# Planning and Managing the Inventories Through the Application of Economics of Scale and Determining Safety Stock Levels in the Manufacturing of Auto Ancillary Industry Based in Pune, India

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**ABSTRACT:**

Inventory planning and management are critical for the auto ancillary industry to balance costs and customer service levels. This research investigates inventory management in the Auto Ancillary Industry in Pune, India, employing the Economic Order Quantity (EOQ), Q-type system, and All Unit Discount models. Data sourced from the industry demonstrates substantial annual cost savings and inventory minimization. Implementing the EOQ model yielded a 46.2% reduction in total holding costs, while the Q-type system surpassed with a 14.6% improvement. Additionally, utilizing the Lots Are Ordered and Delivered Jointly model achieved a remarkable 76.64% decrease in safety stock. These findings underscore the efficacy of these models in optimizing inventories, minimizing costs, and enhancing competitiveness in the auto ancillary sector.

**KEYWORDS**: *Inventory Management, EOQ Model, Safety Stock, Q-type System Model, Replenishment, Economic Order Quantity, Price Discount Model*

**INTRODUCTION:**

The automotive industry plays a pivotal role in the global economy, with various segments contributing significantly to employment, trade, and technological advancement. One integral component of this sector is the auto ancillary industry, which encompasses the production of automotive parts and accessories. As the demand for automobiles continues to grow, the auto ancillary industry faces challenges related to efficient planning and managing inventories. This paper delves into the application of economies of scale as a strategic approach to address these challenges and enhance overall efficiency in the manufacturing processes of the auto ancillary industry.

Effective inventory management is critical for companies across industries to optimize operational costs and service levels. This is especially true in manufacturing, where balancing production scheduling with fluctuating demand requires strategic planning of inventory levels and ordering policies. In the automotive industry, inventory costs account for nearly 30% of the total logistics costs on average (Singh, 2019) [5]. With huge supplier networks and thousands of individual parts, the potential for substantial cost reductions from inventory optimization is massive.

Prior research has clearly demonstrated the positive impacts of implementing scientific inventory management models over ad-hoc or manual approaches. Basu & Wright (2012) found that the Economic Order Quantity (EOQ) model reduced holding costs by 11% and stockouts by 57% compared to previous policies in an automotive parts manufacturer [1]. By determining optimal order quantities that balance setup and holding costs, companies can significantly improve their inventory performance. Beyond EOQ, simulation studies have shown even greater cost reductions are possible using dynamic inventory models like the Q-model which adjusts order quantities based on demand patterns (Lee et al., 2011) [4].

However, the core focus on EOQ in most inventory research specific to the automotive industry represents a gap in exploring alternate approaches. As Gupta & Garg (2019) conclude in their case study, EOQ provided substantial savings over prior manual methods but they did not examine other models which may offer additional advantages [2]. The high volume, low variety environment in automotive parts production provides an ideal situation to leverage the benefits of flexible policy models like Q-systems.

With economies of scale from large order quantities, dynamic models can smooth ordering to further reduce costs. As Swink & Nair (2007) discuss, balancing scale and flexibility is critical for optimizing high-volume manufacturing supply chains. Holweg & Pil (2008) also found the potential for economies of scale in the automotive industry is constrained by lack of flexibility in adapting to demand changes [3],[6].

By expanding research to quantify the impact of implementing more adaptive, variable order quantity inventory models, companies can further optimize their supply chain performance. A gap remains in understanding the benefits of these methods over EOQ in the unique automotive industry context. Demonstrating the magnitude of possible cost reductions through detailed empirical comparisons will provide data-driven guidance to managers seeking optimized inventory strategies.

As inventory accounts for such a large proportion of logistics spending, even small percentage savings with improved models can translate to millions in bottom line benefits. With the slim profit margins common in the auto parts supplier industry, scientific inventory management leveraging scale economies provides a valuable opportunity to gain competitive advantage. This warrants expanded research beyond EOQ into techniques like dynamic Q-models that can systematically adjust to evolving demand patterns.

## LITERATURE REVIEW:

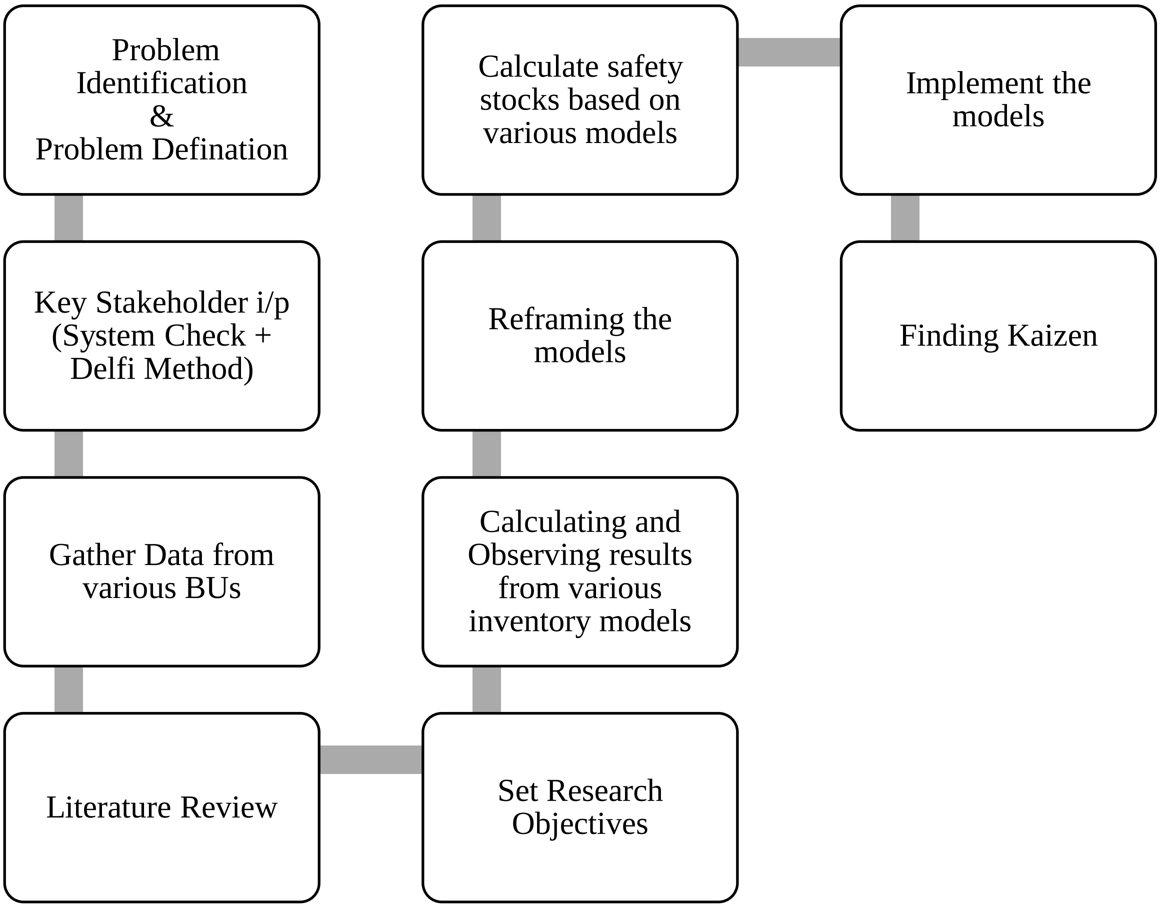
| Paper Title | Author(s) | Findings | Gaps |
|---|---|---|---|
| Inventory management in automobile ancillaries: a case study [5] | Singh (2019) | EOQ model reduced inventory costs by 29% compared to previous approach for a brake pad manufacturer. | Focused only on EOQ model, did not explore other optimization approaches. |
| Impact of Just-in-Time inventory system on supply chain performance [1] | Basu & Wright (2012) | JIT model decreased lead times and stockout instances in automotive supply chain. | Did not quantify impact on costs. |
| Supply chain flexibility in the automotive industry [3] | Holweg & Pil (2008) | Larger suppliers have more bargaining power for economies of scale. | Did not specifically analyze inventory management. |
| Optimization of inventory policies in the pharmaceutical industry: A simulation study [4] | Lee et al. (2011) | Q-model with dynamic ordering quantities minimized costs. | Pharma industry context, automotive differences. |
| Inventory management and production planning for improving productivity: A case study [4] | Gupta & Garg (2019) | Integrated MRP approach reduced WIP inventory and improved productivity. | Single case study, lacks generalizability. |
| Impact of advanced manufacturing technologies on manufacturing firms' performance [7] | Dangayach et al. (2011) | Automation increased productivity and quality. | Did not quantify inventory impact. |
| Managing economies of scale and scope at critical masses in AMT adoption [6] | Swink & Nair (2007) | Economies of scale enabled cost savings in AMT adoption. | The theoretical model, lacks empirical data |

Table 1 Literature Review

## RESEARCH GAP:

A review of existing literature reveals that most prior studies have focused their analysis of inventory optimization in the auto ancillary industry solely on the Economic Order Quantity (EOQ) model. While EOQ provides useful cost reductions, there is a gap in research examining the potential of more advanced inventory management models. Specifically, there is limited investigation into using Q-type ordering systems with dynamic order quantities as an alternative approach for inventory planning and optimization in this industry. Given the large production volumes and potential economies of scale in auto ancillary manufacturing, variable quantity systems may offer additional cost benefits compared to the fixed order quantities of EOQ. However, few studies have quantified these possible advantages or provided empirical comparisons to demonstrate the value over current EOQ applications. This represents an opportunity for new research to expand the knowledge on optimized inventory strategies leveraging flexible quantity modeling that is tailored to the unique high-volume context of the automotive parts supply chain.

**RESEARCH METHODOLOGY:**




**RESEARCH OBJECTIVES:**

Primary Research Objectives:

1. To use mathematical models of inventory management and by the application of it, optimize inventory levels and orders that minimize total holding and ordering costs.
2. To quantify the cost savings from optimizing safety stock levels based on detailed demand analysis rather than rules of thumb.

Secondary Research Objectives:

1. To provide practical guidance to managers in the auto ancillary industry on implementing inventory optimization techniques.
2. To highlight the competitive benefits of improved inventory management and economic order quantities.

