x1:D1P	0.40	0.00	infinity	0.00
x2:D2N	0.30	0.00	infinity	-0.30
x3:D3N	0.20	0.00	infinity	-0.20
x4:D4P	0.10	0.00	infinity	-0.10
x5:I	0.00	-8.00	infinity	0.00
x6:Y	0.00	-569.01	infinity	0.00
x7:B	0.00	-8.00	infinity	-8.00
x8:D1N	0.00	-0.40	infinity	-0.40
x9:D2P	0.00	-0.30	8.00	0.00
x10:T	0.00	0.00	22560.00	0.00
x11:G	0.00	0.00	infinity	0.00
x12:D3P	0.00	0.00	infinity	0.00
x13:R	0.00	-0.10	0.00	0.00
x14:D4N	0.00	0.00	infinity	0.00
x15:INV	0.00	-569.01	infinity	-569.01
x16:Z	0.00	-1.20	infinity	0.00
Constraint	**Current RHS**	**MinRHS**	**MaxRHS**	**DualPrice**
1(=)	112800.00	-infinity	112801.20	-0.40
2(=)	-8.00	-16.00	infinity	0.00
3(=)	0.00	0.00	infinity	0.00
4(=)	2.00	0.00	infinity	0.00

TORA OptimizationSystem, Windows®-version2.00

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LINEARPROGRAMMIGOUTPUTSUMMARY

Title: COTTONBALLS PREEMPTIVE
Final Iteration No.: 10
Objective value 1.2

Table 12. Linear programming output summary (Preemptive)

Variable		Value	ObjCoeff	ObjValContrib
x1:D1P		1.20	1.00	1.20
x2:D2N		0.00	0.00	0.00
x3:D3N		0.00	0.00	0.00
x4:D4P		0.00	0.00	0.00
x5:I		0.00	0.00	0.00
x6:Y		80.00	0.00	0.00
x7:B		0.00	0.00	0.00
x8:D1N		0.00	0.00	0.00
x9:D2P		8.00	0.00	0.00
x10:T		0.00	0.00	0.00
x11:G		0.00	0.00	0.00
x12:D3P		0.00	0.00	0.00
x13:R		2.00	0.00	0.00
x14:D4N		0.00	0.00	0.00
x15:INV		0.00	0.00	0.00
x16:Z		0.40	0.00	0.00
Constraint		RHS	Slack-/Surplus+	
1(=)		112800.00	0.00	
2(=)		-8.00	0.00	
3(=)		0.00	0.00	
4(=)		2.00	0.00	
5(=)		-80.00	0.00	
6(=)		0.00	0.00	
7(<)		0.00	0.00	
8(<)		200.00	200.00-	

Table 13. Sensitivity Analysis (Preemptive)

Variable	Current ObjCoeff	MinObjCoeff	axObjCoeff	ReducedCost
x1:D1P	1.00	0.00	infinity	0.00
x2:D2N	0.00	0.00	infinity	0.00
x3:D3N	0.00	0.00	infinity	0.00
x4:D4P	0.00	0.00	infinity	0.00
x5:I	0.00	-20.00	infinity	0.00
x6:Y	0.00	-1422.52	infinity	0.00
x7:B	0.00	-20.00	infinity	-20.00
x8:D1N	0.00	-1.00	infinity	-1.00
x9:D2P	0.00	0.00	20.00	0.00
x10:T	0.00	0.00	0.00	0.00
x11:G	0.00	0.00	infinity	0.00
x12:D3P	0.00	0.00	infinity	0.00
x13:R	0.00	0.00	0.00	0.00
x14:D4N	0.00	0.00	infinity	0.00
x15:INV	0.00	-1422.52	infinity	-1422.52
x16:Z	0.00	-3.00	infinity	0.00
Constraint	Current RHS	MinRHS	MaxRHS	DualPrice
1(=)	112800.00	-infinity	112801.20	-1.00
2(=)	-8.00	-16.00	infinity	0.00
3(=)	0.00	0.00	Infinity	0.00
4(=)	2.00	0.00	Infinity	0.00

The findings obtained from the inventory management optimization technique provided the best combination of parameters in relation to the raw materials (Table 8) as specified by some metrics of performance of the system under given constraints (Table 9). The results from both the preemptive and non-preemptive methods produced similar outcomes of the objective function. Tables 11 and 12 show the magnitude of reduction in cost of the 16 variables accurately predicted by both procedures. By increasing or decreasing the limits of these variables the allowable changes needed to obtain optimal values are suggested. The achievement of a uniform service level of 100 % demonstrates that a 10 % increase was made (D2P) from the Lingo output. As a result, there would be no stockouts or delays in providing client service, and wasteful waiting periods between the service periods would be removed (D4P = 0.00). All inventory items' turnover ratios were found to be higher than 4 at a minimal increase in overall inventory cost of less than 0.0001%. A high inventory turnover rate indicates that goods are efficiently sold and replaced with new ones. Additionally, this demonstrates how each raw material is used effectively and efficiently throughout production, which lowers the cost of storage. The optimization technique in production planning serve to achieve the outline objectives by simultaneously considering all other objectives at once. Based on the findings, each item's lead time is exactly one day (or 24 hours). This demonstrates that an ordered product can be delivered in less than a day. Cutting the lead time can boost productivity, boosting output and revenue. The results produced using TORA software and Lingo 17.0 software do not differ significantly from one another. This demonstrates that the output is accurate because the TORA program serves as a validation for the Lingo 17.0 software.

4. CONCLUSIONS

A multi-objective inventory model was developed utilizing the preemptive and non-preemptive goal programming techniques for the Central Sterile Supply Department of the University College Hospital in Ibadan, Nigeria. The model was then solved using Lingo 17.0 software and validated using TORA software. This has led to the following conclusions:

1. A turnover ratio > 4, lead time < 24 hours, service level of 100 %, and an insignificant increase of < 0.0001 % in total inventory cost were obtained in each case, even when solved and validated with Lingo 17.0 and TORA software respectively.
2. The multi-criteria optimization model reduced inventory costs with improved profitability. Keeping lead times to a minimum increased production rates and shortened the time taken to deliver an ordered product. When service levels are maximized, stock shortages or customer service delays are minimized, and superfluous wait times between productions are eliminated. Additionally, increasing inventory ratio guaranteed goods are sold profitably while every raw material is used effectively and efficiently in production at minimum holding cost.

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