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Replenishment System-An Effective Tool of Optimization of Resources and Maintenance Management

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***Abstract* - Effective inventory management is crucial for optimizing resources and ensuring smooth maintenance operations. This paper explores two primary replenishment systems-Economic Order Quantity (EOQ) and Order Level Control-designed to address the challenges posed by demand variability and lead-time uncertainty. The EOQ model determines the optimal order size to minimize total inventory costs, while replenishment systems guide the timing of orders. We analyze the Fixed Order Quantity System (Q System), which maintains a constant order size with variable ordering frequency, and the Fixed Order Interval System (P System), which fixes the ordering intervals but varies the order size. Each system's advantages and challenges are discussed, highlighting their applicability based on demand stability, lead-time consistency, and inventory value. Through a comparative analysis, this paper provides insights into selecting the appropriate replenishment strategy to achieve efficient inventory control, cost minimization, and resource optimization.**

Keywords: inventory control, optimization, economic order quantity, safety stock, ordering cost, inventory carrying cost.

I. INTRODUCTION

Optimum inventory can be determined based on a rational replenishment system (reordering process), Economic Order Quantity (EOQ, also known Optimum Order Quantity or, in manufacturing, the Economic Batch Size), and Order Level Control. The EOQ model tells us how much to order, while the reorder system tells us when to order. The problem of inventory control arises due to uncertainty (variability) in demand rate or length of lead- time. If the demand is constant and so is lead- time, a fixed quantity can be ordered at a fixed interval. But both are variable in actual situations. It is therefore not possible to keep both the size and interval between orders as fixed [1]. One method to solve this problem is to fix the size of order and let the ordering frequency vary based on the consumption pattern. This approach is known as Q system (Fixed Order Quantity System, Two Bins System or Minimum-Maximum System). In some organizations, it is referred to as the Automatic Replenishment System or MRP (Materials Requirement Planning).

The other method system is to fix the order frequency or the length of time between orders, allowing order size to vary with usage rate. This is known as the P system (Review System or Fixed Order Interval System or Cycle System).

II. ECONOMIC ORDER QUANTITY (EOQ)

The Economic Order Quantity (EOQ) model is a fundamental tool in inventory management, designed to find the optimal balance between two opposing costs: inventory carrying cost and ordering cost [2]. Inventory carrying cost, also known as stock holding cost, refers to the expenses associated with storing inventory, including warehousing, insurance, depreciation, and opportunity costs. This cost is calculated based on the average inventory level, which is typically half of the order quantity. On the other hand, ordering cost encompasses the expenses incurred each time an order is placed, such as administrative processing, shipping, and handling fees. These costs behave inversely to each other. When orders are placed frequently in small quantities, the ordering cost increases due to the higher number of orders, but the inventory carrying cost decreases because less inventory is held at any given time. Conversely, when orders are placed infrequently in large quantities, the ordering cost decreases but the inventory carrying cost increases due to the higher amount of inventory stored. The EOQ model determines the order quantity at which these two costs are equal, minimizing the total inventory cost. This equilibrium point represents the optimal order quantity that balances the frequency of ordering with the cost of holding inventory.

In power plant operations and other industries, maintaining an optimal inventory of critical components and spare parts is essential to ensure uninterrupted functionality and prevent costly downtimes. The EOQ model is crucial in achieving this balance by identifying the ideal order quantity that minimizes total inventory costs. By applying the EOQ model, power plants can effectively manage the trade-off between ordering costs and holding costs (effective only for

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those spares/materials which by and large have regular and stable consumption pattern), ensuring that inventory levels are sufficient to meet demand without incurring excessive storage expenses [3]. The model accounts for total ordering cost and inventory holding cost, providing a comprehensive framework for inventory control. These two costs must be balanced to achieve the lowest total cost (see Fig. 1).

