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Advanced Economic Order Quantity (EOQ) Models and Warehouse Management Techniques for Optimized Inventory Control in the Cable Manufacturing Industry

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ABSTRACT: This paper presents a comprehensive analysis of advanced EOQ (Economic Order Quantity) models and inventory management techniques applied within the cable manufacturing industry. By incorporating factors such as depreciation, gradual replenishment, shortage costs, and multi-item ordering, these models allow manufacturers to manage inventory efficiently, reducing warehousing costs and enhancing sustainability. This study also explores various warehouse technologies, such as Just-In-Time (JIT) inventory, automated storage and retrieval systems, and ABC analysis automation, to demonstrate how advanced methods can improve inventory turnover and financial stability in competitive industrial environments.

KEY WORDS: Economic Order Quantity, Inventory Management, ABC Analysis, Warehouse Management, Cable Manufacturing, Just-In-Time, Automation

I.INTRODUCTION

Effective inventory management is critical for manufacturing sectors, especially in cable production, where high material costs and the need for inventory optimization are paramount. Advanced EOQ models provide refined calculations that include depreciation, gradual replenishment, shortage costs, and multi-item ordering. These adaptations allow for better alignment with industry complexities, supporting companies in balancing stock levels with demand, reducing holding costs, and improving overall operational efficiency.

Inventory control has evolved to incorporate sophisticated technologies like Just-In-Time (JIT), Automated Storage and Retrieval Systems (AS/RS), and ABC analysis automation. These techniques not only streamline operations but also align with sustainable practices, helping companies reduce waste, improve resource allocation, and respond effectively to market demands. This paper delves into these advanced models and technologies, providing insights into their applicability in cable manufacturing and similar industrial settings. Because most social networks provide shorten service on URLs inside messages it is difficult to identify the content without visiting the site.

II. METHODS AND MODELS

A. Advanced EOQ Models

1. **EOQ with Depreciation Costs**: This model includes depreciation, accounting for the loss of value over time, crucial for industries with perishable or high obsolescence products. The formula for this model is:

$$EOQ = \sqrt{\frac{2 \cdot Q \cdot A}{i + kP}}$$

where ***i*** is the holding cost per unit, ***k*** is the depreciation rate, and ***P*** is the unit price. This model helps in minimizing costs by considering both storage and depreciation expenses.

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2. **EOQ with Gradual Replenishment**: Suitable for production environments with continuous replenishment, this model adjusts EOQ to account for ongoing demand during the replenishment period.

$$EOQ_{GR} = \sqrt{\frac{2QA}{I\left(1 - \frac{q_m}{d}\right)}}$$

Here, ***qm*** represents average daily demand, and ***d*** is the daily replenishment rate, allowing companies to optimize order sizes without overstocking.

3. **EOQ with Shortage Costs**: Integrating shortage costs provides a balance between holding and shortage-related expenses, helping prevent stockouts while managing inventory efficiently.

$$EOQ_{SC} = \sqrt{\frac{2QA\left(H + I\right)}{H}}$$

H denotes shortage costs per unit, and ***I*** is the holding cost, supporting companies in handling demand fluctuations effectively.

4. **Multi-Item Order Model**: This model is useful for companies handling multiple products, each with unique demand and holding costs.

$$EOQ_{MI} = Q\sqrt{\frac{2A}{\overline{Q} \cdot \overline{I}}}$$

Using vectors for holding costs and demands, it facilitates optimal inventory management for diverse product lines.

III. WAREHOUSE MANAGEMENT TECHNOLOGIES

Automating ABC analysis leverages data analytics and software integration, allowing companies to categorize inventory dynamically based on demand and value. Implementing ABC in Warehouse Management Systems (WMS) and integrating with real-time data collection (e.g., RFID, ERP) enables companies to continuously update classifycations and optimize resource allocation efficiently.

JIT(Just in Time) reduces the need for large inventories by ordering items only when needed, aligning closely with demand patterns. This minimizes storage costs and reduces risks associated with obsolescence, ideal for high-turnover items in manufacturing.

AS/RS uses robotics for storing and retrieving inventory items, significantly increasing efficiency and reducing manual labor in warehouse operations. This technology is beneficial for large warehouses or facilities with high picking demands, optimizing space utilization.

A. OTHER KEY TECHNOLOGIES

RFID and Barcode Scanning: Enhances real-time tracking, reducing errors in stock movement and data logging.
Warehouse Management System (WMS): Manages inventory, order picking, and fulfillment efficiently.
Demand Forecasting and Predictive Analytics: Predicts future inventory needs using historical data and machine learning, reducing stockouts and excess inventory.

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IV. APPLICATION IN THE CABLE MANUFACTURING INDUSTRY

In the cable manufacturing industry, effective inventory management can significantly improve operational efficiency and financial performance. High inventory levels are costly, tying up capital and increasing storage expenses. The application of EOQ models, combined with JIT and AS/RS, allows for precise inventory control, minimizing warehousing costs. ABC analysis automation and predictive analytics further optimize stock levels, ensuring that cable manufacturers can respond to demand fluctuations without overstocking.