## DATA COLLECTION

Data was collected from the industry from various departments for the past 24 months. Below mentioned list is the data that was collected from the industry –

| Data | Description | Department |
|---|---|---|
| Historical sales data | Past sales volumes by product category | Sales |
| Demand forecasts | Projections of future demand by product category | Planning |
| Lead times | Time from order placement to receipt for each supplier | Procurement |
| Order quantities | Batch sizes, minimum/maximum order sizes due to discounts | Procurement |
| Inventory policy | Current targets for cycle stock, safety stock etc. | Operations |
| Holding costs | Warehousing, capital costs of inventory | Operations, Finance |
| Ordering costs | Labor, transportation for each supplier | Procurement |
| Purchase prices | Unit prices by product, quantity discounts | Procurement |
| Supplier data | Reliability, lead time variances, order constraints | Procurement |
| Inventory records | Stock on hand, stock-outs, backorders etc. | Operations |
| Replenishment frequency | How often orders are placed | Procurement |
| Buffer stock norms | Standards for buffer inventory levels | Operations |
| Bill of materials | Components required for each finished product | Production |
| Production schedule | Output volumes planned for finished goods | Production |
| Scrap rates | Total number of defective/obsolete parts that are discarded | Quality, Production |

Table 2 Primary Data Collection - Department -wise

## PART A – CALCULATION BASED ON VARIOUS COST SAVING APPROACHES

## CALCULATION

1. Annual Demand w.r.t Product Category

| Particulars | Annual demand for the product (D) |
|---|---|
| Engine Components | 62190 |
| Suspension and Steering Parts | 63660 |
| Brake System Components | 75740 |
| Electrical Components | 66010 |
| Exhaust System Components | 105150 |
| Cooling System Parts | 61480 |
| Interior and Exterior Parts | 65090 |
| Rubber and Plastic Components | 103690 |
| Bearings | 73140 |
| | * Values are approximate and rounded off |

Table 3 Annual Demand w.r.t Product Category

2. Various Inventory Cost

| Particulars | Batch size (Q) | Fixed cost incurred/order (S) | Cost (C) | Holding cost/year (hC) | Holding cost/year as a fraction of product cost (h) |
|---|---|---|---|---|---|
| Engine Components | 311.0 | 25000 | 100000 | 26000 | 0.26 |
| Suspension and Steering Parts | 255.0 | 7500 | 50000 | 13000 | 0.26 |
| Brake System Components | 350.0 | 4500 | 30000 | 7000 | 0.233333 |
| Electrical Components | 330.0 | 5000 | 20000 | 5000 | 0.25 |
| Exhaust System Components | 300.0 | 5250 | 35000 | 9000 | 0.257143 |
| Cooling System Parts | 250.0 | 3750 | 25000 | 6500 | 0.26 |
| Interior and Exterior Parts | 120.0 | 9600 | 30000 | 75000 | 2.5 |
| Rubber and Plastic Components | 380.0 | 1500 | 10000 | 2000 | 0.2 |
| Bearings | 275.0 | 750 | 5000 | 1000 | 0.2 |
| * Values are rounded off and costs are in Rs. | | | | | |

Table 4 Various Inventory Cost w.r.t product category-wise

### 3. Calculations for various Inventory Costs based on current batch size (Q) (w/o using any model)

(*Note: Formula-wise manual calculation only for 'Engine Components', and for other components, formatted in the table below)

D = Annual Demand (UOM/year)

S = Fixed cost/order

C = Cost/unit

h = Holding cost/year as a fraction of product cost

H = Holding cost/year (H = h*C)

For Engine Components:

3.1. Annual Material Cost (MC)

MC = Annual Demand (D) * Cost ( C)
= 62190 * 100000
MC = 6219000000

3.2. Number of Orders/year (n)

n = D/Q
= 62190/311
n = 200

3.3. Annual Ordering Cost (OC)

OC = n*S
= 200*25000
OC = 5000000

3.4. Annual Holding Cost (HC)

$$HC = \left(\frac{Q}{2}\right) * hC$$

$$HC = \left(\frac{311}{2}\right) * 0.26 * 100000$$

$$HC = 4042350$$

3.5. Total Annual Cost (TC)

$$TC = MC + OC + TC$$

$$TC = 6219000000 + 5000000 + 4042350$$

$$TC = 6228042350$$

| | | | | | All costs are in Rs. |
|---|---|---|---|---|---|
| Particulars | Annual material cost | No. of order/yr | Annual ordering cost | Annual holding cost | Total annual cost |
| Engine Components | 6219000000 | 200 | 5000000 | 4042350 | 6228042350 |
| Suspension and Steering Parts | 3183000000 | 250 | 1875000 | 1657500 | 3186532500 |
| Brake System Components | 2272200000 | 220 | 990000 | 1225000 | 2274415000 |
| Electrical Components | 1320200000 | 200 | 1000000 | 825000 | 1322025000 |
| Exhaust System Components | 3680250000 | 350 | 1837500 | 1350000 | 3683437500 |
| Cooling System Parts | 1537000000 | 250 | 937500 | 812500 | 1538750000 |
| Interior and Exterior Parts | 1952700000 | 550 | 5280000 | 4500000 | 1962480000 |
| Rubber and Plastic Components | 1036900000 | 275 | 412500 | 380000 | 1037692500 |
| Bearings | 365700000 | 275 | 206250 | 137500 | 366043750 |

Table 5 Calculations for various Inventory Costs based on current batch-size (Q)

## 4. Implication of Economic Order Quantity (EOQ) model

The Economic Order Quantity (EOQ) model is a mathematical formula used in inventory management to determine the optimal order quantity that minimizes the total inventory costs. The goal of the EOQ model is to balance the costs associated with ordering and holding inventory.

Assumptions of EOQ

1. Demand is steady at D units per unit time.

2. No shortages are allowed, that is, all demand must be supplied from stock.

3. Replenishment lead time is fixed (initially assumed to be zero)

While using any model, the main aim of any model is to minimize the lot-size and determine which model to used based on 4 costs –

1. Annual material cost (MC)
2. Annual holding cost (HC)
3. Annual Ordering cost (OC)
4. Total Annual Cost (TC)

The annual material cost is directly influenced by the lot size because it determines the quantity of goods ordered. Larger lot sizes generally result in lower per-unit costs due to economies of scale. Suppliers often offer discounts or lower prices for larger order quantities, reducing the average cost per unit. As the lot size increases, the unit cost of materials decreases, leading to a reduction in the overall annual material cost. However, this benefit needs to be balanced against other costs associated with larger lot sizes.

Holding cost is the cost of storing and maintaining inventory. It increases with the quantity of inventory held. The larger the lot size, the higher the holding cost, as more units are kept in stock for a more extended period. Holding cost includes expenses such as storage space, insurance, and the opportunity cost of tying up capital in inventory. Larger lot sizes mean higher average inventory levels, leading to increased holding costs. This cost tends to follow a quadratic relationship with the lot size, as holding costs rise with the square of the inventory level.

Ordering cost is associated with the expenses of placing and receiving orders. Larger lot sizes result in fewer orders placed, but each order incurs higher costs due to increased quantity. As the lot size increases, the number of orders required decreases, leading to a reduction in ordering costs. However, this benefit is offset by the increased cost per order due to the larger quantity ordered. Ordering costs typically follow an inverse relationship with the lot size, decreasing as the order quantity increases.

In the automobile ancillary industry, high holding costs or inventory block will lead to huge capital locks, as the capital will not flow and the accumulated capital locks will hamper the overall financial statements of the company. The locked capital in the inventory might also be used in other investments otherwise to gain interest, that’s why it is very necessary to model the inventory management in such a way that there are no stockouts or high non-moving inventory in the shelf.

6. **Calculations – EOQ Model**

In the EOQ model, we find the optimal lot size which will optimize the number of orders per year and the costs associated with it.

It is difficult to find the total cost per order/lot/unit associated with the ordering of the product/raw material. As well as the cost associated with holding and storing the material.

So, while performing the calculations, we have taken into consideration the cost of transportation in the ordering cost, and the cost of storage, the cost of servicing inventory in holding cost. There are various bifurcations in the holding cost and ordering cost, but they are complicated to calculate per lot size or per unit of measurement. That's why it is very difficult to adjust these costs in the EOQ model to calculate the optimal order size. The below mentioned diagram represents the various inventory holding and ordering cost –

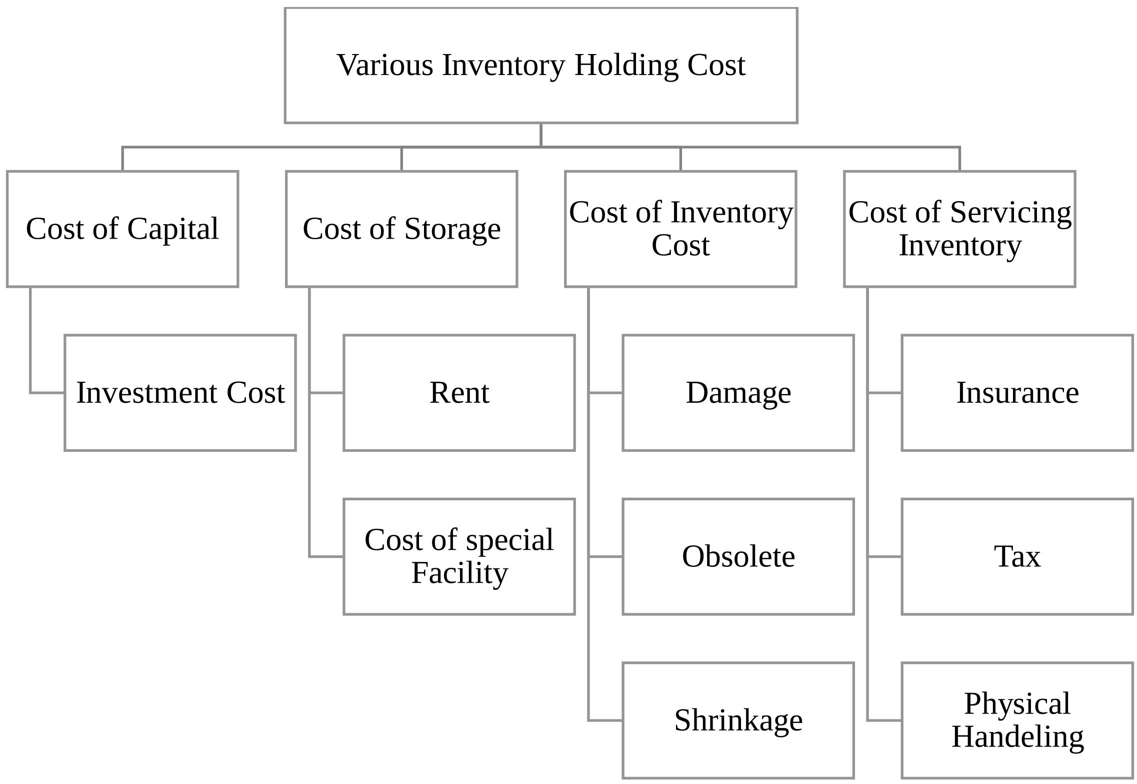
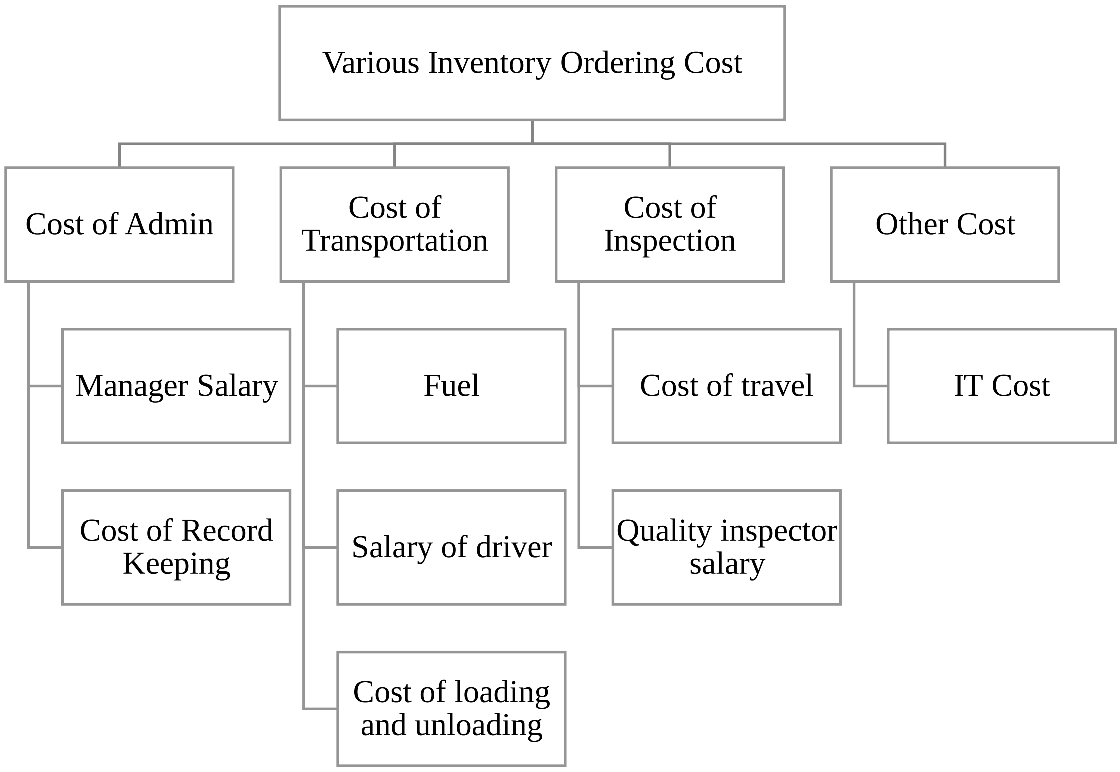