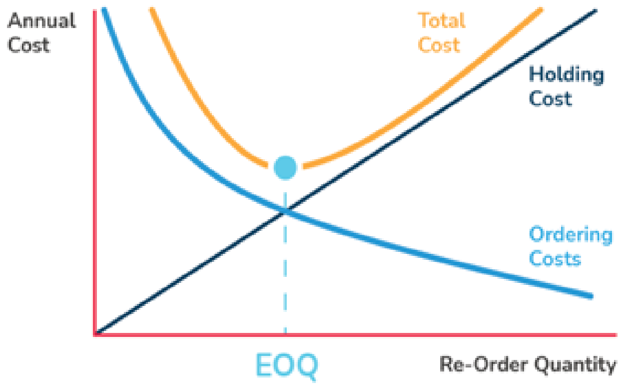

Figure 1: Graphical representation of EOQ

For example, if purchases are made infrequently in large quantities, the ordering cost will be low, but the inventory carrying cost will be high due to the larger stockpile. Conversely, if purchases are made frequently in small quantities, the inventory carrying cost will be low, but the ordering cost will be high due to the increased number of orders. By leveraging the EOQ model, power plants can optimize their inventory management practices, reduce total incremental cost, and enhance overall operational efficiency, ensuring a smooth and cost-effective operation.EOQ may be calculated using the classic EOQ formula

$$EOQ=\sqrt{(2AS/I)} \qquad (1)$$

Where, A is annual consumption of the item (in value), S is ordering cost per order and I is inventory carrying cost as a percentage of inventory value.

While determining the standard order quantity or EOQ, various aspects to be taken care are vendor's discounts, shelf life of items, seasonal nature of materials, availability in market, operation rate contracts (rate contracts are not for supply of materials but meant to freeze price and commercial terms and conditions for a period and supplies are made through call off orders against such rate contracts), agreements for stockless buying also known as consignment buying (here supplier keeps the stock at buyer place and periodical payments are made only for stock drawn/consumed) etc. Sometimes, it may be found that few items in the assembly line are in short supply, then other materials for the same assembly should be geared up accordingly.

III. Q SYSTEM

Also known as Fixed Order Quantity or Two Bins system. However, with the computerization of inventory management, two bins system nomenclature has become almost become obsolete. In Q system, stocks are separated in two bins or parts. First bin contains stocks to satisfy the demand between arrival of one order and placing of next. Second bin meets demand during lead-time, which represents reorder level and contains quantities to meet normal (mean average) lead- time demands and safety stock (as a buffer to meet requirement if variation in demand during lead-time, or length of lead-time and in worst case both). When stock in first bin is finished a reorder is placed for fixed quantity, usually determined by the EOQ. Although the Two Bins System is less commonly used today, it has been largely replaced by Minimum-Maximum based Q method. In this method, the size of ordered quantity is fixed but frequency of order is based on the demand pattern.

3.1 Minimum-Maximum System

This is a modified version of Two Bins System. Instead of physically separating the stocks in two parts or bins, this system differentiates stock levels on inventory records with the reorder level prominently highlighted. The key requirements of system are:

(i) Pre-determination of a fixed order quantity to replenish based on factors such as price, rate of usage and other pertinent factors i.e. ordering and inventory carrying cost. This quantity is often calculated using EOQ formula.

(ii) Pre-determination of a reorder point so that when stock on hand drops to this point, a Purchase Requisition (PR) or Purchase Indent is raised for the fixed quantity. The reorder point is calculated based on the length of lead- time, demand during lead- time and a safety allowance (buffer stock) to account for variability in demand and lead time.

By using this system, organizations can effectively manage inventory levels, ensuring timely reordering and maintaining sufficient stock to meet demand without overstocking.

3.2 Advantages of Minimum-Maximum System

The Minimum-Maximum System offers several benefits that enhance inventory management efficiency and streamline operational processes:

Automatic replenishment: The systems maintain perpetual records of inventory, enabling automatic replenishment when stocks reach the reorder point.

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Optimal stock levels: Stocks are consistently maintained between the planned minimum and maximum levels.

Management by exception: The system utilizes management by exception principle, where no action is needed until the item is reaches the reorder level.

Simplicity and efficiency: This system is straightforward, requiring minimal detailed and frequent control. Once the inventory levels are established, day to day operations can be managed by personnel at sufficiently low level.

