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Optimization of Inventory Control and Procurement strategies in Battery Supply Chain

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KTH Industriell Teknik och Management	Examensarbete **Optimering av lagerkontroll och inköpsstrategier i batteriförsörjningskedjan** Vishal Kumar Prakash	
Godkänt 2024	Examinator Magnus Wiktorsson	Handledare Daniel Tesfamariam Semere
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Sammanfattning

Examensarbete fokuserar på att optimera lagerhantering och anskaffning av råvaror i en tillverkningsindustri som producerar väsentliga råvaror för batteriproduktion. De avhandlingen syftar till att studera olika lagerstyrnings- och upphandlingsstrategier som kan hjälpa Organisation sänker lagringskostnaderna för inventeringen och ökar utbudets anpassningsförmåga kedja till plötsliga förändringar i marknadens efterfrågan. På grund av begränsningarna, studera trender för alla råvarorna var utmanande. Därför, enligt ABC-klassificeringen av material, alla råvaror som användes för direkt produktion klassificerades i olika klasser utifrån flera faktorer. EOQ beräknades genom att ta hänsyn till kostnaderna för transport och beställning kostnader, medan JIT-modellen fokuserade på att sänka innehavskostnaderna genom täta leveranser. Resultatet av denna avhandling visar en potentiell kostnadsminskning på 11,63% och 20,84% om JIT Modellen implementerades för Material-A och Material-B jämfört med nuvarande tillstånd. En detaljerad studie av införlivandet av säkerhetslager anses vara ett potentiellt framtida arbete av denna forskning. Slutligen gav avhandlingen de bästa rekommendationerna som kan implementeras i framtiden för att förbättra lagerhanteringen och öka maximal upphandlingseffektivitet hos organisationen.

Nyckelord

Lagerhantering, ekonomisk orderkvantitet (EOQ), Just-in-Time (JIT), anskaffning, Supply Chain

KTH Industrial Engineering and Management	Master of Science Thesis **Optimization of Inventory Control and Procurement strategies in Battery Supply Chain** Vishal Kumar Prakash	
Approved 2024	Examiner Magnus Wiktorsson	Supervisor Daniel Tesfamariam Semere
	Commissioner KTH	Contact person Ove Bayard

Abstract

The thesis focuses on optimizing inventory management and procurement of raw materials in a manufacturing industry that produces essential raw materials for battery production. The thesis aims to study various inventory control and procurement strategies that can help the Organization lower the holding costs of the inventory and increase the adaptability of the supply chain to sudden changes in market demand. Due to the constraints, studying the trends of all the raw materials was challenging. Therefore, according to the ABC classification of materials, all the raw materials used for direct production were classified under different classes based on several factors. The EOQ was calculated by considering the costs of transportation and ordering costs, while the JIT model focused on lowering the holding costs through frequent deliveries. The result of this thesis demonstrates a potential cost reduction of 11.63% and 20.84% if the JIT model was implemented for Material-A and Material-B when compared to that of current state. A detailed study of the incorporation of Safety stock is considered to be a potential future work of this research. Finally, the thesis provided the best recommendations that can be implemented in the future to improve inventory management and enhance maximum procurement efficiency at the organization.

Keywords:

Inventory Management, Economic Order Quantity (EOQ), Just-in-Time (JIT), Procurement, Supply Chain

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Lastly, I would also like to thank my family and friends for their unwavering support and encouragement during the thesis journey.

Vishal Kumar Prakash

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Table of Contents

Acronyms

EOQ Economic Order Quantity
JIT Just-in-Time
ERP Enterprice Resource Planning

List of Figures

List of Tables

1. Introduction

This chapter provides information about the background of the company (Company-A) and subsidiary company (Company-B) in Sweden. The main aim and purpose of this research thesis are clearly explained in this chapter. A brief description of the research question and limitations of this project are also explained in this chapter.

1.1 *Company Background*

Company-B, is a subsidiary business unit of Company-A, was established in Sweden during 2019. Drawing on the extensive experience from the Company-A in Battery materials, Company-B produces one of the essential semi-finished products for the mass production of Li-ion Batteries. The factory operates two production lines at full capacity, with a maximum yearly output of approximately 3,000 tonnes. This semi-finished product is then supplied to customers all over Sweden and the rest of Europe to manufacture Li-ion batteries. With the increasing demands, Company-B plans to increase the number of production lines to meet the increasing customer demand, to play a significant role in the development of green and environmentally friendly batteries.

1.2 *Thesis Purpose*

Company-B is expanding manufacturing capacity to meet increasing demand for its products. To support this growth, it is critical to optimise the inventory management system and raw material procurement from different vendors. Efficient management of inventory is critical for preventing stockouts, lowering holding costs, and ensuring a continuous production flow. The research attempts to create a thorough raw material procurement plan that is in line with the company's production goals and market demand.

1.3 *Thesis Objectives*

The main objectives of this thesis are listed below:

- Analysing the current state of inventory management and purchasing process at Company-B and identifying the areas of improvement.
- Developing strategies for optimizing the raw material procurement to ensure reliable supply while lowering the costs and lead time.
- To investigate EOQ and JIT models that maintain optimal stock levels and minimize the risk of stockouts and maintaining excessive inventory.

1.4 *Research Questions*

To address the objectives of this Master thesis, the following research questions have been formulated:

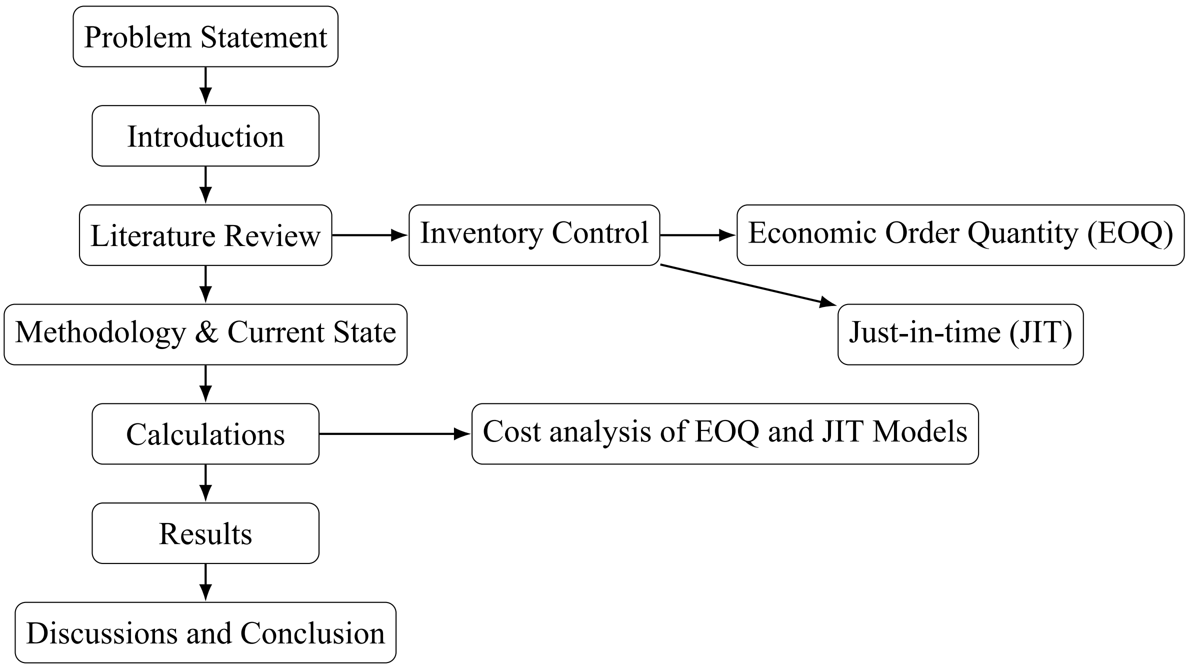
- What are the different procurement strategies Company-B can implement to optimize the supply of raw materials?
- How can the overall performance of the supply chain differ if those strategies are implemented?

1.5 *Limitations*

The following limitations have been established to ensure the thesis remains focused on its core objectives.

- The scope of this thesis focuses only on EOQ and JIT models.
- The thesis focuses exclusively on purchasing strategy of direct materials for production (raw materials), but not on procurement of services or other indirect materials.
- The research is restricted by the availability of data and Company-B's confidentiality protocols, which may prevent access to information that is highly sensitive.

1.6 *Structure of the Thesis*



2. Literature Review

This chapter provides a summary of the literature study, a review of the existing concepts from various research articles.