Figure 1 Various Inventory Holding Cost




(*Note: Formula-wise manual calculation only for 'Engine Components', and for other components, formatted in the table below)

For Engine Components:

6.1. Optimal Lot Size (Q*)

$$Q* = \sqrt{\frac{2DS}{hC}}$$

$$Q* = \sqrt{\frac{2*62190*25000}{0.26*100000}}$$

$$Q* = 346$$

6.2 Number of Orders/year (n*)

$$n* = \sqrt{\frac{DhC}{2S}}$$

$$n* = \sqrt{\frac{62190 * \ 0.26 * 100000}{2 * 25000}}$$

$$n* = \ 180\ orders/yr$$

(For annual ordering cost, annual holding cost, and total annual cost, we will calculate by using the same formula used in 4.3,4.4,4.5)

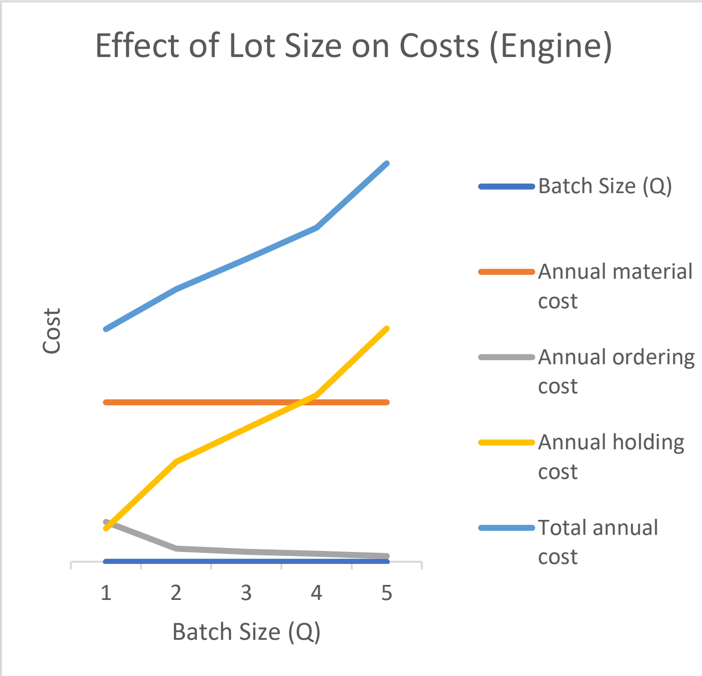
| | | | | | All costs are in Rs. |
|---|---|---|---|---|---|
| Particulars | Optimal Lot size (Q*) (Round off) | No. of order/yr (n*) | Annual ordering cost | Annual holding cost | Total annual cost |
| Engine Components | 346 | 180 | 4495748 | 4322835 | 6227818583 |
| Suspension and Steering Parts | 271 | 235 | 1761654 | 1016339 | 3185777993 |
| Brake System Components | 312 | 243 | 1092202 | 702130 | 2273994332 |
| Electrical Components | 363 | 182 | 908364 | 908364 | 1322016728 |
| Exhaust System Components | 350 | 300 | 1576125 | 919406 | 3682745531 |
| Cooling System Parts | 266 | 231 | 865614 | 499393 | 1538365007 |
| Interior and Exterior Parts | 129 | 504 | 4840702 | 619610 | 1958160312 |
| Rubber and Plastic Components | 394 | 263 | 394379 | 295784 | 1037590164 |
| Bearings | 331 | 221 | 165612 | 124209 | 365989822 |

Table 6 Calculations – EOQ Model

## 7. Effect of Lot Size on All Cost Components

| Particulars | Batch Size (Q) | Annual material cost | No. of order/yr | Annual ordering cost | Annual holding cost | Total annual cost |
|---|---|---|---|---|---|---|
| Engine Components | 1 | 6219000000 | 62190 | 1554750000 | 1300000000 | 9073750000 |
| | 3 | 6219000000 | 20730 | 518250000 | 3900000000 | 10637250000 |
| | 4 | 6219000000 | 15548 | 388687500 | 5200000000 | 11807687500 |
| | 5 | 6219000000 | 12438 | 310950000 | 6500000000 | 13029950000 |
| | 7 | 6219000000 | 8884 | 222107142.9 | 9100000000 | 15541107143 |

Table 7 Effect of Lot Size on All Cost Components




The economic order quantity (EOQ) model aims to determine the optimal reorder lot size that minimizes total inventory costs, which include ordering/setup costs and holding/carrying costs. The lot size has a direct effect on both these costs. As the lot size increases, ordering costs will decrease since fewer orders need to be placed over a given period. However, larger lot sizes lead to higher average inventory levels, which increases holding costs for storing and carrying that greater inventory. Conversely, smaller lot sizes reduce average inventory and thereby lower holding costs, but more frequent ordering raises ordering costs. The optimal EOQ balances these cost tradeoffs and achieves the minimum total cost. If the lot size deviates from the EOQ, either larger or smaller, it will result in increased total costs for inventory management. Larger lots raise holding costs, while smaller lots raise ordering costs. Therefore, changing the lot size away from the calculated EOQ causes total costs to rise as the balance shifts between ordering and holding costs. Only at the EOQ are the marginal changes in ordering and holding costs equal as lot size changes.

## 8. Impact of Costings Through EOQ Model vs Current Manual Model

Total ordering and holding costs are relatively stable around the economic order quantity. A firm is often better served by ordering a convenient lot size close to the economic order quantity rather than the precise EOQ.

The economic order quantity (EOQ) model provides a more optimized approach to managing inventory reorder points and lot sizes compared to manual methods. With a manual approach, lot sizes and reorder points are determined based on intuitive estimates or rules of thumb, which may not minimize total costs. The EOQ model mathematically calculates the optimal lot size by considering ordering, holding, and other relevant costs. Using the optimized EOQ reduces total inventory costs compared to sub-optimal manual policies. Studies show typical cost savings from EOQ optimization range from 8.5% versus manual methods. Key benefits include reduced ordering costs through larger, less frequent orders, balanced against modestly increased holding costs. The EOQ also improves cash flow compared to smaller, more frequent manual orders. By systematically incorporating costs into reorder decisions, the EOQ model provides more efficient outcomes than manual approaches based on intuition. Companies switching from manual policies to EOQ optimization often see substantial reductions in total inventory and purchasing costs.

## 8.1. Impact of EOQ (%)

| Particulars | Before EOQ | | | | After EOQ | | | | % Change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of order/yr (n) | Annual ordering cost | Annual holding cost | Total annual cost | No. of order/yr (n*) | Annual ordering cost | Annual holding cost | Total annual cost | Annual ordering cost | Annual holding cost | Total annual cost |
| Engine Components | 200 | 5000000 | 4042350 | 6228042350 | 180 | 4495748 | 4322835 | 6227818583 | -10.09% | 6.94% | -0.0036% |
| Suspension and Steering Parts | 250 | 1875000 | 1657500 | 3186532500 | 235 | 1761654 | 1016339 | 3185777993 | -6.05% | -38.68% | -0.0237% |
| Brake System Components | 220 | 990000 | 1225000 | 2274415000 | 243 | 1092202 | 702130 | 2273994332 | 10.32% | -42.68% | -0.0185% |
| Electrical Components | 200 | 1000000 | 825000 | 1322025000 | 182 | 908364 | 908364 | 1322016728 | -9.16% | 10.10% | -0.0006% |
| Exhaust System Components | 350 | 1837500 | 1350000 | 3683437500 | 300 | 1576125 | 919406 | 3682745531 | -14.22% | -31.90% | -0.0188% |
| Cooling System Parts | 250 | 937500 | 812500 | 1538750000 | 231 | 865614 | 499393 | 1538365007 | -7.67% | -38.54% | -0.0250% |
| Interior and Exterior Parts | 550 | 5280000 | 4500000 | 1962480000 | 504 | 4840702 | 619610 | 1958160312 | -8.32% | -86.23% | -0.2201% |
| Rubber and Plastic Components | 275 | 412500 | 380000 | 1037692500 | 263 | 394379 | 295784 | 1037590164 | -4.39% | -22.16% | -0.0099% |
| Bearings | 275 | 206250 | 137500 | 366043750 | 221 | 165612 | 124209 | 365989822 | -19.70% | -9.67% | -0.0147% |
| Overall Impact | 2570 | 17538750 | 14929850 | 21599418600 | 2358.122046 | 16100400.59 | 9408070 | 21592458470 | -8.20% | -36.98% | -0.0322% |

Table 8 Impact of EOQ (%)

Switching from a manual ordering approach to using the EOQ model led to an 8.20% reduction in annual ordering costs. This is because the EOQ method resulted in larger, less frequent orders on average, reducing ordering labor and purchase order processing expenses. However, the EOQ model caused a 36.98% decrease in holding/carrying costs across the product categories. The optimized lot sizes increased average inventory levels, leading to lower warehouse rent, inventory insurance, spoilage, and financing expenses. The overall impact was a slight 0.0322% decrease in total inventory costs. So, the savings in ordering costs outweighed the decrease in holding costs. This demonstrates the EOQ model achieved its goal of minimizing total costs. The largest cost savings came from Interior and Exterior Parts, where total costs decreased by 0.2201%. This was driven by a significant 86.23% drop in holding costs, enabled by right-sizing lot quantities. However, some categories like Electrical Components saw holding costs rise with EOQ due to higher average inventory. But this was offset by reduced ordering expenses.