Suitability for specific items: This system is very suitable for large number of 'C' items and low consumption value 'B' items that have a regular and fairly stable consumption pattern, preferably used by more than one department. However, it is essential to ensure that only items meeting the above requirements are brought under this system. Normally, spare parts are excluded since their planning involves considerations like failure rate, life expectancy, and periodical maintenance planning.

Lower safety stock: Safety stock is maintained at lower level as there is built in safety i.e. reorder point varies with rate of usage. The safety stock only needs to provide protection against variation in usage during lead-time or variations in the lead-time itself. If usage is higher, the reorder point is reached earlier.

Economic order quantities: Since reorder quantity is based on EOQ, each material can be procured in most economical quantity.

Positive control: Positive control can be exerted to maintain total inventory investments at desired level simply by manipulating and planning the minimum and maximum levels. If it is found that for some items reorder levels are frequently reached, there is need to review these levels. On the contrary, if we find that movement of items are moving very slowly, such items are taken out of this system.

Centralized requisitioning: Centralized requisitioning ensures that the responsibility of requesting items falls primarily on the stores department. To prevent unnecessary requisitions, other departments are not provided with access to the computerized system. This approach ensures that materials are readily available when needed while maintaining control over theprocurement process and avoiding excessive or unnecessary orders.

Bulk purchasing: Purchase requisitions are generated from stores for bulk quantities, which not only avoid piecemeal purchases but also attract better rates from suppliers.

Controlled buying cost: Since the number of PR is lower, buying costs are controlled.

3.3 Limitation of Minimum-Maximum System

1. It functions correctly only when each of materials exhibits reasonably stable usage and lead-time. When there are frequent fluctuations, a new order quantity & a new order point has to be determined. System as such becomes cumbersome when applied to materials with unstable usage pattern & lead-time.
2. If slow moving items are brought under this system, it tends to increase inventory due to operation of different levels. Since this is based on perpetual inventory records error in posting in stock records or issue of materials deform or distort book balances and lead to undetected materials shortages or over-stock (in inventory control terminology such situations are known as under stocking or overstock- both are not good for the organization).
3. As stated above for management of inventory of spare parts, it has only limited application for those parts, which are cheaper, fast moving and have stable consumption pattern.
4. Since consumption pattern of majority of spares is unpredictable and low, system will not work and finally land up with higher inventory level.

3.4 Determination of Various Levels

Minimum level is the level below which stock should not normally drop. This is safety stock (also known as buffer stock) to provide necessary cushion when consumption is at higher rate or normal delivery period is exceeded or both. If there were no variation in consumption as well as lead time, there would be no need for safety stock. As a result, fixed quantity of materials may be ordered at a fixed interval. Ideal situation would be as shown in Fig. 2.

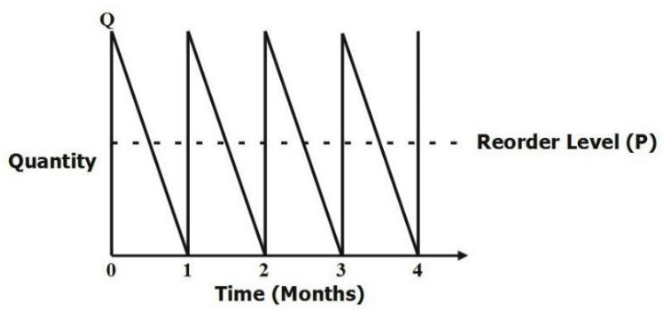

Figure 2: Inventory level as a function of time (Ideal Case)

When stock level reaches level P, we order quantity Q which arrives exactly when stock reaches zero. Thus, the maximum stock is Q and the minimum is zero. In practice, this ideal situation does not exist. Either the rate of consumption

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may increase or the ordered quantities may not come in time, the result is stock out. The Fig.(s) 3 (a) and (b) illustrate how safety stock plays a crucial role in mitigating risks associated with inventory management, ensuring operational stability, and meeting customer demands [4].