2.1 *Inventory Management in Manufacturing*

Investing in inventory ties up a significant portion of a company's working capital and represents a large share of its total assets. To enhance return on investment, organization often seeks to improve inventory turnover, ensuring economic efficiency. Effective inventory management plays a crucial role in reducing costs, accelerating response times, and providing greater flexibility to meet customer needs.[1]

Inventory refers to a comprehensive list of movable items, including raw materials, work-in-progress, and semi-finished goods, necessary for production. It is a vital component of any manufacturing industry. Inventory is important for managing fluctuations in demand or supply that could otherwise disrupt production schedules. It ensures uninterrupted manufacturing, maximizing labour and machinery efficiency while reducing costs. As a result, inventory is crucial for the smooth operation of any organization and essential for its long-term viability.[1]

Effective inventory management is crucial for manufacturing industries of all sizes. Making informed decisions about when to order materials, how much to produce, which procurement strategies to use, and ensuring optimal quality and pricing becomes much easier with proper inventory control. Smaller organizations can often manage inventory manually using basic tools like Excel, allowing them to track orders and stock levels efficiently. However, larger organizations face greater complexity, making manual tracking impractical. To streamline operations, they rely on advanced software systems such as Enterprice Resource Planning (ERP).[2]

Figure 2.1: Objectives of Inventory Management [3]

Efficient inventory management offers numerous goals and benefits, as illustrated in figure 2.1. By accurately determining the right quantity of materials to order, overstocking and dead stock can be avoided, which reduces storage and holding costs. Proper inventory planning ensures that excess cash isn't tied up in surplus stock, allowing it to be allocated toward other areas of the company's growth and development.[1]

Therefore, managing the hazards of excess inventory and stockouts is especially difficult for businesses dealing with complicated supply networks and manufacturing processes. Just-in-Time (JIT) and Economic Order Quantity (EOQ) are two popular inventory management techniques used to strike the right equilibrium. These models, which are popular for maximizing inventory efficiency, will be covered more in detail in a later section of this report.

2.2 *Economic Order Quantity (EOQ) Model*

A key decision for any manufacturing company, regardless of its size or policies, is selecting the right inventory management and control method. One of the most widely used techniques for this purpose is the Economic Order Quantity (EOQ) model.

In order to find the ideal order quantity that minimizes all inventory expenses, including ordering and holding costs, one must apply the Economic Order Quantity (EOQ) model, a basic technique in inventory management.[4] It assists businesses in balancing the costs associated with placing orders and keeping inventory. By optimizing order sizes, EOQ reduces costs and works especially well in contexts with steady demand. In order to adapt to various purchasing methods, the model can also take into account quantity discounts. Items with high demand and consistent consumption benefit most from EOQ.[5]

The EOQ model is highly effective for determining the optimal order quantity, but certain assumptions must be considered. It assumes that the ordering cost per order and the holding cost of inventory are constant and fixed. Additionally, the overall carrying cost is directly proportional to the average inventory level, and the annual demand for a product is known and remains constant. In EOQ purchasing, it is also typically assumed that the delivery cost decreases as the order quantity increases, as supplier's costs tend to decrease with larger lot sizes.[5]

In the EOQ model, manufacturers place multiple orders with their suppliers throughout the financial year, ensuring that each order is large enough to meet production needs for a specific period. The model calculates the optimal order quantity that minimizes the total annual cost, which includes both ordering and holding costs. This optimal quantity can be determined through a mathematical formula.[6] Therefore, based on the assumptions, total annual cost of an item or product (TC_E) in an EOQ model is the sum of ordering cost for particular order, holding cost of that order and purchasing cost. It can be written in an equation as below:

$$TC_E(Q) = \frac{kD}{Q} + \frac{Qh}{2} + P_E D \qquad [6]$$

where,

TC_E = Total annual cost in EOQ model ($)

D = Demand (Quantity/year)

Q = unknown size of the order or lot size

k = fixed cost of placing an order ($)

h = annual inventory holding cost per kg ($/kg/year)

P_E = cost price of each unit in EOQ model ($/kg)

The carrying or holding cost is further broken down as cost of storing goods in the inventory, taxes paid for the goods, insurance for the inventory goods, risk of damaging the goods in the inventory and its obsolescence's. It is also noted in many cases, that the cost of transportation and administrative costs comes under fixed ordering cost.

The above formula can be used only when we know the optimal order quantity Q* which would help to minimise the total cost. Derivation of the optimal order quantity Q* from the cost function is shown in the steps below:

Step 1: Defining the total cost function

The total cost function consists of three main costs.

1. **Ordering Cost:** $\frac{kD}{Q}$ which represents the cost of placing an order where k is the fixed cost per order, D is the annual demand, and Q is the unknown size of the order or Lot size.
2. **Holding Cost:** $\frac{Qh}{2}$ which represents the cost of holding the inventory, where h is the cost of holding per item and $Q/2$ is the average inventory level.
3. **Purchasing Cost:** $P_E D$ which represents the cost of purchasing goods, where P_E is the price per item and D is the total demand.

Therefore, total cost is written as:

$$\boxed{TC_E(Q) = \frac{kD}{Q} + \frac{Qh}{2} + P_E D \qquad .....(1) \qquad [6]}$$

Step 2: Differentiating the Total Cost Function

In order to know the quantity that minimizes the total cost, the first derivative of the total cost function is calculated with respect to Q. To find the optimal Q, the resulting first derivative of the total cost function has been equated to 0. On solving the equation by multiplying Q^2 on both sides, the Optimal Order Quantity Q^* can be written as:

$$Q^* = \sqrt{\frac{2kD}{h}} \quad .....(2) \quad [6]$$

In order to derive the total cost at Optimal Q^*, the above equation is substituted in the total cost function to express the cost at the optimal order quantity. Substituting Q^* value into the ordering and holding cost terms helps to find the total cost at the optimal order quantity. It can be written as:

$$TC_E(Q^*) = \sqrt{2kDh} + P_E D \quad .....(3) \quad [6]$$

Figure 2.2: EOQ Cost Variation Graph [7]

The balance between ordering, holding and total costs is depicted by the EOQ model in Figure 2.2. The cost of maintaining more inventory is reflected in the holding costs, which rise linearly with order size. On the other hand, since fewer orders are required when the order quantity is higher, the ordering expenses decrease. Ordering and holding charges add up to the overall cost. The intersection of these two expenses, which indicates the lowest overall cost, is the ideal order quantity, or EOQ. Therefore, for manufacturing companies, finding this balance is crucial for maintaining efficient inventory management while minimizing overall costs associated.[8]

2.3 *Just-in-Time (JIT) Model*

Just-in-Time (JIT), initially developed by Japanese engineer and businessman Taiichi Ohno, is also known as the ”Toyota Production System”[9]. JIT is an inventory management technique aimed at continuously reducing and eliminating all forms of waste. By implementing this approach, many Japanese companies, including Toyota, have operated with minimal inventory while striving to produce high-quality products and achieve efficient productivity.[10] The core principle of this model is to purchase and produce products only what is needed and when there is the real necessity of that product, allowing the companies to have less inventory in their storage. JIT is also a technique used to reduce holding costs and increase overall turnover, making it a highly effective strategy for enhancing operational efficiency in manufacturing industries.[11]

The core of just-in-time (JIT) procurement is acquiring commodities in small lots from one or a few vendors on schedule, paying consistent prices, and upholding quality standards. Reducing the number of suppliers is a crucial component of this technique. Excessive handling of multiple suppliers might divert the buyer’s attention from other crucial duties like improving the quality of the materials and looking for cost-cutting opportunities.[12] JIT promotes a strong cooperative connection between suppliers and buyers, which is advantageous to both because it focuses on ongoing improvements and shared returns. The fundamental ideas of JIT purchasing are adhered to in this method by segmenting large orders into smaller, more regular deliveries with a chosen set of suppliers. As Jae-Dong Hong emphasized, ”Place one large order for all your requirements and receive deliveries in the smallest conceivable lot size,” capturing the fundamental goal of JIT procurement.[12]

It is one of the good models to incorporate in the procurement strategy of any manufacturing industry. Once the JIT comes into effect from the buyer’s side, it is strongly encouraged to for the suppliers to implement JIT in their production sites to reduce cost, improve quality and become more responsive to the buyer.[5] Once if the supplier starts using JIT, it will be economically advantage for the supplier as the delivery will be frequently of smaller lot sizes which in turn saves them a lot of money on their inventory holding cost.[13] Due to this savings, the supplier could pass some of their savings to Company-B by offering the materials at a considerably lower price. On this perspective, it is economically better for the company to choose JIT as it reduces the purchasing price/item, holding cost and ordering cost.[12]