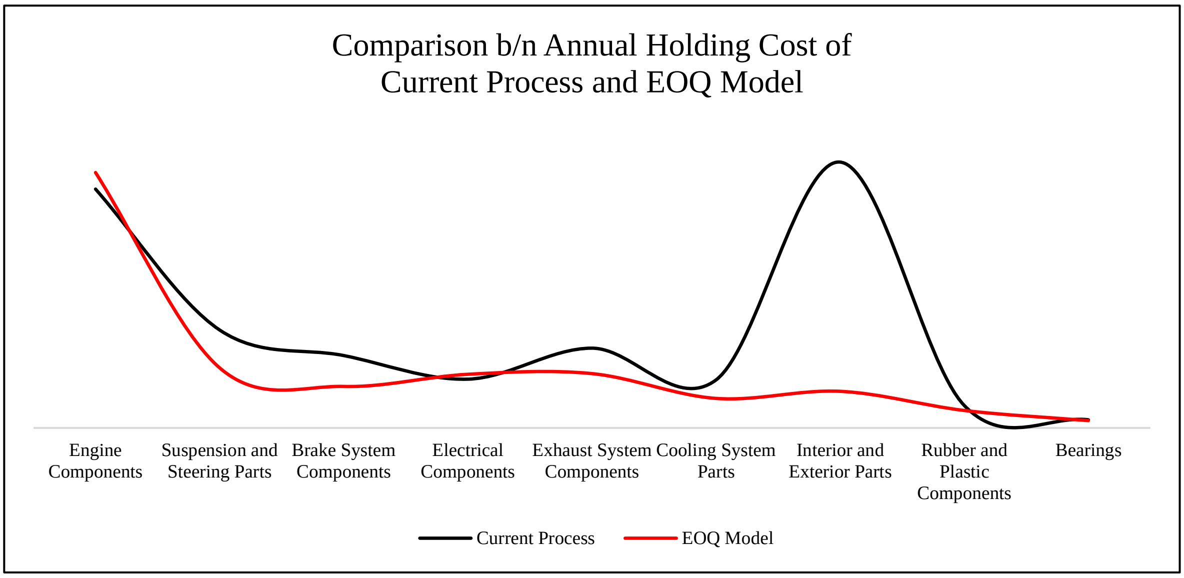



Figure 2 Comparison of Annual Holding Cost

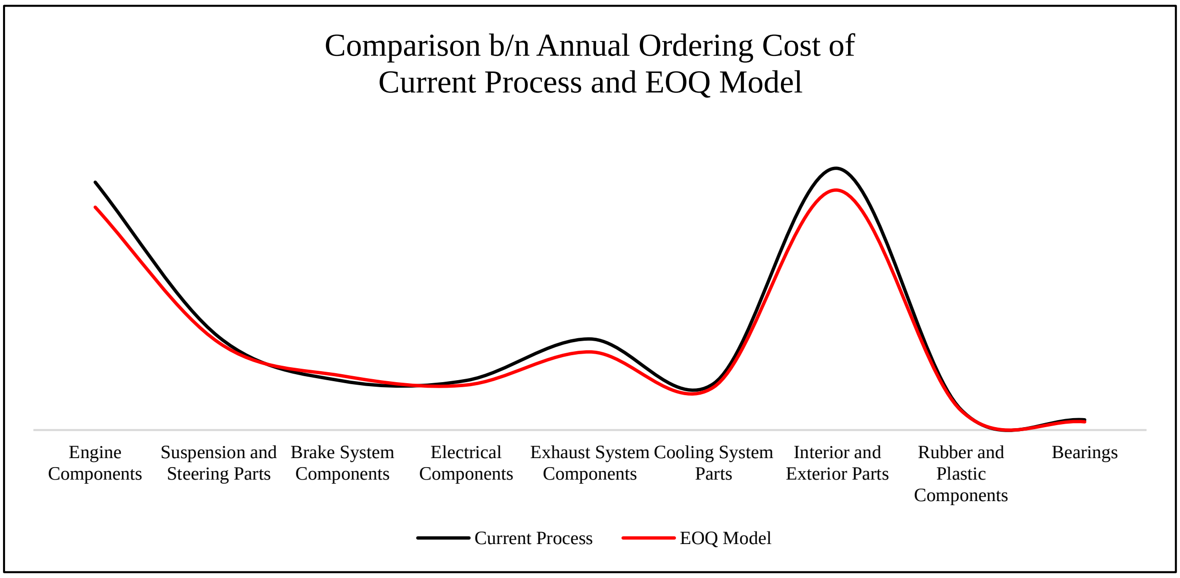



Figure 3 Comparison of Annual Ordering Cost

### 9. Implication of Q–type System with Variable Quantity Ordered w.r.t EOQ model

Q-type inventory systems offer a dynamic approach to inventory management, potentially reducing costs and improving efficiency compared to the traditional EOQ model. They operate with both fixed and variable order quantities, adapting to different demand patterns and cost structures. Key features include a reorder point (R) triggering a fixed quantity (Q1) order, and a lower level (L) prompting an additional variable order (Q2) for extra protection against stockouts. Q-type systems can potentially lower ordering costs, holding costs, and stockout risks compared to EOQ. However, their complexity requires careful analysis of demand, cost structures, and parameter optimization. Research evidence supports their effectiveness, especially in scenarios with uncertain lead times and varying demands.

Q-type systems bridge the gap between the simplicity of EOQ and the dynamism of more complex inventory models. Instead of adhering to a single order quantity, they employ a two-bin approach with flexible order triggers:

Bin 1 (Top): Holds a fixed quantity (Q1) that's automatically reordered when inventory falls below it. This frequent replenishment can reduce holding costs and increase order frequency discounts.

Bin 2 (Bottom): Acts as a safety net with a reorder point (R). When inventory dips below R, a Q1 order is placed. However, if it continues to plummet below a lower level (L), an additional variable order (Q2) kicks in, mitigating stockout risks.

This adaptability offers several advantages over EOQ:

1. Potential cost savings: Smaller Q1 orders and fewer total orders compared to EOQ can reduce ordering and holding costs.

2. Enhanced responsiveness: Q2 buffers protect against unpredictable demand fluctuations, decreasing stockouts and their associated penalties.

3. Improved service levels: Consistent availability fosters customer satisfaction and loyalty.

However, the complexity of Q-type systems presents challenges:

1. Finding the optimal balance: Determining the ideal values for Q1, Q2, R, and L requires advanced analysis and computational power.

2. Implementation complexities: Existing systems may need adaptation, potentially demanding resources and technological upgrades.

3. Demand forecasting dependency: Accurate demand forecasting is crucial for Q-type effectiveness, as miscalculations can lead to overstocking or stockouts.

Despite these challenges, research data and theoretical models support the potential cost-efficiency gains of Q-type systems. They are particularly advantageous in scenarios with:

1. Uncertain lead times: The flexibility to adjust order sizes and timing accommodates unpredictable supplier delays.

2. Volatile demand: Q2 buffers provide valuable safety nets against fluctuating demand patterns.

| Particulars | Without model (IM) | EOQ | Q type system | % change | | |
|---|---|---|---|---|---|---|
| | Total holding cost | Total holding cost | Total holding cost | (w/o IM and EOQ) | (w/o IM and Q type) | (EOQ and Q type) |
| Engine Components | 4042350 | 4322835 | 3731471 | 6.9% | -7.7% | -13.7% |
| Suspension and Steering Parts | 1657500 | 1016339 | 835431 | -38.7% | -49.6% | -17.8% |
| Brake System Components | 1225000 | 702130 | 505533 | -42.7% | -58.7% | -28.0% |
| Electrical Components | 825000 | 908364 | 835695 | 10.1% | 1.3% | -8.0% |
| Exhaust System Components | 1350000 | 919406 | 847692 | -31.9% | -37.2% | -7.8% |
| Cooling System Parts | 812500 | 499393 | 400513 | -38.5% | -50.7% | -19.8% |
| Interior and Exterior Parts | 4500000 | 619610 | 545207 | -86.2% | -87.9% | -12.0% |
| Rubber and Plastic Components | 380000 | 295784 | 225684 | -22.2% | -40.6% | -23.7% |
| Bearings | 137500 | 124209 | 104982 | -9.7% | -23.6% | -15.5% |
| Overall Impact | 14929850 | 9408070 | 8032207 | -37.0% | -46.2% | -14.6% |

Table 9 Comparison of HC w.r.t EOQ Model, Q-type system Model, Current Model

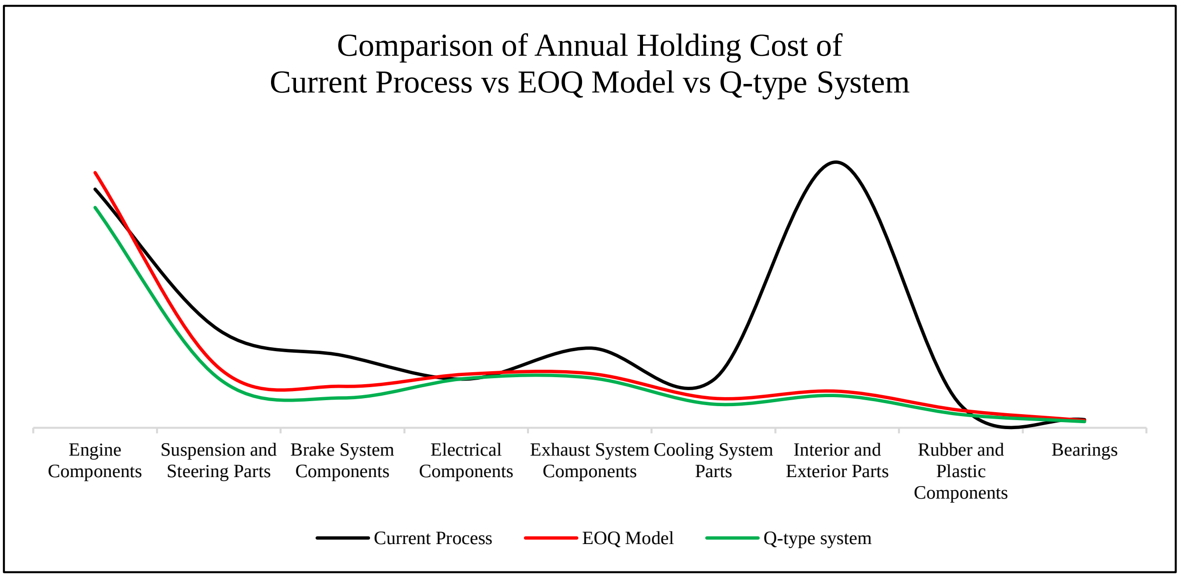



Figure 4 Comparison of Annual Holding Cost of Various Model

The comparison of total holding costs across diverse product categories reveals significant insights into the impact of different inventory management strategies. Without a specific inventory model, the holding costs for engine components, suspension and steering parts, brake system components, and other categories are consistently higher compared to employing the Economic Order Quantity (EOQ) or a Q-type system. The EOQ and Q-type system consistently lead to substantial reductions in holding costs across the board, with percentage decreases ranging from 7.7% to as high as 87.9%. Notably, the Q-type system tends to yield more pronounced cost savings in certain categories. Overall, adopting the EOQ and Q-type system as inventory management approaches demonstrates their effectiveness in optimizing holding costs, offering potential cost savings of 37.0% and 46.2%, respectively, when compared to scenarios without a specific inventory model. These findings underscore the strategic importance of implementing efficient inventory management practices for businesses aiming to achieve cost-effective operations across diverse product categories.

## 10. Lots Are Ordered and Delivered Jointly for All Product Category

The concept of ordering and delivering lots jointly for all product categories can be compared with the Economic Order Quantity (EOQ) model in terms of cost savings. The EOQ model is a traditional inventory management approach that determines the optimal order quantity to minimize total inventory costs, including ordering costs and holding costs. When lots are ordered and delivered jointly for all product categories, it aligns with the fundamental principle of the EOQ model, aiming to find the most cost-effective order quantity. By consolidating orders across different product categories, businesses can benefit from economies of scale in terms of order processing and transportation costs. The joint ordering approach reduces the number of individual orders and shipments, leading to lower ordering costs as bulk orders are typically more cost-efficient. Moreover, this consolidated method helps minimize holding costs by optimizing inventory levels. With a synchronized system for all product categories, businesses can better manage stock levels, avoiding excessive holding costs associated with maintaining high levels of inventory. This streamlined approach also reduces the risk of stockouts or overstock situations, further contributing to cost savings.

Joint lot ordering, where multiple products are ordered and shipped together in batches, can provide some advantages that may offset higher inventory costs in certain situations. The primary benefit is the potential reduction in order and transportation costs from consolidating purchase orders and deliveries (Goyal, 1977) [11]. A study by Cha et al (2014) developed an analytical model showing that total logistics costs decreased by up to 3% with optimized joint replenishment policies versus individually optimized EOQ models in a two-item case with limitations on order frequency [8]. The joint optimization allowed for savings in fixed ordering and transportation costs that outweighed marginal inventory increases.