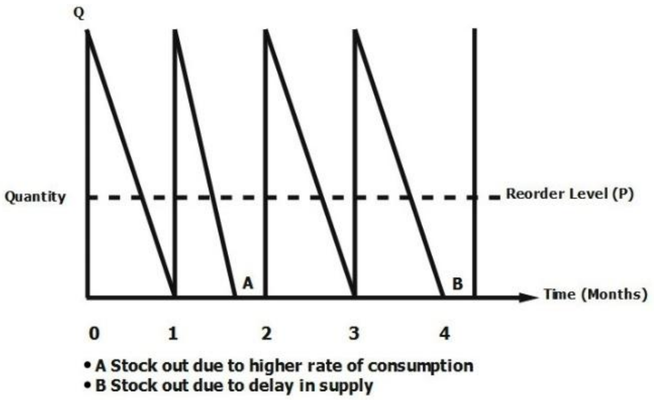

Figure 3 (a): Inventory level in case of stock out

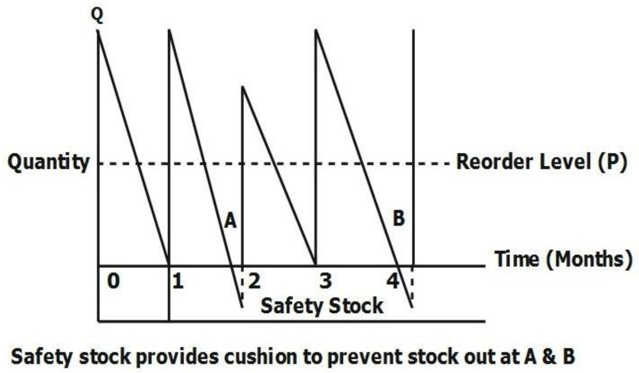

Figure 3 (b): Inventory level with safety stock

A) Safety stock calculations:

Case 1: If demand and length of past lead-times is fairly stabilized and there is normal distribution: The formula for safety stock is

$$\text{Safety stock} = K\sqrt{D} \qquad (2)$$

Where D is the mean average demand and K is a constant with value between 1 to 3.9, depending upon the criticality and degree of safety/service level required (keeping in view stock- out cost of each item). If K=1, it provides 84% service level i.e. there are 16% chances of stock out, K=2 will provide 97.7% service level and K=3 will provide 99.87 service level. For 100% service level, value of K=3.9.

Case 2: If demand during lead-time or the length of lead-time is highly fluctuating and irregular i.e., Poisson Distribution: The formula for calculation of safety stock is:

$$\text{Safety stock} = K\delta \qquad (3)$$

Where K is constant and its value depends as above and δ is standard deviation of demand.

B) Reorder Point: It is the point or level at which replenishment order is issued to ensure that supplies are received; before stocks on hand are consumed and there are no stock-outs. It consists of mean expected demand during LT (lead time) plus safety stock. The calculations are as under:

$$\text{Reorder level} = D + K\sqrt{D} \qquad (4)$$

Where, D is the mean average demand during LT plus safety stock.

In practice, the quantities in pipeline must also be considered. The reorder point fluctuates based on the consumption pattern, requiring continuous monitoring and adjustment to align with actual demand variations and lead times.

C) Maximum level: If the system is working properly, normally maximum stock will be minimum plus standard order quantity. In practice, maximum level varies in view of changes in anticipated consumption pattern and length of LT. This is made clear with following exhibit:

Exhibit 1 Consider a plant X with the following parameters for managing a critical component:

Parameter	Quantity
EOQ	300 Units
Lead-time requirements	150 Units
Safety stock	36 Units
Reorder level	186 Units

Ideal situation: reordering shall be initiated when stock is 186 units and by the time the stock drops to 36 units, fresh stock of 300 units shall be received and maximum stock becomes 336 units. Now demand is increased and reorder is placed when stock is 186 units but by time fresh quantity of 300 units is received when 16 units of safety stock are also consumed. Maximum stock level is set to 336 units to maintain operational continuity without overstocking.