Just as with the EOQ model, the Just-in-Time (JIT) model requires certain assumptions to be made in order to calculate costs. According to the JIT concept, procuring materials from the suppliers who are close to the buyer’s facility can drastically cut down on traditional EOQ model costs like holding costs and some part of ordering costs. However, additional expenses such as transportation, inspection, and storage are taken care of by the vendors and those costs are subsequently transferred to the purchaser and included in the purchase price, which affects the total cost of procurement.[6] Thus, the total annual cost of the JIT system (TC_J) is calculated by multiplying the unit price P_J, which remains constant, and the annual demand D.

$$TC_J = P_J D \qquad .....(4) \qquad [5]$$

where,

TC_J = Total annual cost in JIT model ($)

D = Demand (Quantity/year)

P_J = Cost price of each unit in JIT model ($/kg)

2.4 *Comparison of EOQ and JIT Models*

The comparison of both Economic Order Quantity model and Just-in-time model is listed in the tabular column below:

Aspect	**Economic Order Quantity (EOQ)**	**Just-in-time (JIT)**
Objective of the model	Minimizing the total cost by placing the order at the Q* point.[8]	Minimizing the total cost by placing the order only when it is necessary and receiving in smaller lot sizes.[5]
Stock Levels	Maintains certain optimal level to meet the production demands.[14]	This model focuses on keeping the inventory as low as possible, often close to zero.[11]
Purchase Quantity	Orders are placed at fixed optimal quantity to minimize the overall costs and to satisfy the production demands.[6]	Orders are placed in bulk, but receive them in smaller lots , which in turn leads to potential saving in Holding and some part of ordering costs.
Supplier Management	In this model, the company can have many vendors, even as a short-term contract.[13]	In this model, the company should plan to have very few reliable suppliers and focus for a long-term contract.[12]
Inventory Holding Cost	Holding cost increases linearly with the order size and EOQ tries to minimize this to result in lower total costs.[8]	Holding costs in this model is almost eliminated as materials are received just in time for production.[12]

Aspect	Economic Order Quantity (EOQ)	Just-in-time (JIT)
Supplier Location	The supplier can be located anywhere but it's the responsibility of the buyer to plan well in ahead regarding the order lead time.	It is recommended that the suppliers is located close to the buyers locations as the order are delivered more frequently,[6] which in turn reduces the transportation and holding cost for both the buyer and supplier
Risks	In this model, if there is a sudden change in the market demand, the procured material has the chance of getting obsolete.[15]	Even if there is a change in the market trend, this model allows both the supplier and buyer to quickly adapt to the changes and the risk of obsolescence is relatively very low.
Implementation Challenges	This model is easy to implement as it requires only stable forecasted demand to determine the order quantity.[15]	Implementation is bit complex when compared with that of EOQ, as it required accurate demand forecast, excellent supplier coordination and good inventory tracking.[13]

Table 2.1: EOQ and JIT Models

In order to know which model should be implemented in Company-B, it is necessary to know the cost difference between these two models. Let Z be the cost difference between EOQ and JIT, then:

$$Z = TC_E - TC_J$$

$$Z = \sqrt{2kDh} - (P_J - P_E) \cdot D \qquad .....(5)$$

On rearranging the above equation by multiplying and dividing the square root term by P_E and factoring the second term with P_E:

$$Z = \frac{2kDh}{P_E} \cdot P_E - \left(P_E \cdot \left(\frac{P_J}{P_E} - 1\right)\right) \cdot D$$

Thus,

$$\boxed{Z = \tfrac{2kDh}{P_E} \cdot C - \left(\tfrac{P_J}{P_E} - 1\right) \cdot C \qquad .....(6) \qquad [6]}$$

Where C represents the general cost expression of EOQ model $C = D \cdot P_E$. The first term on the right side of the equation (6) represents the inventory holding costs and ordering costs under the Economic Order Quantity model. The second term on the right-hand side represents the difference in the material costs between JIT and EOQ model. This above equation helps to determine which model to be preferred. Farzaneh emphasized that EOQ model should be preferred if the value of $Z < 0$ and JIT model should be preferred if the value of $Z \geq 0$.[6] After the comparison of both the models, it is also very important to know the maximum price under JIT model in which the buyer can purchase the material and still be benefited for choosing JIT over EOQ. In order to obtain the desired solution, equation (5) is equated to 0 and $P_J Max$ is derived as follows:

$$\sqrt{2kDh} - (P_J - P_E) \cdot D = 0$$

On solving,

$$\boxed{P_J Max = \sqrt{\frac{2kh}{D}} + P_E \qquad \text{.....(7)} \qquad [6]}$$

Z will become negative, if the unit price go beyond $P_J Max$ which in turn make EOQ a better solution for managing the inventory at lower costs.

3. Methodology and Current State

This chapter describes the current state of the company's raw material procurement process and how those materials are grouped in different classes.

3.1 *Overview of Inventory & Procurement System*

Company-B's inventory and procurement system plays a crucial role in supporting its manufacturing operations by ensuring the availability of raw materials and components needed for production. The company employs a hybrid approach, combining traditional manual tracking methods alongside inventory management software such as Enterprise Resource Planning (ERP) to monitor stock levels. The procurement process is driven by production forecasts, supplier lead times, and historical consumption patterns, with the goal of balancing material availability. Suppliers are chosen based on factors such as cost, reliability, and lead times, with long-term relationships built to ensure consistency in supply.

While the system is designed to avoid stockouts and production delays, it faces several operational challenges. These include difficulty in accurately predicting fluctuations in demand, which can lead to overstocking or understocking of materials. Additionally, the current process lacks a fully integrated data-driven approach, which limits its responsiveness to sudden market changes or production adjustments. As a result, inventory holding costs can rise, and procurement inefficiencies may impact overall production flow. This research aims to identify different strategies to tackle these challenges and explore opportunities for streamlining the system to enhance both efficiency and cost-effectiveness.

3.2 *Analysis of Inventory Management Practices*

At Company-B, the inventory management practices are driven by a strong focus on ensuring that sufficient raw materials are always available to meet production demands. The company's primary objective is to avoid any potential disruptions in manufacturing due to material shortages. Consequently, the inventory system is designed to prioritize material availability, often without considering the implications of excess inventory. This approach ensures smooth production flow but leads to the accumulation of surplus stock, resulting in higher holding costs and inefficiencies in resource allocation. Since the company does not actively monitor or manage excess inventory, there is little attention given to optimizing stock levels or implementing cost-saving strategies. This represents an opportunity for improvement, as a more balanced approach could help Company-B meet production demands while also minimizing unnecessary inventory costs.

3.3 *Raw Material Classification*

The literature review clearly highlights the critical role of inventory management in a company's overall profitability. To manage inventory efficiently, it is essential to categorize materials, as companies often maintain a diverse inventory of raw materials to meet production demands. One effective approach to managing large inventories is by grouping them into relevant categories. This grouping allows for better monitoring and control of inventory performance. Therefore, In this research the widely recognized "ABC Classification" technique, developed in the 1950s, has been implemented for classifying inventory in different classes.

This classification approach acknowledges that not all inventory holds equal value when viewed from the perspective of the final product. Materials are categorized based on their value, volume of usage, and their importance in the final product. Class ‘A’ items are considered the most critical due to their high value and significant impact on production. Class ‘B’ items are important, but rank lower than Class ‘A’ while still being more crucial than Class ‘C’ items. Mitchell highlighted that the top 20% of inventory should be classified as Class ‘A’, the next 30% as Class ‘B’, and the remaining 50% as Class ‘C’, ensuring a structured and efficient inventory management system.[16]

Class ‘A’ – Represent 20% of the materials and account for highest 5% of dollar value.
Class ‘B’ – Comprise 30% of the materials and contribute to next 20% of the dollar value.
Class ‘C’ – Remaining 50% of the materials, accounting for the bottom 75% of dollar value.

A similar technique was applied to categorize the inventory materials of Company-B. The classification was based on several factors, including material usage, lead time, quality, dollar value, and the item's significance to the final product. After thorough analysis and careful consideration of these criteria, the materials were classified into two categories: Class 'A' and Class 'C'.