ABC analysis is an inventory categorization technique that divides inventory into three categories (A, B, and C) based on the value or importance of each item. Automating ABC analysis involves using technology to streamline the process, enabling real-time categorization, continuous monitoring, and data-driven decision-making. Here's a deeper look into how ABC analysis can be automated and the specific technologies and processes involved. ABC analysis automation is essential for efficient inventory management, enabling real-time categorization and prioritization of inventory items based on demand and value. The process begins with integrating Inventory Management Software (IMS) or a Warehouse Management System (WMS), which serves as the foundation for automation by recording data on inventory items, such as cost, usage frequency, and demand. Modern systems often include built-in ABC analysis features that automatically classify items into categories A, B, or C based on predefined parameters, like annual usage value or sales frequency. Defining ABC classification rules is a crucial step, where categories are typically organized by percentage contribution to overall inventory value. Commonly, Category A represents the top 20% of items, contributing to 70-80% of the inventory value; Category B includes the next 30%, contributing around 15-25% of value; and Category C covers the remaining 50%, with the lowest contribution. Once these rules are established, the IMS or WMS calculates each item's contribution and assigns it to the appropriate category. These thresholds can be adjusted as per the company's specific needs and data trends. Accurate, real-time data collection on inventory levels, costs, and usage is essential for maintaining up-to-date ABC classifications. By applying the principles of ABC analysis to the following inventory data, we can categorize materials into A, B, and C groups based on their contribution to the total inventory value. This categorization helps prioritize high-value items for stricter control, ensuring efficient resource allocation and inventory management. Below is the inventory data: (tab.1)

№	Material Name	Unit	Quantity	Cost (ths UZBsums)
1	Copper	tons	11 000	1 052 700 000
2	Aluminum Wire Rod 9.5 mm	tons	2 074	66 590 815
3	Lead	tons	298,7	8 267 657
4	Materials for PVC Production	tons	1 530,3	20 848 266
5	PVC Insulation	tons	1 264,7	20 645 496
6	Black PVC Sheath	tons	1 843,2	25 510 461
7	White PVC Sheath	tons	111,4	1 514 633
8	PVC Film	tons	43,6	1 091 410
9	PVC Dye	tons	14,2	622 818
10	Insulating Polyethylene	tons	86,9	2 454 719
11	Tubular Polyethylene	tons	108,4	2 435 508
12	Peroxide-Crosslinked Polyethylene	tons	902	36 725 939
13	PPI-3030 (Russia)	tons	137,6	3 240 818
14	PPO-30-35 (Russia)	tons	269	5 020 514
15	Cable Paper	tons	157	3 119 222
16	Cable Yarn PDAM	tons	17,2	665 051

Tab 1. Material List with Quantities and Costs (Cable Manufacturing)

This real-time data is typically gathered through barcode scanning, RFID tags, or IoT devices, which automatically update inventory levels and movement. The continuous data stream enables the system to reflect current demand patterns in ABC categorization. Automated reclassification and adjustment are also vital to keep the classification dynamic, allowing it to adapt to changing demand, seasonality, or value fluctuations. ABC systems can be set to re-run the classification

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periodically or whenever there's a significant change in demand or item value, ensuring that high-demand or high-value items receive prioritization.The use of Business Intelligence (BI) and Data Analytics tools further enhances ABC analysis by providing insights into categorization and visualizing inventory performance. BI platforms like Power BI or Tableau analyze data from IMS or WMS, presenting detailed reports on ABC classification, inventory turnover, and stock levels. These insights allow managers to identify which items to prioritize for stocking, monitoring, or optimization. Machine Learning (ML) adds an additional layer of dynamic capability to ABC classification by adjusting it based on multiple criteria, such as seasonal demand, market trends, or lead time variability. ML algorithms can analyze historical data, identifying patterns that suggest certain items should be reclassified. For example, a model might detect a temporary demand increase for specific items and recommend their reclassification to Category A. Additionally, ML can employ clustering algorithms, such as K-means, to group items based on multidimensional criteria beyond just value and demand. Automated alerts and reorder triggers are another advantage of ABC automation, allowing different reorder levels for A, B, and C items to maintain stock levels appropriately. For instance, Category A items may have lower reorder points and higher reorder frequencies, while Category C items might be reordered less often. The system sends alerts when an item approaches its reorder point, preventing stockouts for critical items. Integrating ABC analysis with supplier and demand forecasting systems further enhances inventory management by aligning stock levels with supplier lead times and expected demand. High-priority items, such as Category A, are often sourced from reliable suppliers to avoid delays, while forecasting tools anticipate demand shifts for Categories B and C. This integration enables adjustments to reorder points and quantities, optimizing stock levels in line with both supply chain and demand factors.