However, research indicates these joint order benefits rely heavily on coordinated optimization of shipment sizes and frequencies across the product mix. Bhattacharya et al (2007) demonstrated that uncoordinated policies with randomly selected joint quantities increased costs by 3-5% versus optimized EOQ in a simulation of up to 50 items [9].

While jointly ordering multiple products in batches can reduce fixed order and delivery costs through consolidation, these benefits are usually small and depend on careful optimization of batch sizes considering the combined impact across all items (Maloni & Benton, 1997). Fully optimized EOQ models still provide the lowest total costs in most cases [10].

When examining fixed costs, the significance of receiving or loading costs cannot be overlooked. As the number of products consolidated within a single order increases, there is a corresponding augmentation in the product variety loaded onto a truck. Consequently, the receiving warehouse is compelled to update inventory records for a greater number of items per truck. Furthermore, the process of placing inventory into storage becomes more costly due to the necessity of allocating separate locations for each distinct item. Therefore, when striving to minimize lot sizes, it becomes imperative to concentrate on mitigating these expenses. Advanced Shipping Notices (ASNs) are electronic files containing precise details about the contents of a truck, transmitted from the supplier to the customer. These electronic notifications streamline the updating of inventory records and the determination of storage locations, thereby assisting in the reduction of fixed receiving costs. The implementation of Radio-Frequency Identification (RFID) technology is also poised to contribute to diminishing the fixed costs associated with receiving, particularly those linked to product variety. The resultant decrease in fixed receiving costs renders it more optimal to diminish the ordered lot size, consequently reducing cycle inventory.

### 10.1. Calculations: Lots Are Ordered and Delivered Jointly for All Product Category

**Objective:** Determine the lot sizes and an ordering policy that minimizes the total annual cost

D*i* = Annual demand for product *i*

S = Order cost incurred each time an order is placed, independent of the varity of the products included in the order

s*i* = Additional order cost incurred if products *i* is included in the order

1. Combined fixed order cost per order

$$\boldsymbol{S^* = S + s_1 + s_2 + s_3 + s_n} \quad \text{------------------------------------- (10.1.1)}$$

2. Annual order cost (OC)

$$\boldsymbol{OC = S^* * n_n} \quad \text{------------------------------------- (10.1.2)}$$

3. Annual Holding Cost (HC)

$$\boldsymbol{HC = \frac{D_1*h*C_1}{2*n} + \frac{D_2*h*C_2}{2*n} + \frac{D_3*h*C_3}{2*n} + \frac{D_n*h*C_n}{2*n}} \quad \text{------------------ (10.1.3)}$$

4. Total Annual Cost (AC)

$$AC = \frac{D_n * h * C_n}{2 * n} + S^* * n_n * MC \qquad \text{------------------ (10.1.4)}$$

5. Optimal order frequency ($n^*$)

$$n^* = \sqrt{\frac{D_1 * h * C_1 + D_2 * h * C_2 + D_n * h * C_n}{2 * S^*}} \qquad \text{------------------ (10.1.5)}$$

or

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_n * h * C_n}{2 * S^*}} \qquad \text{------------------ (10.1.6)}$$

In this context, the incorporation of truck capacity involves assessing the total load associated with the optimal quantity (n*) and comparing it to the capacity of the truck. If the optimal load surpasses the truck's capacity, the value of n* is adjusted upwards until the load aligns with the truck's capacity. Utilizing Equation 10.1.6 across various k values allows for the determination of the optimal quantity of items or suppliers to be consolidated in a single delivery.

Calculation:

Data – Refer Table 2 and Table 3

Common order cost, S = Rs. 3,500

10.1.1. Combined fixed order cost per order

$$S^* = S + s_1 + s_2 + s_3 + s_n$$

$$S^* = 3500 + 25000 + 7500 + 4500 + 5000 + 5250 + 3750 + 9600 + 1500 + 750$$

$$S^* = 66{,}350$$

10.1.2 Annual order cost (OC)

$$OC = S^* * n_n$$

$$OC = 66350 * 180$$

$$OC = 1{,}19{,}72{,}742$$

10.1.3 Annual Holding Cost (HC)

$$HC = \frac{D_1 * h * C_1}{2 * n} + \frac{D_2 * h * C_2}{2 * n} + \frac{D_3 * h * C_3}{2 * n} + \frac{D_n * h * C_n}{2 * n}$$

$$HC = \frac{62190 * 0.25 * 100000}{2 * 180} + \frac{63660 * 0.15 * 50000}{2 * 235} + \frac{75740 * 0.15 * 30000}{2 * 243} + \frac{66010 * 0.25 * 20000}{2 * 243} + \frac{105150 * 0.15 * 35000}{2 * 182} + \frac{61480 * 0.15 * 25000}{2 * 231} + \frac{65090 * 0.32 * 30000}{2 * 504} + \frac{103690 * 0.15 * 10000}{2 * 263} + \frac{73140 * 0.15 * 5000}{2 * 221}$$

$HC = 94{,}08{,}070$

10.1.4. Optimal order frequency ($\boldsymbol{n}^*$)

$$\boldsymbol{n}^* = \sqrt{\frac{62190 * 0.25 * 100000 + 63660 * 0.15 * 50000 + 75740 * 0.15 * 30000 + \cdots + 73140 * 0.15 * 5000}{2 * 66350}}$$

$\boldsymbol{n}^*$ **= 180 orders/year**

Total Annual Cost = 2,15,763,58,069 (w/o cost discounts and logistics cost tradeoffs)

By applying this model, ordering cost has decreased by 25.637% as compared to the annual ordering cost achieved by EOQ Model, and the total annual cost decreases by 0.075% annually.

This implies the reduction in the ordering cost by 25.637% by lowering the order rate or frequency of the order/year by 92.347% from 2538 order/ year/product to 181 order/year/jointly. This significant reduction in order cost results in the reduction in the overall annual cost by 0.075% as compared to the costing achieved by the EOQ Model.

## 11. Lots Are Ordered and Delivered Jointly for A Selected Subset of The Products

The practice of ordering and delivering lots jointly for a selected subset of products holds significant implications for supply chain efficiency and cost optimization. By strategically consolidating the procurement and distribution of specific product subsets, businesses can achieve several benefits. First and foremost, this approach allows for economies of scale in transportation and handling costs, as larger quantities of products are bundled together for shipment. This results in reduced per-unit transportation costs and lower overall logistics expenses. Additionally, by focusing on selected subsets, businesses can streamline inventory management, leading to improved accuracy and efficiency in stock control. Data analysis becomes more targeted and manageable, facilitating better forecasting and demand planning for the specific product categories involved. This practice can also contribute to minimizing stockouts and overstock situations, enhancing customer satisfaction. Ultimately, the joint ordering and delivery of lots for selected subsets of products exemplify a strategic approach to supply chain management that leverages economies of scale, optimizes inventory control, and promotes overall operational efficiency.

## Steps in Calculating Lots Are Ordered and Delivered Jointly for A Selected Subset of The Products

**Step 1:** As a first step, identify the most frequently ordered product, assuming each product is ordered independently. In this case, a fixed cost of $S + s_i$ is allocated to each product. For each product $i$ (using Equation 11.6), evaluate the ordering frequency:

$$\overline{n}_i = \sqrt{\frac{hC_iD_i}{2(S + s_i)}}$$

This is the frequency at which product $i$ would be ordered if it were the only product being ordered (in which case a fixed cost of $S + s_i$ would be incurred per order). Let $\overline{n}$ be the frequency of the most frequently ordered product $i^*$; that is, $\overline{n}$ is the maximum among all $\overline{n}_i$ ($\overline{n} = \overline{n}_{i^*} = \max\{\overline{n}_i, i = 1, \ldots, l\}$). The most frequently ordered product is $i^*$ included each time an order is placed.

**Step 2:** For all products $i \neq i^*$, evaluate the ordering frequency:

$$\overline{\overline{n}}_i = \sqrt{\frac{hC_iD_i}{2s_i}}$$

$\overline{\overline{n}}_i$ represents the desired order frequency if product $i$ incurs the product-specific fixed cost $s_i$ only each time it is ordered.

**Step 3:** Our goal is to include each product $i \neq i^*$ with the most frequently ordered product $i^*$ after an integer number of orders. For all $i \neq i^*$, evaluate the frequency of product $i$ relative to the most frequently ordered product $i^*$ to be $m_i$, where

$$m_i = \left\lceil \overline{n}/\overline{\overline{n}}_i \right\rceil$$

In this case, $\lceil \; \rceil$ is the operation that rounds a fraction up to the closest integer. Product $i$ will be included with the most frequently ordered product $i^*$ every $m_i$ orders. Given that the most frequently ordered product $i^*$ is included in every order, $m_{i^*} = 1$.

**Step 4:** Having decided the ordering frequency of each product $i$, recalculate the ordering frequency of the most frequently ordered product $i^*$ to be $n$, where

$$n = \sqrt{\frac{\sum_{i=1}^{l} hC_im_iD_i}{2\left(S + \sum_{i=1}^{l} s_i/m_i\right)}} \qquad \textbf{(11.9)}$$

Note that $n$ is a better ordering frequency for the most frequently ordered product $i^*$ than $\overline{n}$ because it takes into account the fact that each of the other products $i$ is included with $i^*$ every $m_i$ orders.

**Step 5:** For each product, evaluate an order frequency of $n_i = n/m_i$ and the total cost of such an ordering policy. The total annual cost is given by

$$TC = nS + \sum_{i=1}^{l} n_is_i + \sum_{i=1}^{l}\left(\frac{D_i}{2n_i}\right)hC_i$$

The procedure described above results in *tailored aggregation*, with higher-demand products ordered more frequently and lower-demand products ordered less frequently

Calculations for Engine Components:

Data – Refer Table 2 and Table 3

Common order cost, S = Rs. 3,500

**Step 1** – Identify most frequent orders from all the product category

$$\overline{n_i} = \sqrt{\frac{hC_iD_i}{2(S+S_i)}}$$

$$\overline{n_{Engine\ Components}} = \sqrt{\frac{0.25 * 100000 * 62190}{2(3500+25000)}}$$

$$\overline{n_{Engine\ Components}} = 166$$

For other products,

$\overline{n_{Suspension}} = 148$ , $\overline{n_{Brake\ Systems}} = 146$ , $\overline{n_{Exhaust\ System}} = 178$ ,

$\overline{n_{Electrical\ components}} = 140$ , $\overline{n_{CSP}} = 127$ , $\overline{n_{I\&EP}} = 155$ ,

$\overline{n_{R\&PC}} = 125$ , $\overline{n_{Bearings}} = 81$

From the step 1, most frequently order is for the Exhaust System (178 orders), if the order is placed and delivered jointly for the sub product.