Material-A has been classified under Class 'A' due to its critical role in both production and customer satisfaction, despite being used in smaller quantities. Its viscosity is essential for maintaining the quality of the final product and ensuring temperature resistance, making it the most important raw material in the manufacturing process. From a customer perspective, its contribution to conductivity, which is a key product specification, further emphasizes its importance. Additionally, its function as a binding agent during the coating process highlights the value of this material. Material-A is one of the most expensive materials which company purchases. Therefore, effective management and control are crucial for optimizing costs and maintaining quality and ensuring customer satisfaction. Hence Material-A has been classified under class 'A'.

Material-B has been classified under Class ’C’ because its role is primarily as a solvent with limited impact on the final product’s quality. While its quality is considered during production, its contribution is minimal compared to Material-A. During the coating process, Material-B evaporates and does not add significant value to the customer’s final product. Additionally, its cost is considerably lower than that of Material-A. Hence Material-B has been classified under Class ‘C’.

The company purchases Material-A from Supplier A whose base location is in China and Material-B is procured from Supplier-B also from China and all the costs and assumptions were based on this geographical location.

Supplier	**Supplier A**	**Supplier B**
Supplier Location	China	China
Class	Class ‘A’	Class ‘C’
Materials	Material-A	Material-B

Table 3.1: Types of Materials

3.4 *Purchase and Demand of Material-A*

Month	**Quantity of PO (in Kgs)**	**Monthly Purchase (in kgs)**	**Monthly Demand (in Kgs)**	**Ending Inventory (in Kgs)**	**Mode of Transport**
Aug-23	1120	4760	3397	1363	Air
	840				Air
	1120				Air
	840				Air
Sep-23	2800	4480	2030	3813	Ocean
	1680				Air
Oct-23	1680	1680	3700	1793	Ocean
Nov-23	2520	2520	3370	943	Ocean
Dec-23	1960	1960	1820	1083	Ocean
Jan-24	5600	8400	700	8783	Ocean
	2800				Ocean
Feb-24	7840	7840	1400	15223	Ocean
Mar-24	0	0	2760	12463	-
Apr-24	0	0	3430	9033	-
Jun-24	280	840	2940	4623	Air
	560				Air

Month	Quantity of PO (in Kgs)	Monthly Purchase (in kgs)	Monthly Demand (in Kgs)	Ending Inventory (in Kgs)	Mode of Transport
Jul-24	5600	11200	4970	10853	Ocean
	5600				Ocean
Total		**45220**	**34367**	**76696**	
Frequency		**18**	**12**	**12**	
Average		**2512**	**2864**	**6391**	

Table 3.2: History of Material-A purchases, demand and Ending Inventory

From the table 3.2, it is evident that the purchasing volume of Material-A consistently exceeds actual demand. Additionally, the data reveals that Material-A orders are not evenly distributed across all transactions. Notably, 5 out of the 10 orders were placed below the required demand level. The significant variation between the quantities ordered and the actual demand highlights the need for improved material planning to ensure more efficient procurement processes.

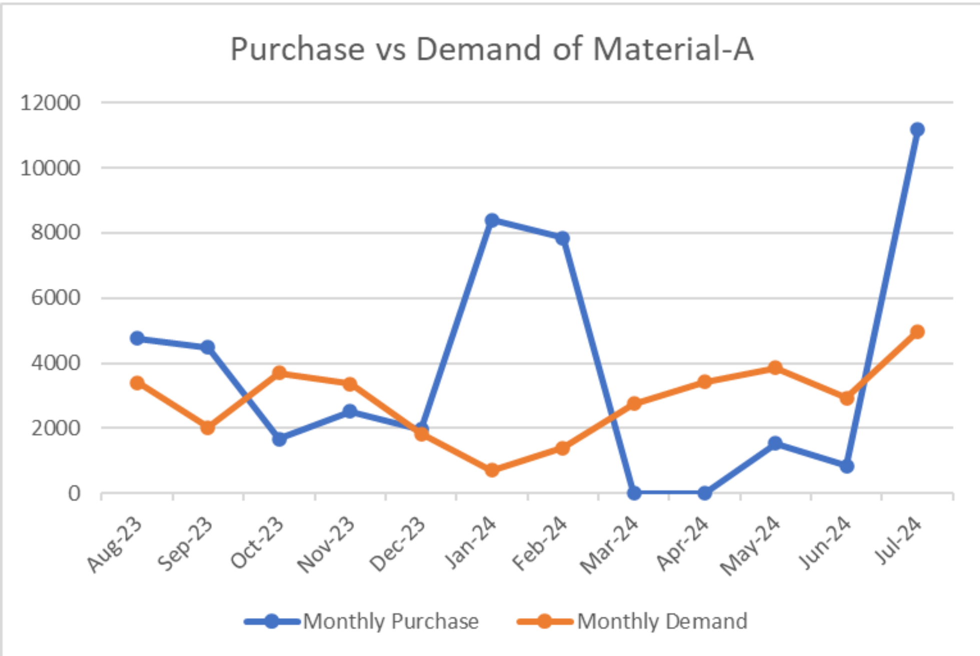


Figure 3.1: Trend of Purchasing vs Demand of Material-A

From the figure 3.1 "Purchase vs Demand" graph illustrates the relationship between monthly purchases and demand from August 2023 to July 2024. Throughout most of this period, demand remains relatively stable, hovering around 2,864 kgs per month. However, purchasing patterns fluctuates significantly. Notably, there are two major purchases: one in January 2024, where purchase rise to around 8,400 kgs, and another in July 2024, which recorded the peak at approximately 11,200 kgs, both significantly exceeding demand. In contrast, purchases drop sharply in March and April 2024, falling well below the consistent demand levels. This inconsistency suggests that the purchasing strategy may not be well aligned with actual demand, potentially leading to periods of both excess inventory and stock shortages. A more consistent approach to purchasing, closely aligned with demand patterns, could help optimize the company's inventory management.

3.5 *Purchase and Demand of Material-B*

Month	**Monthly Purchase (in Tonnes)**	**Monthly Demand (in Tonnes)**	**Ending Inventory (in Tonnes)**	**Unit Price**	**Mode of Transport**
Aug-23	100.000 T	56.870 T	43.130 T	$2.70	Ocean
Sep-23	100.000 T	72.640 T	70.490 T	$2.70	Ocean
Oct-23	0.000 T	39.100 T	31.390 T		
Nov-23	200.000 T	79.850 T	151.540 T	$2.42	Ocean
Dec-23	0.000 T	35.000 T	116.540 T		
Jan-24	0.000 T	12.250 T	104.290 T		
Feb-24	0.000 T	10.350 T	93.940 T		
Mar-24	0.000 T	29.650 T	64.290 T		
Apr-24	0.000 T	38.760 T	25.530 T		
May-24	80.000 T	84.320 T	21.210 T	$2.70	Ocean
Jun-24	120.000 T	72.340 T	68.870 T	$2.70	Ocean
Jul-24	40.000 T	68.560 T	40.310 T	$3.20	Ocean
Total	640.000 T	599.690 T	831.530 T		
Frequency	6	12	12		
Average	53 T	50 T	69.30 T		

Table 3.3: History of Material-B purchases, demand, and Ending Inventory

The table 3.3 presents inventory data over a 12-month period, from August 2023 to July 2024, detailing monthly purchases, demand, cumulative ending inventory, and the mode of transport. The data shows that purchases are not consistent every month, with no purchases from December 2023 to April 2024, and large purchases made in November 2023 and June 2024. The demand varies significantly, with the highest being in November 2023 at 79.850 tonnes and the lowest in February 2024 at 10.350 tonnes. Cumulative ending inventory fluctuates accordingly, peaking at 151.540 tonnes in November 2023. Throughout the period, all inventory is transported by ocean, indicating a reliance on this mode for shipping. This highlights the importance of balancing purchase frequency and inventory levels to meet demand effectively.