№	Material Name	Cost (ths UZBsums)	Total Value Contribution (%)	ABC Category
1	Copper	1052700000	84.11819900016135	B
2	Aluminum Wire Rod 9.5 mm	66590815	5.321078586257177	B
12	Peroxide-Crosslinked Polyethylene	36725939	2.9346630999048036	B
6	Black PVC Sheath	25510461	2.0384668328905247	B
4	Materials for PVC Production	20848266	1.6659243737021923	C
5	PVC Insulation	20645496	1.6497216120310014	C
3	Lead	8267657	0.6606444540620091	C
14	PPO-30-35 (Russia)	5020514	0.40117468959351765	C
13	PPI-3030 (Russia)	3240818	0.25896435209205365	C
15	Cable Paper	3119222	0.24924796895761497	C
10	Insulating Polyethylene	2454719	0.1961494645497075	C
11	Tubular Polyethylene	2435508	0.19461436934595325	C
7	White PVC Sheath	1514633	0.12102992315589568	C
8	PVC Film	1091410	0.08721140265105548	C
16	Cable Yarn PDAM	665051	0.05314229349601625	C
9	PVC Dye	622818	0.04976757714912367	nan

Tab 2. Analysis of Materials by Significance and Cost (ABC Analysis)

A. TECHNOLOGIES USED IN ABC AUTOMATION

Inventory Management Systems (IMS) and Warehouse Management Systems (WMS) form the foundation of ABC automation, as they handle inventory data and perform the initial categorization of items. Barcode and RFID technology are crucial components that provide real-time updates on inventory, ensuring that ABC classifications are accurate and current. Business Intelligence (BI) tools, such as Power BI and Tableau, play an essential role by analyzing and visualizing ABC data, allowing managers to gain insights into inventory performance and trends. Machine learning and artificial intelligence (AI) add flexibility to ABC analysis by dynamically adjusting classifications based on evolving data patterns. This adaptability makes ABC analysis more responsive to changes in demand and usage. Enterprise Resource Planning (ERP) systems often come with built-in ABC analysis modules or can integrate with IMS/WMS to centralize data and streamline the automation process. Additionally, Internet of Things (IoT) devices provide real-time data on inventory movement, location, and environmental conditions, which is especially valuable for tracking and monitoring high-priority items accurately. Together, these technologies enhance the efficiency and accuracy of ABC analysis in inventory management.

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B. BENEFITS OF ABC ANALYSIS AUTOMATION

Automated ABC analysis offers several key advantages that streamline inventory management and improve efficiency. First, it enables improved inventory control by allowing companies to focus on high-priority items, ensuring optimal stock levels are maintained and reducing excess inventory for low-priority items. This targeted approach minimizes waste and helps to keep storage costs under control. Moreover, automation enhances decision-making by providing up-to-date data through Business Intelligence (BI) tools, allowing managers to make more informed decisions about inventory, purchasing, and resource allocation. This real-time insight into inventory status empowers managers to act quickly and effectively in response to changes. Another important benefit is the reduction of manual work. By automating the classification process, companies save time and reduce errors, which improves accuracy and frees up staff for other essential tasks. Additionally, automated ABC analysis brings adaptability to demand fluctuations. Through automated reclassification and machine learning, the system can adjust inventory classifications dynamically based on demand trends. This flexibility ensures that stock levels align more closely with real-time demand, helping companies respond effectively to market changes. Finally, focusing on high-priority items also results in cost savings. By prioritizing these critical items, companies can reduce both holding and ordering costs, leading to better overall financial performance and enhancing the profitability of inventory management practices. However, over-reliance on automation may reduce human oversight, potentially missing unique business nuances or anomalies. Maintenance and updates of automated systems require additional investment and technical expertise. Lastly, focusing heavily on Category A items might neglect opportunities for optimizing lower-priority inventory (Categories B and C), limiting overall efficiency gains. To address the drawbacks of automated ABC analysis, companies can adopt scalable systems with modular features, allowing small businesses to start with basic functionality and upgrade as needed. Regular data audits, combined with human oversight and integration of advanced analytics tools, ensure accurate categorization and holistic inventory management, balancing focus across all categories.

V. CONCLUSION

In conclusion, advanced inventory management techniques such as EOQ models, JIT practices, and automated ABC analysis offer a robust framework for optimizing inventory control in the cable manufacturing industry and other industrial sectors. By incorporating depreciation, gradual replenishment, shortage costs, and multi-item ordering, EOQ models enable companies to refine their order quantities and reduce overall warehousing costs. The integration of JIT inventory management further enhances efficiency by minimizing unnecessary stock, reducing holding costs, and aligning inventory with actual demand. Automating ABC analysis provides a significant advantage by enabling real-time inventory categorization and resource allocation. Technologies like Inventory Management Systems (IMS), RFID, Business Intelligence (BI) tools, and machine learning allow companies to maintain optimal stock levels, adapt dynamically to demand fluctuations, and make data-driven decisions. The flexibility provided by machine learning and the accuracy of real-time tracking tools ensure that high-priority items are always available, while low-priority items are managed cost-effectively. The benefits of these advanced techniques are evident in improved inventory control, enhanced decision-making, reduced manual work, adaptability to demand fluctuations, and cost savings. By focusing on high-priority items and optimizing inventory based on demand patterns, companies can reduce operational costs, improve financial performance, and increase overall competitiveness in a rapidly evolving industrial landscape. Embracing these modern inventory management practices is essential for companies seeking sustainability, resilience, and efficiency in their operations.

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