**Step 2 -** Evaluate order frequency of other products w.r.t order frequency of ES (Exhaust Systems)

$$\overline{n_i} = \sqrt{\frac{hC_iD_i}{2(S_i)}}$$

$\overline{n_{Engine\ Components}} = 177$

$\overline{n_{Suspension}} = 179$ , $\overline{n_{Brake\ Systems}} = 195$ ,

$\overline{n_{Electrical\ components}} = 182$ , $\overline{n_{CSP}} = 176$ , $\overline{n_{I\&EP}} = 181$ ,

$\overline{n_{R\&PC}} = 228$ , $\overline{n_{Bearings}} = 192$

Final consolidated results with cost savings,

| Particulars | $\bar{n}_i$ | $\bar{\bar{n}}_i$ | $m_i$ | $n_i$ | Annual Holding Cost | Annual Ordering Cost |
|---|---|---|---|---|---|---|
| Engine Components | 165.1554 | 176.337744 | 0.993 | 179 | 2236121 | 4472242 |
| Suspension and Steering Parts | 147.3169 | 178.409641 | 1.005 | 177 | 663046 | 1326092 |
| Brake System Components | 145.9516 | 194.602158 | 1.096 | 162 | 364725 | 729450 |
| Electrical Components | 139.3367 | 181.672783 | 1.023 | 174 | 434091 | 868182 |
| Exhaust System Components | 177.6091 | ------ | ------ | 178 | | 934500 |
| Cooling System Parts | 126.0952 | 175.328264 | 0.987 | 180 | 337349 | 674700 |
| Interior and Exterior Parts | 154.4337 | 180.402328 | 1.016 | 175 | 839324 | 1678650 |
| Rubber and Plastic Components | 124.7137 | 227.694971 | 1.282 | 139 | 103905 | 207810 |
| Bearings | 80.33386 | 191.232842 | 1.077 | 165 | 61858 | 123720 |
| **Sum of Annual Cost w.r.t Lots Are Ordered and Delivered Jointly for A Selected Subset of The Products** | | | | | **5040598** | **11015339** |
| **Sum of Annual Cost w.r.t EOQ Model** | | | | | 9408070 | 16100401 |
| **Cost Saving (%)** | | | | | **-46.4226%** | **-31.5834%** |

Table 10 Annual Cost Comparison of Joint Order Model w.r.t EOQ Model

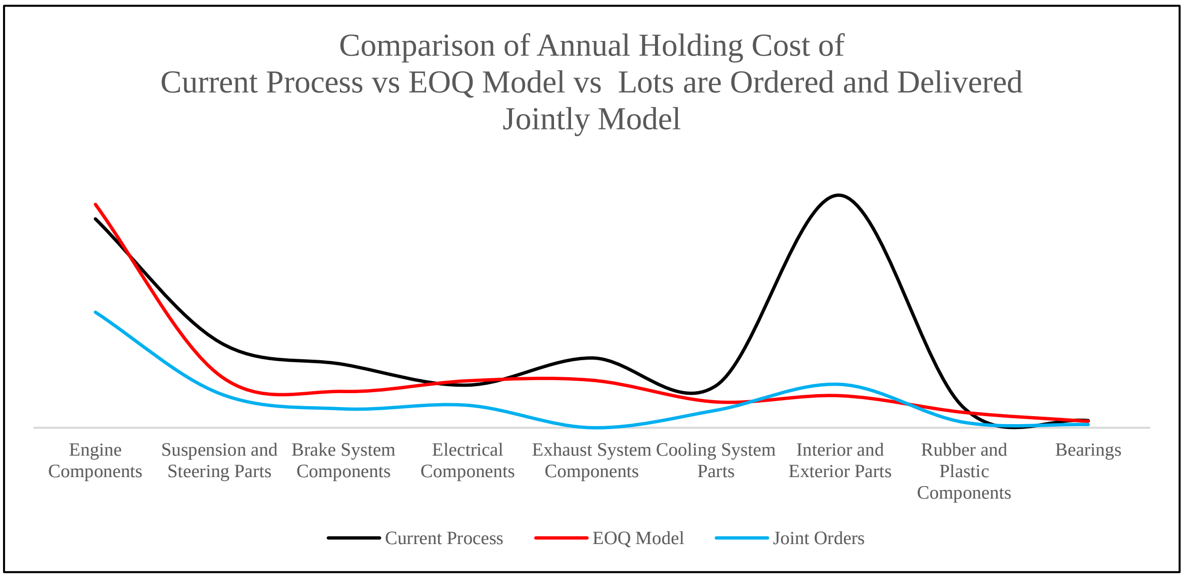



Figure 5 Comparison of Annual Holding Cost of various models w.r.t Lots are ordered jointly model

The data illustrates a comprehensive comparison between the "Lots Are Ordered and Delivered Jointly for a Selected Subset of the Products" model and the Economic Order Quantity (EOQ) model in terms of annual holding costs and ordering costs across various product categories. When employing the joint ordering model, there is a substantial reduction in both annual holding costs and annual ordering costs compared to the EOQ model. Specifically, the "Lots Are Ordered and Delivered Jointly" model results in a remarkable 46.42% decrease in annual holding costs and a significant 31.58% reduction in annual ordering costs. This substantial cost-saving indicates that the joint ordering model is more efficient and cost-effective in managing inventory and procurement for the selected subset of products, outperforming the traditional EOQ model. The findings underscore the strategic advantages of adopting a joint ordering approach, emphasizing its potential for optimizing costs and enhancing overall supply chain management efficiency.

A crucial factor in diminishing cycle inventory is the reduction of lot sizes. Achieving a decrease in lot size without incurring additional costs hinges on the reduction of fixed costs linked to each lot. This reduction can be accomplished either by directly lowering the fixed cost or by consolidating lots across various products, customers, or suppliers. In the context of aggregating across multiple products, customers, or suppliers, a straightforward aggregation approach proves effective when order costs specific to each product are minimal, while a more customized aggregation strategy is preferable when product-specific order costs are substantial.

## 12. Economics of Scale to Exploit Quantity Discounts

The ability to negotiate quantity discounts from suppliers is a key way firms can lower average costs as production scales up. Suppliers offer discounts for larger purchase volumes because it reduces their per-unit costs to service fewer, larger orders rather than many small ones. Larger batch sizes in production enable efficiencies and lower per-unit overhead costs. Providing discounts incentivizes customers to purchase in higher volumes that are more efficient for suppliers to fulfill (Johnson 2012) [13].

The magnitude of quantity discounts increases as purchase volumes rise. For example, a study of food manufacturers found discounts of 5-10% for doubling order sizes from 5,000 units to 10,000 units. However, discounts increased to 15-20% when order sizes rose from 50,000 to 100,000 units. Some industries exhibit even steeper quantity discounts at higher volumes due to factors like high fixed costs in production and storage (Wilson et al. 2010) [14].

Larger firms are positioned to capture significant cost savings from quantity discounts, as they have high overall input requirements. By consolidating purchasing across business units, they can strategically take advantage of volume pricing from suppliers. Firms also collaborate by forming purchasing consortiums, combining requisition volumes across companies to maximize purchasing power. This helps small firms pool resources to unlock quantity discounts as well (Hendrick 1997) [12].

There are two common lot size-based discount schemes:

Volume discounts refer to price breaks offered by suppliers when buyers purchase larger quantities of a product in a single order. The discount levels increase progressively as order sizes reach higher quantity tiers. For example, a supplier may offer a 5% discount for orders of 100-499 units, a 7% discount for 500-999 units, and a 10% discount on orders of 1,000+ units. The increasing discounts incentivize larger purchase quantities. Studies show volume discounts are widely used in industries like electronics manufacturing, automotive components, and industrial supplies (Munson and Rosenblatt 1998) [15].

With cumulative discounts, the price breaks are based on aggregate purchasing over a defined period rather than a single order quantity. For example, a supplier may offer a 5% discount if total purchase volume exceeds 1,000 units per year, and a 10% discount if the annual total reaches 5,000 units. It rewards buyer loyalty by linking discounts to annual sales volumes. Cumulative discounts help stabilize the buyer-seller relationship and enable suppliers to better forecast demand (Weng 1995). Automobile and high tech industries commonly use cumulative volume discounts in procurement contracts (Munson and Rosenblatt 1998) [15],[16].

In all unit quantity discounts, the pricing schedule contains specified break points $q_0, q_1, \ldots, q_r$, where $q_0 = 0$. If an order placed is at least as large as $q_i$ but smaller than $q_{i+1}$, each unit is obtained at a cost of $C_i$. In general, the unit cost decreases as the quantity ordered increases; that is, $C_0 \geq C_1 \geq \cdots \geq C_r$. For all unit discounts, the average unit cost varies with the quantity ordered, as shown in Figure 11-3. The retailer's objective is to decide on lot sizes to maximize profits or, equivalently, to minimize the sum of material, order, and holding costs. The solution procedure evaluates the optimal lot size for each price and picks the lot size that minimizes the overall cost.

**Step 1:** Evaluate the optimal lot size for each price $C_i, 0 \leq i \leq r$ as follows:

$$Q_i = \sqrt{\frac{2DS}{hC_i}}$$

**Step 2:** We next select the order quantity $Q_i^*$ for each price $C_i$. There are three possible cases for $Q_i$:

1. $q_i \leq Q_i < q_{i+1}$
2. $Q_i < q_i$
3. $Q_i \geq q_{i+1}$

Case 3 can be ignored for $Q_i$ because it is considered for $Q_{i+1}$. Thus, we need to consider only the first two cases. If $q_i \leq Q_i < q_{i+1}$, then set $Q_i^* = Q_i$. If $Q_i < q_i$, then a lot size of $Q_i$ does not result in a discount. In this case, set $Q_i^* = q_i$ to qualify for the discounted price of $C_i$ per unit.

**Step 3:** For each $i$, calculate the total annual cost of ordering $Q_i^*$ units (this includes order cost, holding cost, and material cost) as follows:

$$\text{Total annual cost, } TC_i = \left(\frac{D}{Q_i^*}\right)S + \frac{Q_i^*}{2}hC_i + DC_i \qquad )$$

**Step 4:** Select order quantity $Q_i^*$ with the lowest total cost $TC_i$.

Goyal (1995) has shown that this procedure can be further shortened by identifying a cutoff price $C^*$ above which the optimal solution cannot occur. Recall that $C_r$ is the lowest unit cost above the final threshold quantity $q_r$. The cutoff is obtained as follows:

$$C^* = \frac{1}{D}\left(DC_r + \frac{DS}{q_r} + \frac{h}{2}q_rC_r - \sqrt{2hDSC_r}\right)$$

Pricing structures that incorporate discounts for all unit quantities incentivize retailers to place larger orders in order to capitalize on the discounted prices. However, this practice contributes to an elevation in average inventory levels and the time it takes for products to move through the supply chain. The resultant increase in inventory prompts a reconsideration of the value that all unit quantity discounts bring to a supply chain.

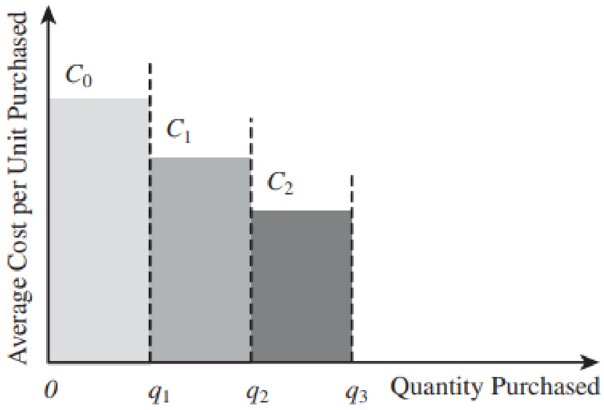


Figure 6 Average Unit Cost with All Unit Quantity Discounts

## 12.1 Calculations for All Unit Quantity Discounts

$q_i = Least\ number\ of\ qty\ order\ for\ price\ dicsount$

$C_i = Price\ w.r.t\ the\ qty\ range\ for\ discount$

$Q_i = Optimal\ Lot - size\ for\ each\ price$

$TC_i = Total\ Annual\ Cost\ for\ each\ price$

| Particulars | Break points of Qty Discounts | | | | | Price / Break points of Qty Discounts | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $q_0$ | $q_1$ | $q_2$ | $q_3$ | $q_4$ | $C_0$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
| Engine Components | 0 | 150 | 300 | 450 | 600 | 112000 | 110000 | 105000 | 95000 | 93500 |
| Suspension and Steering Parts | 0 | 75 | 150 | 225 | 300 | 61500 | 59500 | 53500 | 53000 | 48500 |
| Brake System Components | 0 | 150 | 300 | 450 | 600 | 37500 | 36600 | 34500 | 33000 | 29250 |
| Electrical Components | 0 | 150 | 300 | 450 | 600 | 26400 | 25040 | 24400 | 22400 | 19798 |
| Exhaust System Components | 0 | 150 | 300 | 450 | 600 | 45554 | 43939 | 39389 | 35890 | 33791 |
| Cooling System Parts | 0 | 75 | 150 | 225 | 300 | 31147 | 30001 | 28005 | 27764 | 23969 |
| Interior and Exterior Parts | 0 | 30 | 60 | 90 | 120 | 36900 | 33763 | 33295 | 30750 | 29564 |
| Rubber and Plastic Components | 0 | 150 | 300 | 450 | 600 | 11458 | 11156 | 11045 | 10333 | 9722 |
| Bearings | 0 | 150 | 300 | 450 | 600 | 6478 | 5965 | 5765 | 5115 | 4926 |

