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[ijirset@gmail.com](mailto:ijirset@gmail.com)

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# Optimizing Spare Parts Management through Advanced Inventory and Demand Forecasting Techniques

EL-ASSAL A.M, ROUBI ZAIED, TAMER M. ELDOGDOG

Department of Mechanical Engineering, Benha, Faculty of Engineering, Benha University, Egypt

Department of Mechanical Engineering, Benha, Faculty of Engineering, Benha University, Egypt

Department of Mechanical Engineering, Benha, Faculty of Engineering, Benha University, Egypt

**ABSTRACT:** Integrating advanced technologies into spare parts management enhances demand forecasting accuracy and optimizes reorder points by calculating the economic order quantity through key variables. The research problem focuses on calculating safe inventory limits, classifying spare parts, and integrating various methods to enhance inventory management efficiency. This is achieved through advanced algorithms to accurately predict demand and manage spare parts, ensuring continuous production operations. In light of these technologies, the study aims to reduce downtime and improve demand forecasting accuracy by analyzing historical data to predict future demand and determine the optimal reorder point, ensuring parts availability and avoiding excess inventory. Accordingly, as the research methodology, the economic order quantity (EOQ) is calculated. Advanced models are also relied upon to analyze demand data and storage costs to determine the economic quantity that reduces total demand and storage costs. Thus, we can reach the safe inventory limit and report demand fluctuations and delivery periods. This enables the safe inventory limit to be accurately calculated to avoid shortages of critical parts, which makes it necessary to rely on classification methods, such as ABC and XYZ analysis. These are used to classify spare parts according to their importance and turnover rate, to work on allocating resources more effectively in order to integrate traditional inventory management methods with modern techniques to achieve the ideal balance between efficiency and accuracy. Furthermore, we can use predictive practical results that end with recommendations. Advanced techniques in spare parts management enhance demand forecasting accuracy, reduce inventory costs, and improve overall logistics efficiency by optimizing reorder points.

**KEYWORDS:** Advanced technologies, Spare parts management, Spare parts classification, Reorder point, Economic order quantity, Safety stock, Demand forecasting, Logistic operations.

## I. INTRODUCTION

The study addresses the need for quality control and efficient inventory management in a competitive industrial environment. In recent years, there has been significant development in advanced technologies, which have proven their ability to transform many industries, particularly in the need to focus on accurately predicting spare parts requirements and determining the optimal reorder point. These remain two major challenges facing many companies, as spare parts management is a vital element in supply chains, directly affecting the efficiency of operational processes and operating costs (Gutierrez, Polo Triana, & León Becerra, 2024; Narendran, 2023).

In this context, the integration of advanced technologies into spare parts management emerges as a powerful tool to improve the accuracy of demand forecasting and determine the optimal reorder point (Dash, McMurtrey, Rebman, Kar, & Sustainability, 2019; Gayam, Yellu, & Thuniki, 2021). These technologies are characterized by their ability to analyze vast amounts of complex data and uncover hidden patterns and trends (Sharma, Shishodia, Gunasekaran, Min, & Munim, 2022).

By applying these technologies to supply chain data, companies can enhance their understanding of operations and improve their ability to predict future demand. Additionally, these technologies can analyze multiple factors that affect demand, such as economic conditions, climate variations, and market shifts, helping build more accurate forecasting models. Thus, integrating advanced technologies into inventory management structures enables organizations to enhance the process of determining the optimal reorder point.

The optimal reorder point depends on several factors, including demand rate, lead time, order cost, and storage cost (Jayender, Kundu et al. 2021). Advanced technologies enable dynamic analysis of these factors and help determine

the most efficient inventory level to meet demand without incurring excessive costs (Encapera, Gosavi et al. 2021, Jauhar, Jani et al. 2024). To achieve this goal, the integration of these technologies into spare parts management is expected to significantly improve supply chain performance. By enhancing the accuracy of demand forecasting and determining the optimal reorder point, organizations can reduce excess inventory, improve customer service, and lower operating costs, while uncovering new opportunities to optimize operations and reduce expenses. This research focuses on integrating advanced technologies into spare parts management to improve demand forecasting accuracy and determine the optimal reorder point.

Current challenges in spare parts management will be analyzed, relevant technological advancements will be reviewed, and a framework will be provided to support the integration of these technologies. The anticipated benefits of this integration and the potential challenges organizations may face will also be discussed. Through this research, we seek to provide valuable insights to practitioners and decision-makers in the field of supply chain management regarding the potential of these technologies to enhance spare parts management and improve companies' competitiveness (Sharma et al., 2022).