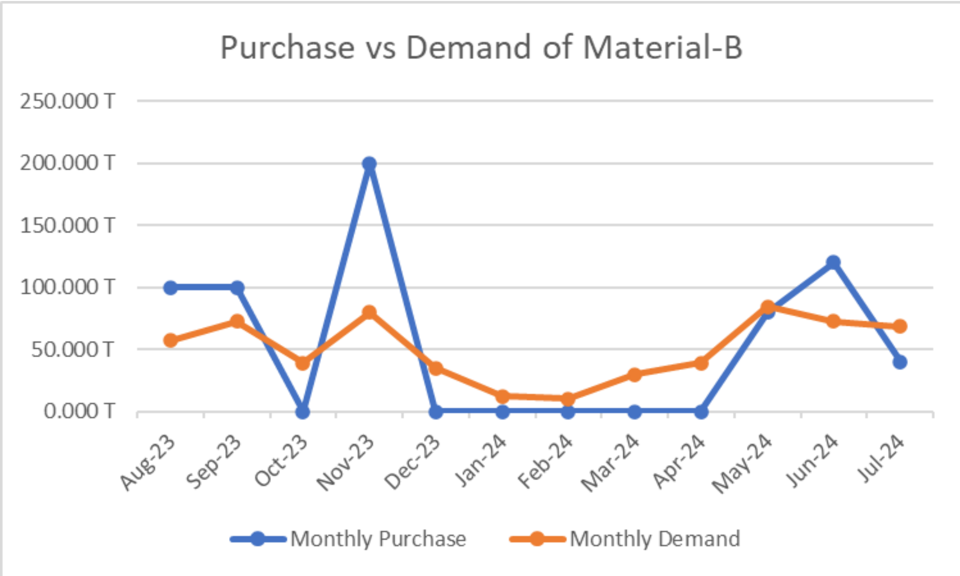


Figure 3.2: Trend of Purchasing vs Demand of Material-B

3.6 *Different types of Cost*

3.6.1 *Ordering Cost*

The material ordering cost refers to the expenses incurred during the process of procuring materials, including customs clearance and transportation costs. The duration of material clearance in the port is directly proportional to the ordering cost, meaning that longer clearance times tend to increase the overall cost. Some of the cost which were taken into consideration for calculating the ordering costs are listed in the table below. Since some of the materials are temperature resistant, Company-B uses refrigerated containers during extreme winter conditions for transporting the materials. Therefore, both the cost of both dry and refeer containers has been listed.

The rate for each component of charges were the average of the expenses spent by the Company-B for each and every shipment in that particular mode of transportation. The rates for individual components has been hidden due to confidentiality reasons.

Air Shipping Charges		
S. No	**Description of Charges**	**Rate (in $)**
1	Air Freight/kg	[redacted]
2	Fuel Surcharges/kg	
3	Handling fee at Destination	
4	Electronic Data Interchange Fee	
5	Customs Clearance Charges	
6	Insurance	
7	Documentation Fee	
8	Warehouse Charge	
9	Trucking charges from Airport to final destination	
Total Charges		**$1,368.310**

Table 3.4: Price Chart of Air Shipment

Ocean Shipping Charges			
S. No	**Description of Charges**	**20 ft Dry (in $)**	**20 ft Reefer (in $)**
1	Ocean freight	[redacted]	[redacted]
2	Insurance		
3	International Ship & Port facility security		
4	Terminal Handling charge at Destination		
5	Surrender fee		
6	Customs Duty		
7	Handling Charge		
8	Document fee		
9	Port Charge		
10	Labor Cost		
11	Electricity Charge		
12	Port Release Fee		
13	Trucking Charge		
14	Genset Charge		
Total Charges		**$5,642**	**$9,484**

Table 3.5: Price Chart of Ocean Shipment

Table 3.2 and table 3.3 shows that the company uses both air and ocean freight for material transportation, depending on the urgency of the requirement. Notably, the transportation costs vary significantly between these two methods. To determine the total ordering cost, the estimated costs for both air and ocean shipping from table 3.4 and table 3.5 are used to determine the ordering cost of Material-A and Material-B.

	Ordering Cost for Material-A	**Ordering Cost for Material-B**
Total	**$140,074.80**	**$180,390.00**
Frequency	18	6
Average	**$7,781.93**	**$30,065.00**

Table 3.6: Ordering Cost of Material-A and Material-B

3.6.2 *Holding Cost*

Holding costs encompass all expenses related to storing goods in the warehouse. The company rents the warehouse, and key costs include rent, electricity, insurance, utilities, maintenance, security, and property taxes. Additionally, the company uses a tractor for loading and unloading materials, with its associated costs included in the utility expenses. Due to the confidentiality of financial data and restricted access to individual cost components,the holding cost per kg of inventory is set to be 19.4% of unit price for material-A and 35% of unit price for Material-B. Table 3.7 outlines the annual holding cost for storing the inventory.

<table>
<tr><th>Components</th><th>Annual Inventory Holding Cost of Material-A</th><th>Annual Inventory Holding Cost of Material-B</th></tr>
<tr><td>Warehouse Rent</td><td rowspan="6">$9.273</td><td rowspan="6">$0.958</td></tr>
<tr><td>Electricity</td></tr>
<tr><td>Insurance</td></tr>
<tr><td>Utility & Maintenance</td></tr>
<tr><td>Security</td></tr>
<tr><td>Property tax</td></tr>
</table>

Table 3.7: Components of Inventory Holding Cost

	Holding Cost for Material-A	**Holding Cost for Material-B**
Total	**$59,286.01**	**$66,372.26**

Table 3.8: Holding Cost for Material-A and Material-B

Table 3.8 shows the costs of holding the inventory of Material-A and Material-B and the total holding cost is used further for calculating the total cost of inventory.

3.7 *Findings from Current State*

Based on all the above data, now it is easy to calculate the total costs. The values of each term in the formula is listed in the table 3.9 below.

	Material-A	**Material-B**
Fixed Ordering Cost (k)	\$7,781.93	\$30,065.00
Demand (D)	34367 Kg	599.690 T
Unit Price	\$47.80	\$2.42 - \$3.20
Annual Holding cost/kg (h)	\$9.273	\$0.958

Table 3.9: Cost Functions

3.7.1 *Total Cost in Current State*

With all the above values and data, the total cost of purchases in the current state can be calculated as follows:

$$TC_E(Q)\textit{Material - A} = \text{Ordering Cost} + \text{Holding Cost} + \text{Purchasing Cost}$$

$$TC_E(Q) = \$140,074,80 + \$59,286.01 + \$1,642,742.6$$

$$\boxed{TC_E(Q)\textit{Material - A} = \$\mathbf{1,842,103.41}}$$

$$TC_E(Q)\textit{Material - B} = \text{Ordering Cost} + \text{Holding Cost} + \text{Purchasing Cost}$$

$$TC_E(Q) = \$180,390.00 + \$66,372.26 + \$1,692,000.00$$

$$\boxed{TC_E(Q)\textit{Material - B} = \$\mathbf{1,938,762.26}}$$

4. Calculation of Proposed Models

This chapter evaluates the effects of implementing the Economic Order Quantity (EOQ) and Just-in-Time (JIT) models on Company-B's supply chain. By conducting cost-benefit analysis for both models, it is easy to assess potential savings in ordering, holding, and purchasing costs, as well as their impact on lead times. The chapter compares the benefits and trade-offs of each strategy to determine the most suitable approach for optimizing the company's inventory and purchasing efficiency.

4.1 *Analysis of EOQ Model for Material-A*

In order to proceed for the EOQ calculation, it is important to determine the economic order quantity (EOQ) using the equation which was mentioned earlier.

$$Q^* = \sqrt{\frac{2kD}{h}}$$

$$\text{K} = \$7,781.93; \quad \text{D} = 34,367\,\text{kg}; \quad \text{h} = \$9.273$$

$$Q^* = \sqrt{\frac{2 \times \$7781.93 \times 34,367\,\text{kg}}{\$9.273}} = 7594.77\,\text{kg} \approx 7595\,\text{kg}$$

Month	Planned order Releases	Planned order receipts	Demand	Cumulative Ending Inventory
	7595 kg			
	7595 kg			
Aug-23		7595 kg	3397 kg	4198 kg
Sep-23		4198 kg	2030 kg	2168 kg
Oct-23		7595 kg	3700 kg	6063 kg
Nov-23	7595 kg	6063 kg	3370 kg	2693 kg
Dec-23		2693 kg	1820 kg	873 kg
Jan-24		873 kg	700 kg	173 kg
Feb-24	7595 kg	7595 kg	1400 kg	6367 kg
Mar-24		6367 kg	2760 kg	3607 kg
Apr-24	7595 kg	3607 kg	3430 kg	177 kg
May-24		7595 kg	3850 kg	3922 kg
Jun-24		3922 kg	2940 kg	982 kg
Jul-24		7595 kg	4970 kg	3607 kg

Month	Planned order Releases	Planned order receipts	Demand	Cumulative Ending Inventory
Total	**37975 kg**		**34367 kg**	**34829 kg**
Frequency	5		12	12
Average	7595 kg		2864 kg	2902 kg