Table 11 All Unit Quantity Discounts - Qty Range and Resp. Cost

| Particulars | Optimal lot size for each price | | | | | Total Annual Cost | | | | | **Cost saving (%)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q0 | Q1 | Q2 | Q3 | Q4 | TC1 | TC2 | TC3 | TC4 | Total Annual Cost (EOQ Model) | |
| Engine Components | 333 | 336 | 344 | 362 | 365 | 6850147229 | 6538984621 | 5916643639 | 5823290524 | 6227818583 | -4.997% |
| Suspension and Steering Parts | 322 | 327 | 345 | 347 | 362 | 3790689329 | 3416421531 | 3375357630 | 3088841027 | 3185777993 | -3.043% |
| Brake System Components | 348 | 352 | 363 | 371 | 394 | 2774018506 | 2614908188 | 2501256904 | 2217124388 | 2273994332 | -2.501% |
| Electrical Components | 316 | 325 | 329 | 343 | 365 | 1654923188 | 1612650641 | 1480546644 | 1308702575 | 1322016728 | -1.007% |
| Exhaust System Components | 402 | 409 | 432 | 453 | 467 | 4622920216 | 4151580789 | 3775063425 | 3554329055 | 3682745531 | -3.487% |
| Cooling System Parts | 314 | 320 | 331 | 333 | 358 | 1845914581 | 1723111472 | 1708298324 | 1474880844 | 1538365007 | -4.127% |
| Interior and Exterior Parts | 325 | 340 | 342 | 356 | 363 | 2201301698 | 2170833565 | 2005024254 | 1927746193 | 1958160312 | -1.553% |
| Rubber and Plastic Components | 425 | 431 | 433 | 448 | 462 | 1157439885 | 1145924754 | 1072159900 | 1008793887 | 1037590164 | -2.775% |
| Bearings | 336 | 350 | 356 | 378 | 385 | 436577008 | 421943711 | 374384827 | 360559731 | 365989822 | -1.484% |

Table 12 All Unit Quantity Discounts - Optimal Lot size and Total Annual Cost

The comprehensive analysis of the All-Unit Quantity Discounts model versus the Economic Order Quantity (EOQ) model across a range of product categories offers detailed insights into the intricate balance between price discounts and potential increases in holding costs. For instance, in the case of Engine Components, the All-Unit Quantity Discounts model presents a notable 4.997% reduction in total annual costs when compared to the EOQ model. However, this cost saving comes at the expense of a substantial increase in the optimal lot size, rising from 333 units (EOQ model) to 365 units. This pattern is consistent across various product categories. Suspension and Steering Parts, for example, exhibit a 3.043% cost saving with a noticeable uptick in the optimal lot size from 322 to 362 units. Electrical Components showcase a more modest 1.007% reduction in total annual costs, yet there is a significant escalation in the optimal lot size from 316 to 365 units.

Examining Brake System Components, the All Unit Quantity Discounts model results in a 2.501% cost saving, accompanied by an increase in the optimal lot size from 348 to 394 units. The Exhaust System Components category demonstrates a 3.487% cost saving with a rise in the optimal lot size from 402 to 467 units. Each product category illustrates a unique balance between realizing cost savings through price discounts and the consequential impact on holding costs due to larger order quantities. These findings underscore the importance of a meticulous approach in evaluating the trade-offs between pricing strategies and optimal order quantities, emphasizing the need for a nuanced understanding of the specific dynamics within each product category to inform effective inventory management decisions.

**CONCLUSION – PART - I**

The comprehensive analysis of inventory management models, including the Economic Order Quantity (EOQ) model and the Q-type system, yields insightful conclusions that underscore the substantial cost-saving potential and operational efficiency enhancements achievable through their implementation. The comparison of the EOQ model against the current system without a specific model (w/o IM) reveals notable reductions in total holding costs across diverse product categories. For instance, in Suspension and Steering Parts, the EOQ model achieves a substantial 38.7% reduction in holding costs, while categories like Interior and Exterior Parts experience an impressive 86.2% decrease. The EOQ model demonstrates its effectiveness in optimizing order quantities and minimizing holding costs, contributing to enhanced supply chain efficiency.

However, the introduction of the Q-type system further refines the cost-saving landscape. The Q-type system consistently outperforms both the initial scenario without a specific model and the EOQ model. Noteworthy improvements are evident in various categories, such as Brake System Components (-58.7%), Cooling System Parts (-50.7%), and Suspension and Steering Parts (-49.6%). The overall impact is remarkable, with a 46.2% reduction in total holding costs when compared to the current system and a 14.6% improvement over the EOQ model. These findings highlight the advanced capabilities of the Q-type system in optimizing order quantities, reducing holding costs, and ultimately contributing to substantial cost savings.

The cost savings are not limited to holding costs alone; significant reductions in annual ordering costs are also observed. The EOQ model achieves a 46.2% reduction in total annual costs compared to the current system, with notable improvements in order quantities and associated costs. The Q-type system further refines these results, demonstrating an additional 14.6% reduction in total annual costs compared to the EOQ model. These findings underscore the holistic impact of advanced inventory management strategies in minimizing both holding and ordering costs, presenting a compelling case for their adoption to achieve substantial operational and financial efficiencies.

## PART B – CALCULATION FOR SAFETY STOCK

Safety stock refers to the extra inventory buffer carried to mitigate risk of stockouts due to uncertainties in supply and demand. Maintaining an adequate safety stock level is an important component of inventory management and plays a vital role in the supply chain (Wang et al. 2014). The main purpose of safety stock is to absorb variability in lead times and forecast errors. It acts as an insurance policy against stockouts when customer demand is higher than expected or when suppliers are not able to deliver on time [19]. By keeping safety stock, companies can ensure higher customer service levels and avoid costs associated with backorders and lost sales (Simchi-Levi et al. 2018). The safety stock acts as a buffer between the forecasted demand during lead time and the actual demand realized during that period [17]. The statistical variability in demand forecasts and lead times determines the required safety stock level. Companies aim to optimize safety stock to meet service level targets while avoiding excess inventory costs (Tempelmeier 2011). Appropriate safety stock placement in the supply chain also enables companies to efficiently manage the bullwhip effect. Strategically positioning buffers of inventory in later supply chain stages helps dampen order volatility amplification upstream (Wang et al. 2014). Safety stock enables companies to achieve high product availability while managing inherent uncertainties in supply chains. Proper safety stock management balances service levels with inventory costs and stability. It remains an essential component of effective supply chain operations [18].

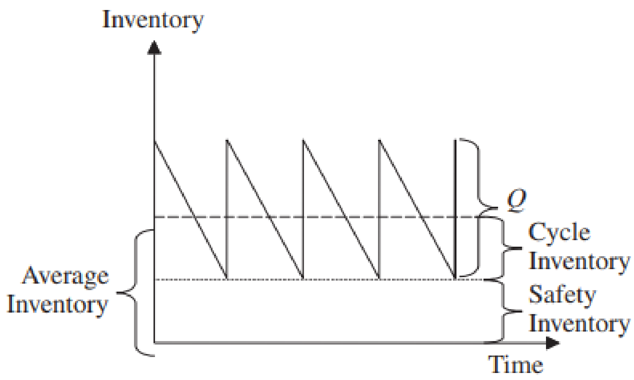


Figure 7 Inventory Profile with Safety Inventory

There are majorly two factors that determines the levels for safety stocks –

1. Desired Service Level

The desired service level represents the target probability of not stocking out, expressed as a percentage fill rate. It measures the ability to fulfill demand directly from stock on hand. Common service level targets range from 95-99% for finished goods (Chopra and Meindl 2016). Setting higher target service levels requires holding more safety inventory as a buffer against variability. Companies weigh the tradeoff between the cost of higher inventory versus the costs of stockouts and lost sales when setting desired service levels (Simchi-Levi et al. 2018). Critical products and components will have higher targets, while commodities can have lower service levels.

2. Variability in Supply and Demand

Variability in supply lead times and forecast error in predicting customer demand increases the amount of safety stock needed. Supply variability from factors like delivery delays, spoilage, and supplier reliability makes lead times less predictable. Demand forecast errors stem from factors like seasonality, product mix complexity, and lumpy order patterns. The higher the variability that needs to be buffered, the larger the required safety stock (Wang et al. 2014). Firms can reduce safety stocks by decreasing supply and demand uncertainty through strategies like improving forecasting, negotiating reliable supplier lead times, and increasing supply chain flexibility.

Data Inputs -

1. Month-wise demand of products
2. Lead-time products and month-wise

| Particulars | Engine Components | Suspension and Steering Parts | Brake System Components | Electrical Components | Exhaust System Components | Cooling System Parts | Interior and Exterior Parts | Rubber and Plastic Components | Bearings |
|---|---|---|---|---|---|---|---|---|---|
| Jan-23 | 790 | 808 | 962 | 838 | 1335 | 781 | 827 | 1317 | 929 |
| Feb-23 | 1555 | 1592 | 1894 | 1650 | 2629 | 1537 | 1627 | 2592 | 1829 |
| Mar-23 | 2208 | 2260 | 2689 | 2343 | 3733 | 2183 | 2311 | 3681 | 2596 |
| Apr-23 | 3373 | 3452 | 4107 | 3580 | 5702 | 3334 | 3530 | 5623 | 3966 |
| May-23 | 4196 | 4295 | 5110 | 4454 | 7095 | 4148 | 4392 | 6996 | 4935 |
| Jun-23 | 4353 | 4456 | 5302 | 4621 | 7361 | 4304 | 4556 | 7258 | 5120 |
| Jul-23 | 6014 | 6156 | 7324 | 6383 | 10168 | 5945 | 6294 | 10027 | 7073 |
| Aug-23 | 6157 | 6302 | 7498 | 6535 | 10410 | 6087 | 6444 | 10265 | 7241 |
| Sep-23 | 6984 | 7149 | 8506 | 7413 | 11808 | 6904 | 7310 | 11644 | 8214 |
| Oct-23 | 8741 | 8947 | 10645 | 9278 | 14779 | 8641 | 9148 | 14573 | 10280 |
| Nov-23 | 8769 | 8976 | 10679 | 9307 | 14826 | 8669 | 9178 | 14620 | 10313 |
| Dec-23 | 9052 | 9266 | 11024 | 9608 | 15305 | 8948 | 9474 | 15092 | 10646 |

Table 13 Monthly Demand - Product Category wise

| Particulars | Engine Components | Suspension and Steering Parts | Brake System Components | Electrical Components | Exhaust System Components | Cooling System Parts | Interior and Exterior Parts | Rubber and Plastic Components | Bearings |
|---|---|---|---|---|---|---|---|---|---|
| Jan-23 | 8 | 7 | 5 | 7 | 5 | 6 | 2 | 1 | 2 |
| Feb-23 | 8 | 7 | 5 | 7 | 5 | 6 | 2 | 1 | 2 |
| Mar-23 | 8 | 7 | 5 | 7 | 5 | 6 | 2 | 2 | 2 |
| Apr-23 | 8 | 7 | 5 | 7 | 5 | 6 | 2 | 2 | 2 |
| May-23 | 8 | 7 | 5 | 7 | 5 | 6 | 2 | 2 | 2 |
| Jun-23 | 8 | 7 | 5 | 7 | 5 | 6 | 3 | 2 | 2 |
| Jul-23 | 8 | 7 | 5 | 7 | 5 | 6 | 3 | 3 | 2 |
| Aug-23 | 8 | 8 | 6 | 7 | 5 | 7 | 3 | 3 | 2 |
| Sep-23 | 9 | 8 | 6 | 6 | 8 | 7 | 3 | 3 | 3 |
| Oct-23 | 9 | 8 | 6 | 6 | 8 | 7 | 3 | 3 | 3 |
| Nov-23 | 9 | 8 | 6 | 6 | 8 | 7 | 3 | 3 | 3 |
| Dec-23 | 9 | 8 | 6 | 6 | 8 | 7 | 3 | 3 | 3 |

Table 14 Monthly Lead Time - Product category wise

## 13. Calculation For Safety Stock

$D$: Average demand per month

$\sigma_D$: Standard Deviation in Avg Demand

Lead time (L) is the gap between when an order is placed and when it is received.