Spare parts orders are often highly volatile due to factors such as seasonal demand changes, shifts in demand for finished products, or unforeseen events such as major breakdowns or natural disasters. This volatility makes it difficult to accurately forecast the required quantities of spare parts, leading to shortages or excess inventory (Goltsos, Syntetos, Glock, & Ioannou, 2022). Companies also face challenges with the availability of accurate and comprehensive data on spare parts, such as failure rates, delivery times, and actual storage costs, which complicates the building of accurate forecasting models and decision-making processes (Sgarbossa & Russo, 2017; Weaver et al., 2013).

In terms of costs, there are additional expenses associated with inventory, including damage, theft, and financial losses due to the working capital tied up in stock. Storing spare parts requires significant space and financial resources, especially for expensive or high-volume parts (Danielsbacka, 2020). Moreover, the complexity of modern supply chains, involving many suppliers, warehouses, and logistics partners, makes it challenging to track the movement of spare parts and locate them at any given time, complicating inventory management.

In this context, integrating advanced technologies into spare parts management becomes essential for improved risk management by helping companies identify potential risks in the supply chain, such as shipment delays or supply disruptions (Ganesh, Kalpana, & Engineering, 2022; Mittal, 2023). Additionally, it enables the development of contingency plans to mitigate the impact of these risks and enhance supply chain sustainability. These technologies can also analyze sustainability-related data, such as carbon emissions and energy consumption, helping companies make more sustainable decisions regarding inventory management and the supply chain in general.

By analyzing data related to equipment performance and maintenance history, these technologies can predict parts failure before it occurs, allowing for preventive maintenance and reducing downtime. They can also help analyze customer behavior and preferences to provide personalized services, such as recommending appropriate spare parts or customized maintenance plans. Ultimately, the integration of these technologies with Internet of Things (IoT) devices enables real-time tracking of spare parts status, providing more accurate data to improve decision-making processes. This creates a great opportunity to enhance the efficiency of supply chains and reduce costs. By addressing current challenges and leveraging the numerous advantages of advanced technologies (Rajest, Singh, Obaid, Regim, & Chinnusamy, 2023; Wuest, Weimer, Irgens, Thoben, & Research, 2016).

**Research Problem:** The main research problem is how to practically address the challenges facing companies in managing spare parts. The central question is how can companies use advanced technologies to improve the accuracy of demand forecasting and manage spare parts efficiently, with the aim of addressing issues of shortages and excess inventory, thereby reducing the negative impact on operational performance and costs. This problem branches into several sub-questions:

- What are the requirements for accurately forecasting demand and determining the optimal reorder point?
- How can problems of shortages or excess inventory be overcome?
- What is the negative impact on operational performance and cost as a result of ineffective management of spare parts?

Table 1: Spare Parts Management Terminology

Term	Definition
<b>Spare Parts Management</b>	The process of managing the inventory, procurement, and distribution of spare parts used in the maintenance and repair of equipment to ensure availability and minimize downtime(Siponen, Haapasalo, Harkonen, & Engineering, 2019; Zhang, Huang, & Yuan, 2021).
<b>Classification</b>	The categorization of spare parts into different groups based on criteria such as importance, usage, and cost, facilitating inventory management and decision-making for purchasing and storage(Teixeira, Lopes, & Figueiredo, 2018).
<b>Reorder Point</b>	The level at which new quantities of spare parts should be ordered to ensure continuous production without interruption, depending on demand level and lead time(Zhu, van Jaarsveld, Dekker, & Safety, 2022).
<b>Economic Order Quantity (EOQ)</b>	A model that determines the optimal order quantity that minimizes the total costs of storage and ordering spare parts, balancing order and holding costs(Khanna, Patel, & Rajnikant, 2023; SONI, 2017)
<b>Safety Stock</b>	Additional inventory kept to address demand uncertainty or supply delays, ensuring that critical parts are available during operations(Rozhkov, Ivanov, Blackhurst, & Nair, 2022; Saputro, Figueira, & Almada-Lobo, 2021).
<b>Calculation</b>	The mathematical process or algorithm used to calculate the required quantities of parts, such as EOQ or Reorder Point, to ensure effective inventory management(Meileni, Putra, Apriyanti, Satriadi, & Oktapriandi, 2020; Milewski & Wiśniewski, 2022).
<b>Demand Forecasting</b>	The prediction of future demand for spare parts using analytical and machine learning techniques, aiding in inventory planning and avoiding shortages or surpluses(Nguyen, 2024).
<b>Logistics Operations</b>	the coordination of components and goods movement and storage from the point of production to the point of consumption, encompassing tasks like distribution, warehousing, transportation, and inventory control(Kmieciek, 2022).