Scenario 1-Increased Demand: Suppose the demand unexpectedly increases, resulting in faster depletion of inventory. A reorder is placed at 186 units, but by the time the new 300-unit order arrives, 16 units of safety stock have been consumed due to higher usage. In this scenario, the adjusted maximum stock level becomes 320 units to accommodate the increased demand rate while maintaining adequate safety stock.

Scenario 2-Early Supply: Alternatively, if the supply chain operates more efficiently than expected, the new 300-unit order might arrive sooner than anticipated. In this case, the

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maximum stock level could vary, ranging from 336 to 486 units, depending on the exact timing of the inventory replenishment relative to the consumption rate.

Exhibit 2: Consider a plant Y with the following parameters for managing a critical component:

Parameter	Value
Annual consumption in units (A)	Rs. 1000
Ordering cost per order (S)	1800 Units
Carrying cost as % of inventory (I)	20%
Price per unit (P)	Rs.200
Lead-time	One month
Lead time requirement (D)	150 units
Service level	99.83 i.e. value of K is 3

(i) Standard Order Quantity = √2AS/PI

= (√ (2×1800×1000×100))/ (200×20) = 300 Units

(ii) Minimum level=K√D=3√150=36 Units

(iii) Reorder Level=D+K√D=150+3√150=186 units

(iv) Maximum level = Standard Order Qty. + Min.

= 300+36 = 336 units

After determined various levels, graphic representation will be as under. Q-300, Min-36, ROL- 186 and Max-336 (See Fig.4)

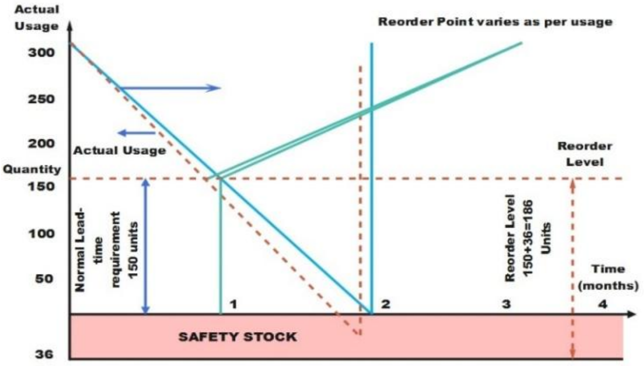

Figure 4: Graphical representation of reorder and safety stock

IV. P SYSTEM

In this system order quantity varies, but the order interval is fixed. A fixed period of time is established at end of which the inventory of the concerned item is reviewed, and a reorder is placed based on the current demand. The inventory is divided into two parts:

(i) *Review period quantity*: This is the quantity intended to satisfy the mean expected demand during the interval between placing two successive orders i.e. review period, and

(ii) *Lead time and safety stock quantity:* This quantity is intended to meet the normal requirements during lead time and a safety allowance to provide protection against random variation in demand during both review period and the lead-time.

This approach ensures that the inventory levels are regularly monitored and adjusted according to the actual consumption patterns, thus optimizing inventory management and reducing the risk of stockouts or overstocking.

Optimum review period: The optimum review period is a key factor in inventory management, balancing the carrying and ordering costs to minimize total inventory costs. The formula to determine the optimum review period (N) to achieve this balance is as follows:

N= √ (24S/IM) (5)

Where,

N = Optimum review period in months
M = Average monthly usage in monetary value
S = Ordering cost per order
I = Carrying cost as % of inventory

Exhibit 3: For an average monthly usage of Rs. 30,000; ordering cost per order of Rs. 1000; carrying cost as % of inventory being 20%., the optimum review period is calculated as,

N= √ (24S/IM) =√ ((24×1000×100)/(20×30000)) =2 Months

This review period will be equivalent to the EOQ, as evident from the relationship of above formula:

Q= MN =M√ (24S/IM) = √ (2S/I) since 12M =A

Where, Q is the EOQ (Economic Order Quantity) and A is the annual usage in monetary value.

Therefore, the quantity calculated using the optimum review period is consistent with the EOQ model, ensuring that inventory management is both efficient and cost-effective.