Table 4.1: EOQ model of Material-A

From table 4.1 it is clear that the order lead time is 3 months for the EOQ model. The current state involves frequent purchasing (18 times annually), resulting in higher average inventory levels (6,391 kg) and a total purchased quantity of 45,220 kg. In contrast, the EOQ model reduces the number of purchases to just 5, with a fixed order quantity of 7,595 kg, maintaining a lower average inventory (2,902 kg) and better aligning with demand. This optimized approach results in fewer orders, more stable inventory, and reduced holding costs, making it a more efficient and cost-effective system. In order to calculate the total costs, it is very essential to know the individual components. The fixed ordering cost has been calculated by considering the number of containers used for transporting the materials. Since the container can hold a maximum of 2800 kg, the ordering cost has been calculated by keeping 3 containers for each shipment.

$$\text{Ordering Cost:} = \frac{\$16,926.00 \times 34367\,kg}{7595\,kg} = \$76,591.61$$

$$\text{Holding Cost:} \quad \frac{h^*Q}{2} = \frac{\$9.273 \times 7595\,\text{kg}}{2} = \$35,213.92$$

$$\text{Purchasing Cost:} \quad P_E D = \$47.8 \times 34367\,\text{kg} = \$1,642,742.60$$

$$\text{Total Cost of Material-A in EOQ Model:} \quad \$\mathbf{1},\mathbf{754},\mathbf{548}.\mathbf{13}$$

4.2 *Analysis of JIT Model for Material-A*

In the “Just-in-Time (JIT) model” for Material A, the unit price has been reduced to \$46.70, reflecting the lower holding costs passed on to the supplier. The lead time has been shortened from 3 months to just 1 month, allowing for faster replenishment. In line with JIT principles, orders are placed in bulk but received in smaller, uniform quantities over time to minimize inventory levels. The transportation of Material A is managed through company's logistics partner DHL, with the supplier located in Stockholm, ensuring efficient and timely delivery. Due to the feasibility of packaging conditions imposed by the supplier, the materials are packed in 10kg bags. Therefore, the materials are delivered in multiples of 10kg during all weeks.

Month	Planned order Releases	Planned Order Receipts Every week	Demand	Ending Inventory	Frequency of Delivery Every Month	Ordering Cost (in USD)
	34510 kg					
Aug-23		680 kg	3397 kg	3 kg	5	$1,901.88
Sep-23		510 kg	2030 kg	10 kg	4	$1,521.50
Oct-23		930 kg	3700 kg	20 kg	4	$2,069.35
Nov-23		680 kg	3370 kg	30 kg	5	$1,901.88
Dec-23		460 kg	1820 kg	20 kg	4	$1,521.50
Jan-24		140 kg	700 kg	0 kg	5	$910.47
Feb-24		350 kg	1400 kg	0 kg	4	$1,149.07
Mar-24		690 kg	2760 kg	0 kg	4	$1,521.50
Apr-24		860 kg	3430 kg	10 kg	4	$2,069.35
May-24		770 kg	3850 kg	0 kg	5	$2,282.55
Jun-24		740 kg	2940 kg	20 kg	4	$1,826.04
Jul-24		1000 kg	4970 kg	30 kg	5	$2,967.36
Total				143 kg		$21,642.47

Table 4.2: JIT Model of Material-A

It is to be noted from table 4.2 ending inventory is very less when compared with current state and EOQ model, which in turn decreases the annual holding cost of the material-A.

$$\text{Ordering Cost:} = \$21,642.47$$

$$\text{Holding Cost:} = \$9.060 \times 143\,\text{kg} = \$1,295.55$$

$$\text{Purchase Cost:} \quad P_J D = \$46.7 \times 34367\,\text{kg} = \$1,604,938.90$$

$$\text{Total Cost of Material-A in JIT-Model:} \quad \$\mathbf{1,627,876.93}$$

From the above calculations, it is very evident that the overall cost in JIT model has been considerably decreased when compared with that of current state and EOQ model. It can also be seen from the bar graph in the upcoming chapter showing the JIT model has the lowest of all the costs. Therefore, the implementation of this Just-in-time model is viable for this class of materials.

4.3 *Analysis of EOQ Model for Material-B*

For Material-B, while the calculation framework is similar to that of Material-A, a key complexity arises from the fact that the unit price fluctuates based on the order quantity. This requires a thorough evaluation of the Economic Order Quantity (EOQ) across different price tiers to ensure the most cost-effective solution. To achieve this, initially, the price slabs that occur at various order sizes has been identified and EOQ has been calculated for each price range, considering holding costs, ordering costs and purchase costs. Once EOQ's are established for each price range, total costs are compared, which include purchase costs, transportation fees, holding costs, and any risks of stockouts to determine the most optimal order quantity. The goal is to select an EOQ that strikes the right balance between minimizing costs and ensuring sufficient inventory, thus meeting the operational and financial objectives of Company-B. This approach will enable the business to optimize procurement decisions, reduce excess inventory, and maintain production efficiency in the long term.

S.No	**Quantity (in Tonnes)**	**Rate (in $/kg)**
1	$\leq 60T$	$3.20
2	61 T-150 T	$2.70
3	Above 151 T	$2.42

Table 4.3: Price Variations

For Material-B, the demand (D) and fixed ordering costs remain constant across all cases, while the holding cost varies based on the unit price. The calculation begins with the unit price set at $2.42, where the EOQ is first determined. If the EOQ is found to be greater than 151 T, this is considered as a viable option for optimizing inventory management. However, if the EOQ is less than 151 T, the minimum total cost will occur at 151 T, making this as the preferred order quantity.

Demand D = 599.690 T
Fixed Ordering Cost k = $30,065.00
Interest rate = 35%
Unit price $P_E = \$2.42$
Holding Cost h = $0.847

$$EOQ(Q_3^*) = \sqrt{\frac{2 \times \$30,065.00 \times 599.690 \times 1000}{\$0.847}} \approx 207\,T$$

Since $EOQ(Q_3^*) > 151\,T$, the minimum cost occurs at $Q = 207\,T$. So, the individual cost components are calculated as follows:

Month	Planned order Releases	Planned order receipts	Demand	Cumulative Ending Inventory
	207.000 T			
Aug-23		207.000 T	56.870 T	150.130 T
Sep-23	207.000 T	150.130 T	72.640 T	77.490 T
Oct-23		77.490 T	39.100 T	38.390 T
Nov-23		207.000 T	79.850 T	165.540 T
Dec-23		165.540 T	35.000 T	130.540 T
Jan-24		130.540 T	12.250 T	118.290 T
Feb-24		118.290 T	10.350 T	107.940 T
Mar-24	207.000 T	107.940 T	29.650 T	78.290 T
Apr-24		78.290 T	38.760 T	39.530 T
May-24		207.000 T	84.320 T	162.210 T
Jun-24		162.210 T	72.340 T	89.870 T
Jul-24		89.870 T	68.560 T	21.310 T
Total	**621.000 T**		**599.690 T**	**1179.530 T**
Frequency	**3**		**12**	**12**
Average	**207.000 T**		**49.974 T**	**98.249 T**

Table 4.4: EOQ Model of Material-B

$$\text{Ordering Cost:} \quad \frac{kD}{Q_3^*} = \frac{\$30,065.00 \times 599.690\,T}{207\,T} = \$87,099.90$$

$$\text{Holding Cost:} \quad \frac{Q_3^* h}{2} = \frac{207 \times 1000 \times \$0.847}{2} = \$87,664.50$$

$$\text{Purchasing Cost:} \quad P_E D = \$2.42 \times 599.690 \times 1000 = \$1,451,249.80$$

Total Cost of Material-B in EOQ Model: $TC_E(Q_3^*) =$ **$1,626,014.20**

On calculating the EOQ for the other unit prices, the total cost for Q_3^* at $2.42/kg is lower than the cost of Q_2^* at $2.70/kg, making it more economical to order 207 T at $2.42/kg in each order cycle to minimize total costs of Material-B under EOQ model for Company-B.

Table 4.4 shows how the material is ordered and it is clear that the lead time for each order is 2 months. It is to be noted that the number of orders has been decreased to only 3 times if this model was implemented. But, on the other hand the amount of ending inventory has been increased when compared to that of the current state.

4.4 *Analysis of JIT Model for Material-B*

In the Just-in-Time (JIT) model for Material B, the unit price remains constant regardless of the order size, with a minimum order quantity of 151 tonnes. The lead time has been reduced from 2 months to 1 month, and the material is supplied on a weekly basis from the supplier in Gåvle. This frequent supply of Material-B helps the company to lower the ending inventory and reduces holding costs. In line with JIT principles, the material is ordered in bulk, nearly matching the total annual demand of 599.690 tonnes. The transportation is efficiently handled by the company's logistics partner DHL ensuring timely deliveries.