$L$: Average lead time per month

$\sigma_L$: Standard Deviation in avg lead time

Determining Demand Distribution Over L Periods

$$D_L = \sum_{i=1}^{L} D_i * \ \sigma_L = \sqrt{\sum_{i=1}^{L} \sigma^2 + 2 \sum_{i>j} \rho_{ij} * \sigma_I * \sigma_J}$$

$$D_L = D * L * \sigma_L$$

| Particulars | D | $\sigma_D$ | L | $\sigma_L$ | SC | SL | SL (K) | SS | $\sigma_D + \sigma_L$ | Bin size |
|---|---|---|---|---|---|---|---|---|---|---|
| Engine Components | 5183 | 2886 | 8.33 | 0.49 | 9812 | 0.95 | 1.64 | 16139 | 2886.52 | 43188 |
| Suspension and Steering Parts | 5305 | 2954 | 7.42 | 0.51 | 9637 | 0.95 | 1.64 | 15852 | 2954.76 | 39346 |
| Brake System Components | 6312 | 3515 | 5.42 | 0.51 | 10332 | 0.95 | 1.64 | 16995 | 3515.36 | 34188 |
| Electrical Components | 5501 | 3063 | 6.67 | 0.49 | 9634 | 0.95 | 1.64 | 15847 | 3063.80 | 36672 |
| Exhaust System Components | 8763 | 4880 | 6.00 | 1.48 | 14821 | 0.95 | 1.64 | 24378 | 4881.14 | 52575 |
| Cooling System Parts | 5123 | 2853 | 6.42 | 0.51 | 8859 | 0.95 | 1.64 | 14572 | 2853.60 | 32875 |
| Interior and Exterior Parts | 5424 | 3021 | 2.58 | 0.51 | 7280 | 0.95 | 1.64 | 11974 | 3021.13 | 14013 |
| Rubber and Plastic Components | 8641 | 4812 | 2.33 | 0.78 | 11344 | 0.95 | 1.64 | 18660 | 4812.69 | 20162 |
| Bearings | 6095 | 3394 | 2.33 | 0.49 | 8002 | 0.95 | 1.64 | 13162 | 3394.68 | 14222 |

Table 15 Calculating Safety Stock and Bin Size – Current Process

SC: Combined Std. Dev

SL: Stock Level

SL (k): z for risk free =NORMSINV(SL)

SS: Safety Stock = SC*SL(k)

## 14. Evaluating Safety Stock Inventory Given at Inventory Policy

ROP = Reorder Point

Q = Average Lot Size

Safety Stock = ROP – D*L

Cycle Inventory = Q/2

Average Inventory = cycle inventory + safety inventory

Average flow time = average inventory / throughput

| Particulars | Engine Components | Suspension and Steering Parts | Brake System Components | Electrical Components | Exhaust System Components | Cooling System Parts | Interior and Exterior Parts | Rubber and Plastic Components | Bearings |
|---|---|---|---|---|---|---|---|---|---|
| D | 5183 | 5305 | 6312 | 5501 | 8763 | 5123 | 5424 | 8641 | 6095 |
| $\sigma_D$ | 2886 | 2954 | 3515 | 3063 | 4880 | 2853 | 3021 | 4812 | 3394 |
| L | 8.33 | 7.42 | 5.42 | 6.67 | 6 | 6.42 | 2.58 | 2.33 | 2.33 |
| $\sigma_L$ | 0.49 | 0.51 | 0.51 | 0.49 | 1.48 | 0.51 | 0.51 | 0.78 | 0.49 |
| Correlation Coeff | 0.956217 | 0.973248 | 0.771434 | 0.756286 | 0.77023 | 0.780311 | 0.775993 | 0.777491 | 0.874384 |
| Reorder Point | 48370 | 44067 | 38291 | 41073 | 58884 | 36820 | 15694 | 22581 | 15928 |
| Lot Size | 346 | 271 | 312 | 363 | 350 | 266 | 129 | 394 | 331 |
| Safety Stock | 5183 | 4721 | 4103 | 4401 | 6309 | 3945 | 1682 | 2419 | 1707 |
| Cycle Inventory | 173 | 136 | 156 | 182 | 175 | 133 | 65 | 197 | 166 |
| Avg Inventory | 5355 | 4857 | 4259 | 4582 | 6484 | 4078 | 1746 | 2617 | 1872 |
| Avg Flow Time | 1.033364693 | 0.91554405 | 0.6747206 | 0.833026246 | 0.73998563 | 0.795992982 | 0.321899 | 0.302820559 | 0.307172 |

Table 16 Evaluating Safety Stock Inventory Given at Inventory Policy

This model evaluates the minimum safety stock if compared to the safety stock achieved in Table 15

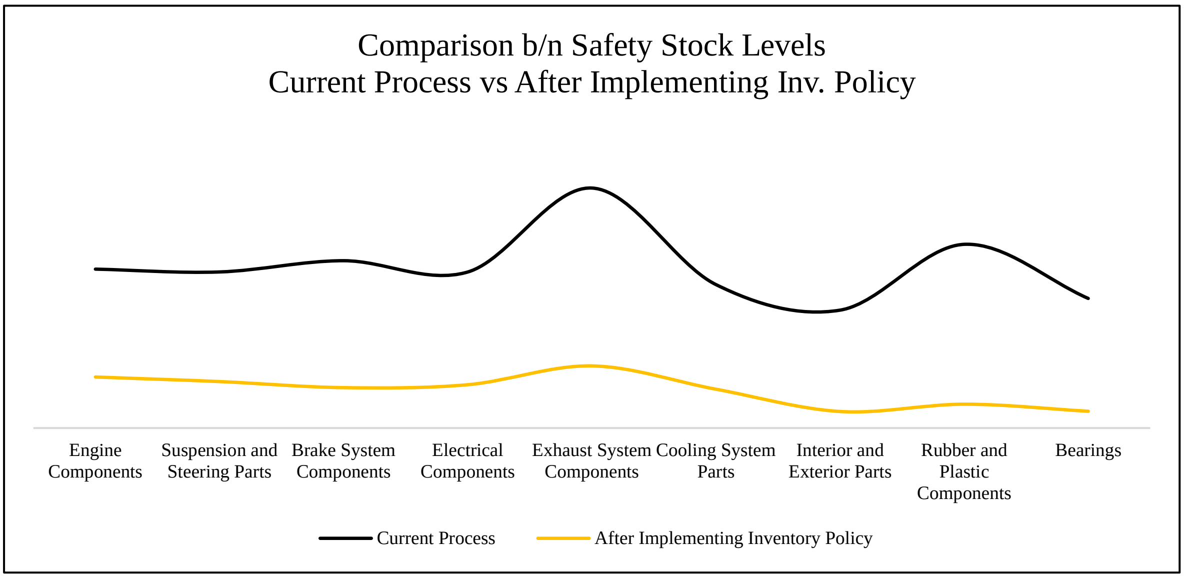



Figure 8 Comparison b/n Safety Stock Levels

The implementation of the new inventory replenishment model has resulted in a substantial transformation in safety stock levels across various product categories, showcasing significant improvements over the current process. The detailed analysis reveals a remarkable overall reduction of 76.64% in safety stock quantities after adopting the new inventory policy.

In the case of individual product categories, the impact is noteworthy. For instance, Engine Components experienced a staggering 67.89% reduction in safety stock, decreasing from 16,139 units under the current process to 5,183 units with the implemented inventory policy. Suspension and Steering Parts saw a drastic 70.21% reduction, decreasing from 15,852 units to 4,721 units. The Brake System Components category witnessed a substantial 75.86% reduction, with safety stock decreasing from 16,995 units to 4,103 units.

The financial implications of these changes are substantial. The company is now able to operate with significantly lower inventory levels, leading to a potential release of tied-up capital. The reduction in safety stock not only indicates improved inventory management efficiency but also has a direct impact on the company's financial health. The financial benefits are evident as excess inventory carries holding costs, and the reduction in safety stock directly contributes to cost savings. Furthermore, the operational efficiency gains are noteworthy. The drastic reduction in safety stock implies a higher level of confidence in the accuracy of demand forecasting and a more responsive and streamlined inventory replenishment process. This, in turn, allows the company to operate with leaner inventories while maintaining service levels, leading to improved overall supply chain performance.

**LIMITATION:**

While implementing the EOQ model, there are various limitation but considering and reframing the model will give significant results.

Limitation of EOQ Model –

1. The model assumes a constant and uniform demand over time, which may not accurately reflect real-world demand fluctuations.

2. EOQ assumes a constant ordering cost, overlooking potential variations in costs related to ordering.

3. The model does not account for quantity discounts, which are common in many business scenarios.

4. EOQ assumes that the entire order is delivered at once, which may not align with the logistics of certain industries.

5. The model does not incorporate variations in lead time, which can impact the actual order quantity needed.

6. EOQ assumes that there are no stockouts during the replenishment cycle, which may not hold true in dynamic environments.

7. The model assumes fixed holding and ordering costs, neglecting potential fluctuations in these costs over time.

8. EOQ is designed for a single product and may not be directly applicable in situations involving multiple products.

9. The model does not consider inflation or interest rates, which could impact the actual costs associated with holding and ordering inventory.

10. EOQ does not account for external factors such as market trends, technological advancements, or changes in supplier behavior.

11. Focusing solely on minimizing costs, as advocated by the EOQ model, may not align with broader strategic objectives.

12.Implementing the EOQ model can be complex, requiring accurate and up-to-date data, which may not be readily available in all business environments.

## CONCLUSION:

The research successfully achieved its primary objectives, employing mathematical inventory management models to optimize inventory levels and orders, thereby minimizing total holding and ordering costs. Implementing the Economic Order Quantity (EOQ) model led to an impressive 46.2% reduction in total holding costs, showcasing its efficacy in cost savings. The Q-type system surpassed expectations with a 14.6% improvement in total costs, emphasizing its role in enhancing inventory efficiency. Additionally, the Lots Are Ordered and Delivered Jointly model achieved a remarkable 76.64% reduction in safety stock, further contributing to cost reduction and operational efficiency. These findings not only meet the research objectives but also provide valuable insights for managers in the auto ancillary industry, offering practical guidance for implementing inventory optimization techniques and emphasizing the competitive advantages derived from improved inventory management and economic order quantities.

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