4.1 Characteristics of P system

Suitability for high value items: This system, with its frequent and careful reviews, is more suitable for 'A' items and high value 'B' items, which are few in number and need close control by senior officers of materials management department.

Periodic reordering: This system is based on periodic reordering of all items, ensuring that inventory levels are consistently reviewed and adjusted.

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Restocking mechanism: With every cycle stock of each item is brought up to their level which depends on review period, LT and rate of usage.

Rapid turn-over: A short review period enables rapid turn-over of stock, ensuring that inventory levels are frequently updated and aligned with current demand.

Higher safety stock: The P system requires a higher safety stock to provide protection against variation of demand during review period and lead time.

Delegation challenges: Delegation of authority at low level is extremely difficult, as it needs freshly to determine order quantity every time an order is placed. This process is complex and must be handled by experienced personnel.

Judgment-based ordering: Decision on order quantity must be made on judgment, keeping in view the past consumption pattern and anticipated changes as per production planning [5].

Comprehensive review: The system compels a periodic review of all items, ensuring that inventory levels are regularly assessed and adjusted. This requirement itself make the system difficult, as due to changes in usage, many items may not be required to be ordered until succeeding review period or usage may increase to point where they should have been ordered before current review date. Consequently, this system must be augmented with minimum balance figure which signs/needed for early reorder if usage is increased.

Workload management: This system tends to peak purchasing workload around the review date. However, this can be mitigated to some extent by regulating the frequency of reviews for different categories of items.

V. COMBINATION OF P AND Q SYSTEM

In practice best advantage can be obtained by combining these two basic systems (P and Q systems). The system may primarily function as a review system (P system), where inventory levels are reviewed and orders are placed at fixed intervals, such as every 6 months. Additionally, it provides for the issuance of replenishment orders when the inventory reaches a predetermined minimum level, regardless of the fixed interval. This ensures that stockouts are avoided even if demand fluctuates significantly between review periods. For example, if the ordering cycle is 6 months, an order is placed either at the end of this cycle or when the minimum level is reached, whichever occurs first.

The Minimum and Maximum System (Q system) may stipulate that when the reorder level of one item is reached, a systematic review of all related items (especially those procured from the same sources) is conducted. This shall ensure that a sizable number of items are ordered to attract sufficient number of bidders. It also reduces the number of purchase orders. For instance, if one type of electrode reaches the reorder level, the entire range of electrodes is reviewed, and those nearer to reorder level are also purchased.

This combined approach ensures that the manufacturer maintains optimal inventory levels, minimizes the risk of stockouts, and benefits from cost savings through bulk purchasing and reduced administrative workload [6].

VI. CONCLUSION

The paper highlights the critical role of replenishment systems in modern inventory management. By exploring various methodologies such as the Economic Order Quantity (EOQ) model, the Minimum-Maximum system, and the integration of P and Q systems, the paper underscores how these strategies can optimize resource utilization and streamline maintenance management. Effective replenishment systems not only balance ordering and carrying costs but also ensure the timely availability of critical components, thereby reducing downtime and enhancing operational efficiency. Through a comprehensive review of these systems and their practical applications, the paper provides valuable insights for inventory managers, particularly in high-stakes environments like power plants. Ultimately, the implementation of well-designed replenishment systems can lead to significant cost savings, improved resource allocation, and a more robust maintenance management framework, positioning organizations to achieve higher levels of productivity and reliability.

The practical examples provided in the paper, such as the EOQ calculations for critical components in different plant scenarios highlight how precise calculations and strategic planning can lead to significant cost savings and improved resource allocation. Further research could explore the integration of advanced technologies like artificial intelligence and machine learning to enhance the accuracy of demand forecasting and dynamic inventory adjustments. Additionally, future studies could tailor replenishment systems to the specific needs of various industries, considering their unique operational challenges and resource requirements. By leveraging well-designed replenishment systems, organizations can achieve higher levels of productivity, reduce Total Incremental Cost (TIC), and enhance overall operational efficiency. As inventory management continues to evolve, ongoing research and innovation will be essential to refine these systems and maximize their effectiveness.

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