Month	Planned Order Release	Planned Order Receipts Every Week	Demand	Ending Inven-tory	Frequency of Delivery Every Month	Ordering Cost (in USD)
	603.100 T					
Aug-23		11.400 T	56.870 T	0.130 T	5	$8,009.77
Sep-23		18.200 T	72.640 T	0.160 T	4	$8,916.71
Oct-23		9.800 T	39.100 T	0.100 T	4	$5,317.22
Nov-23		16.000 T	79.850 T	0.150 T	5	$10,264.36
Dec-23		8.800 T	35.000 T	0.200 T	4	$4,817.24
Jan-24		2.500 T	12.250 T	0.250 T	5	$2,738.77
Feb-24		2.600 T	10.350 T	0.050 T	4	$2,191.01
Mar-24		7.500 T	29.650 T	0.350 T	4	$4,544.50
Apr-24		9.800 T	38.760 T	0.440 T	4	$5,317.22
May-24		17.000 T	84.320 T	0.680 T	5	$10,496.39
Jun-24		18.200 T	72.340 T	0.460 T	4	$8,916.71
Jul-24		13.800 T	68.560 T	0.440 T	5	$8,954.09
Total			599.690 T	3.410 T		$80,483.98

Table 4.5: JIT Model of Material-B

$$\text{Ordering Cost: } = \$80,438.98$$

$$\text{Holding Cost: } = 3.410 \text{ Tonnes} \times \$0.847 = \$2,888.27$$

$$\text{Purchasing Cost: } \quad P_J D = \$2.42 \times 599.690 \text{ Tonnes} = \$1,451,249.80$$

$$\text{Total Cost of Material-B in JIT-Model: } \quad \$\mathbf{1,534,622.05}$$

The above calculation displays a cost analysis for Material-B, under JIT model. It evaluates ordering costs, holding costs, purchasing costs, and total cost in this model. The JIT model exhibits the lowest holding costs, indicating its efficiency in minimizing inventory levels. As the EOQ model achieves higher ordering and holding costs, the JIT model outperforms in overall cost-effectiveness, presenting the lowest total purchasing cost. In contrast, the current state incurs the highest expenses across all categories, underscoring the financial benefits of adopting more structured inventory management strategies like the JIT or EOQ models.

The primary reason for receiving the materials in multiples of 200kg and 500 kg in JIT model is due to the packaging standards set by Company-B and the supplier. During production, materials are consumed in batches of 2 or 4 tonnes. To ensure the easier transfer of material into the mixing tanks, materials are transported in drums of 200L capacity and IBC tanks of 1000L capacity as shown in the figures.Therefore, a small amount of material remains as ending inventory in this model.

Figure 4.1: 1000L IBC [17] and 200L Drum [18]

4.5 *Lead Time*

Reducing lead time is also one of the key objectives for Company-B as it seeks to optimize its supply chain and procurement processes. One way to achieve this is through improved supplier collaboration and communication, ensuring faster response times and more reliable deliveries. Additionally, sourcing materials from local or nearby suppliers, such as those based in Gåvle for Material-B, can significantly cut transportation times. Company-B can also leverage techniques like inventory buffering, utilizing safety stock for critical items to mitigate delays, while automating internal processes, such as order approvals and inventory management, to reduce administrative lead times. The company's logistics partner DHL, plays a crucial role in optimizing transportation schedules, and exploring faster shipping modes can further reduce lead times. By adopting Just-in-Time (JIT) principles, as implemented in Material-A and Material-B analysis, Company-B can reduce excess inventory while ensuring timely deliveries through frequent, smaller orders. These strategies will collectively help the company to minimize the current 2-3 months of lead time to 1 month, improving overall efficiency, reducing holding costs, and enhancing its ability to meet production demands in a timely manner.

5. Results

This chapter describes about the results from the calculations of the proposed models.

5.1 *Material-A Results*

As mentioned earlier, in the current state, the EOQ model for Material-A was calculated with the supplier located in China, and the ordering costs were determined by accounting for transportation costs with each shipment. In the EOQ model, the order size was kept constant at 7,595 kgs. The resulting ending inventory in this model was 34,829 kgs, significantly lower than the current state model of 76,696 kgs, representing a reduction of 45.4% in the quantity of material idle time in the inventory.

On the other hand, the materials are received in smaller quantities on a weekly basis under JIT model, which reduced the annual ending inventory level to 143 kg, resulting in lower holding costs. All the cost analysis in this JIT model was calculated by keeping the base location of the suplier in Stockholm, leading to reduced transportation costs and a shorter lead time of just 1 month. In contrast, the lead time in the EOQ model remained the same as in the current state due to the supplier's location in China. This comparison between EOQ and JIT models highlights the significant impact on both inventory levels and lead time, with JIT offering better improvements.

	Current State	**EOQ Model**	**JIT Model**
Ordering Cost	$140,074.80	$76,591.61	$21,642.47
Holding Cost	$59,286.01	$35,213.92	$1,295.55
Purchasing Cost	$1,642,742.60	$1,642,742.60	$1,604,938.90
Total Costs	**$1,842,103.41**	**$1,754,548.13**	**$1,627,876.93**

Table 5.1: Material-A Cost Results

Figure 5.1 highlights the various cost components in the current state alongside the proposed EOQ and JIT models. Upon applying the values to equation 6, as discussed earlier, the result shows that the value of Z is greater than 0. This indicates that the JIT model is the most appropriate choice for this class of materials, as it effectively reduces total costs. Furthermore, according to equation 7, the maximum purchasing price per kilogram of material in the JIT system should not exceed $49.85. If the price surpasses this threshold, the value of Z becomes negative, making EOQ the more cost-effective option.

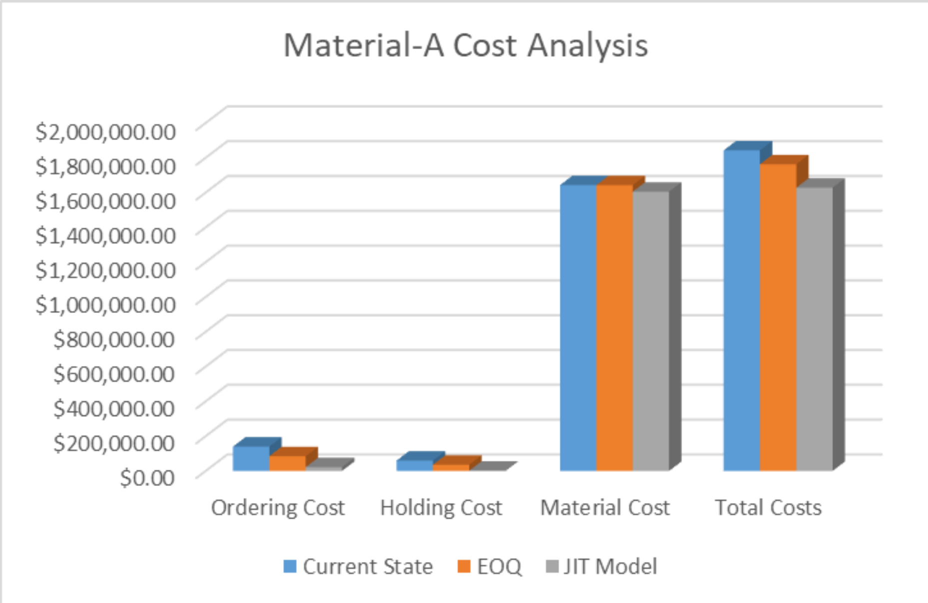


Figure 5.1: Cost Analysis of Material-A

5.2 *Material-B Results*

The calculations for this material were carried out similarly to those for Material-A. For this material, ordering costs were calculated solely based on ocean shipping. In the EOQ model, the material is sourced from the same supplier in China as in the current state. Since the material has price variations based on order quantity, the economic order quantity was calculated for each price tier, and inventory costs were compared. After evaluating the total costs across different price categories, it was determined that ordering 207 tonnes per order in the EOQ model is the most viable option. Given the material is shipped from China via ocean freight, the lead time remains the same as the current state, at 2 months.

In the JIT model, materials are ordered in bulk, slightly higher than the total annual demand of 599.690 tonnes, and are delivered to the factory weekly from Gåvle, resulting in lowering the holding costs as low as possible. Even though, the materials are delivered to the factory on frequent weekly shipments, the ordering cost in the JIT model is approximately 7.60% lower than that of the EOQ model. The lead time in the JIT model is reduced to 1 month, providing greater flexibility for both the supplier and buyer to adapt to market fluctuations.

	Current State	**EOQ Model**	**JIT Model**
Ordering Cost	$180,390.00	$87,099.90	$80,483.98
Holding Cost	$66,372.26	$87,664.50	$2,888.27
Purchasing Cost	$1,692,000.00	$1,451,249.80	$1,451,249.80
Total Costs	**$1,938,762.26**	**$1,626,014.20**	**$1,534,622.05**

Table 5.2: Material-B Cost Results

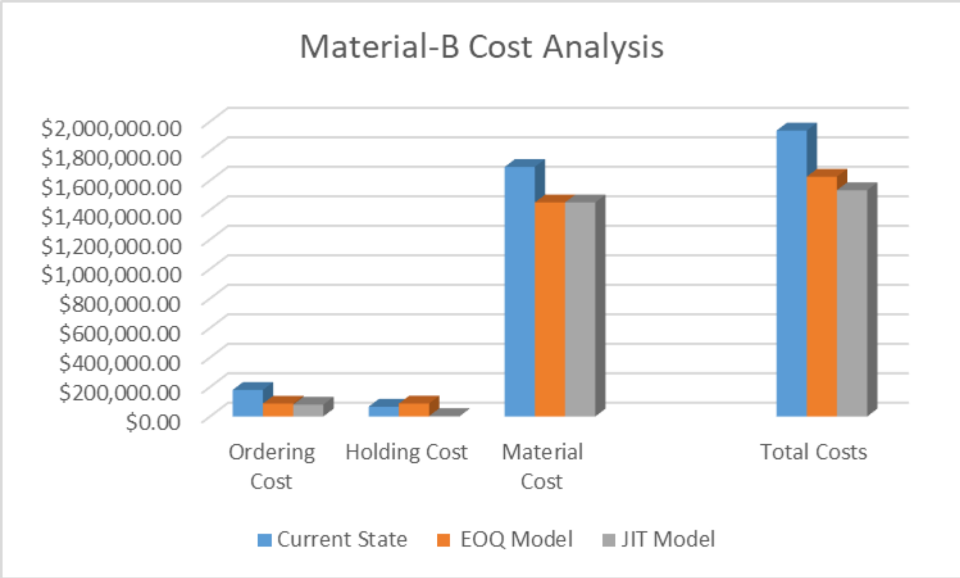


Figure 5.2: Cost Analysis of Material-B

Figure 5.2 clearly shows that the ordering costs in the current state is almost double when compared to that of the EOQ model. The material costs for both the EOQ and JIT models remain unchanged. After applying the values to equation 6, as discussed previously, the value of Z is still greater than 0, indicating that the JIT model is the most effective approach for minimizing overall costs. However, if the unit price exceeds $2.711/kg, the value of Z turns negative, making the EOQ model a more economical option.

6. Discussions and Recommendations

In this research, while much emphasis has been placed on inventory optimization through the Economic Order Quantity (EOQ) and Just-in-Time (JIT) models, there are other critical areas that could further improve inventory management, which have not been deeply explored. One such area is supplier diversification. Currently, the reliance on a limited number of suppliers can create bottlenecks, especially if a single supplier faces logistical challenges or delays. A diversified supplier base would reduce risks associated with over-dependence on one supplier, enhancing the company's ability to switch between vendors if any disruptions occur.

Additionally, technological integration between Company-B and its suppliers could be strengthened. Implementing a real-time inventory management system that is directly linked to suppliers would allow for more agile responses to changing production demands. This could significantly improve the accuracy of demand forecasting and streamline the procurement process further. However, this was not deeply researched in the current project, due to limited access to the technological infrastructure.

With additional resources and time, several improvements could have been made to this study. First, a more comprehensive supplier analysis would have conducted, considering not only cost and lead times but also factors like environmental impact, reliability, and scalability. A more detailed supplier audit would provide better insights into potential risks and how supplier performance could be optimized over time.

Moreover, data collection could have been more granular. Instead of solely relying on historical data provided by the Company-B, more dynamic data sources could be incorporated, such as real-time demand fluctuations and market trends. This would have allowed for a more adaptive and predictive approach to inventory management, particularly when forecasting future demand. This would offer greater flexibility in planning, preparing the company for various contingencies.

Finally, with better technological resources, implementing advanced forecasting algorithms or machine learning models could have further optimized both EOQ and JIT models. These technologies could provide more precise demand predictions and uncover hidden inefficiencies in the current procurement strategy.

Several challenges were encountered throughout the research. One of the major difficulties was the fluctuation of material prices, particularly for Material-B, where prices varied based on order quantities. This created complexity in calculating the optimal Economic Order Quantity, as it required an in-depth comparison of costs across multiple price levels. Additionally, the lead time variations between suppliers added another layer of difficulty in aligning the EOQ and JIT models effectively.

Logistical complexities also posed a significant challenge, especially with implementing the JIT model for Material-B. Managing frequent smaller shipments from suppliers located in different regions (e.g., Gåvle for Material-B and Stockholm for Material-A) required precise coordination. Any disruptions in transport or delays in shipments would have a significant impact on production, potentially leading to stockouts or inefficiencies. While the JIT model offers significant advantages in reducing inventory levels, its success is heavily dependent on supplier reliability and logistics planning.

Lastly, communication with suppliers presented a challenge, especially in gathering accurate cost data and understanding how quickly they could adapt to changes in order quantities. The research assumed that suppliers would be flexible enough to meet both JIT and EOQ requirements.

7. Future Work

One area of future exploration is the integration of advanced forecasting algorithms, such as machine learning or AI-based models, to improve demand forecasting. By analysing historical data and external factors, such as market trends, customer behaviour, and economic shifts, these tools could predict fluctuations in demand more accurately. Dynamic demand forecasting would enable Company-B to optimize procurement processes by reducing stockouts, minimizing excess inventory, and improving cost efficiency.

While this thesis analysed the EOQ and JIT models individually, future studies could investigate the implementation of hybrid inventory models. These models could combine the strengths of both EOQ and JIT, adapting to real-time changes in demand and supply.

A key area for future study would also be supplier diversification. Expanding the supplier base would reduce risks associated with over-reliance on a limited number of vendors, thereby increasing resilience in the event of supply chain disruptions. A detailed analysis of alternative suppliers, evaluating not only cost but also lead times, reliability, and geographical proximity, could help Company-B improve procurement processes while lowering supply chain risk. This would also include a focus on identifying regional suppliers and more logistics partners to reduce transportation costs and lead time.

In the future, it is also essential to focus on safety stock as a key element of inventory management. Safety stock acts as a buffer against uncertainties in demand fluctuations, supply chain disruptions, or longer-than-expected lead times. When performing analysis for future demand, the inclusion of the safety stock becomes critical to ensure that stockouts are minimized without holding excessive inventory, which would increase holding costs.

8. Conclusion

The thesis is aimed to optimize inventory management at Company-B by comparing the Economic Order Quantity (EOQ) and Just-in-Time (JIT) models for two key raw materials, Material-A and Material-B. The analysis revealed significant opportunities for cost savings and process improvements through the application of these models, demonstrating the critical importance of strategic inventory management.

For Material-A, the results showed that the JIT model offers the most cost-effective solution, reducing total costs by 11.63% compared to the current state. This reduction was primarily driven by the elimination of holding costs, achieved through more frequent, smaller deliveries. The EOQ model, while still providing savings of 4.75%, proved to be less cost-efficient in this case, particularly in environments where supplier proximity allows for rapid replenishment.

For Material-B, a more complex case due to fluctuating material prices, both EOQ and JIT models showed potential for significant savings. The JIT model led to a 20.84% reduction in total costs compared to the current state, while the EOQ model saved 16.13%. The choice between these models depends largely on the company's strategic priorities. If the focus is on minimizing overall costs, JIT is the preferable option, but if the goal is to reduce ordering costs, EOQ would be more suitable.

In conclusion, optimizing inventory management at Company-B through the application of JIT model can lead to significant cost reduction and enhance better operational efficiency when compared to that of current state and EOQ model. The results from this thesis provide a clear path for decision-making, depending on the company's strategic focus. Further improvements, such as incorporating safety stock analysis and advanced forecasting techniques, will enhance the company's ability to balance cost savings with continuous production in the future.

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