- The study aims to address the Importance and Objectives of Integrating AI into Spare Parts Management
- Importance:
- Advanced technologies play a crucial role in analyzing vast volumes of data to detect patterns and trends, aiding in the determination of inventory levels, procurement, and logistics decisions. By managing all aspects that impact inventory levels, companies can reduce costs and enhance demand forecasting accuracy.
- Improved customer satisfaction and loyalty can result from having spare parts readily available when needed, thanks to technology-powered demand forecasting and inventory management. Additionally, these technologies can help identify potential supply chain disruptions and develop contingency plans, reducing the impact of unforeseen events and enhancing overall operational efficiency.
- The primary objectives of integrating advanced technologies into spare parts management are:
- Develop models based on market trends, historical data, and external variables to precisely predict the demand for spare parts.
- Optimize inventory levels to minimize stock outs and surplus inventory while balancing supply and demand.
- Improve supply chain visibility to track the movement of spare parts throughout the supply chain, providing real-time insight and enabling proactive problem-solving. Implement technology-driven solutions to streamline procurement and logistics, reduce delivery times, and improve order fulfillment.

- Increase operational efficiency by freeing up resources for strategic initiatives, automating routine tasks, and improving decision-making processes.
- Optimize spare parts utilization by analyzing equipment performance data and predicting maintenance needs to improve asset utilization.

**II.**

**LITERATURE SURVEY**

**Data collection methods:**

**A. Literature Review: The study variables are divided into two axes:**

**Table 2: The first axis is spare parts management in light of the techniques of using AI techniques in this field**

No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
1	Artificial Intelligence in Spare Parts Management: A Comprehensive Review	(Kulshrestha, Agrawal, & Shree, 2024)	The study provides a comprehensive review of AI applications in spare parts management, focusing on predictive analytics and inventory optimization.	Enhanced predictive maintenance and inventory management efficiency.	AI, predictive analytics, inventory management
2	The role of business intelligence adoption as a mediator of big data analytics in the management of outsourced reverse supply chain operations	(Hatamlah et al., 2023)	This study explores the impact of AI on modernizing logistics for spare parts management, with an emphasis on automation and real-time data processing.	Increased automation, improved logistics efficiency, and cost savings.	AI, automation, logistics management
3	Servitization as a key driver for digital transformation of manufacturing companies' spare parts service	(Dombrowski & Fochler, 2018)	The study reviews the impact of digital transformation on spare parts management in companies.	Improved operational efficiency and cost reduction.	Digital transformation, spare parts management
4	A proactive model in sustainable food supply chain: Insight from a case study	(Sgarbossa & Russo, 2017; Singh, Adhikari, & Technology, 2023)	The study focuses on optimizing spare parts inventory levels using AI.	Reduced inventory costs and improved service levels.	AI, inventory optimization

No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
5	Using AI in Supply Chain Management	(Mittal, 2023)	The study reviews AI applications in improving supply chain management.	Enhanced forecasting accuracy and cost reduction.	AI, supply chain management
6	Internet of Things (IoT) Application for Management in Automotive Parts Manufacturing	(Krommuang, Suwunnamek, & Applications, 2022)	The study explores the integration of IoT and AI for effective spare parts management.	Enhanced monitoring and real-time decision-making.	IoT, AI, spare parts management
7	Artificial intelligence in operations management and supply chain management: An exploratory case study	(Helo, Hao, & Control, 2022)	The study focuses on applying AI to improve spare parts management in factories.	Improved inventory efficiency and reduced waste.	AI techniques, inventory management
8	AI Enhanced Predictive Maintenance for Manufacturing System	(Banerjee, Kumar, Sharma, & Techniques, 2024)	The study reviews the use of AI to enhance maintenance operations efficiency.	Reduced failures and improved performance.	AI, maintenance efficiency
9	Predictive maintenance of machine tool systems using artificial intelligence techniques applied to machine condition data	(W. J. Lee et al., 2019)	The study discusses the use of AI for predictive maintenance in industrial settings.	Early detection of issues and reduced downtime.	AI, predictive maintenance
10	A Real-Time Deep Machine Learning Approach for Sudden Tool Failure Prediction and Prevention in Machining Processes	(Hassan, Sadek, & Attia, 2023)	The study reviews the use of machine learning to analyze maintenance data.	Reduced downtime and improved performance.	Machine learning, equipment maintenance
11	Role of Big Data Analytics in supply chain management: current trends and future perspectives	(Maheshwari, Gautam, & Jaggi, 2021)	The study explores the use of big data to enhance logistics operations.	Improved demand forecasting accuracy and increased efficiency.	Big data, logistics management

No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
12	Big Data Analytics in Sustainable Supply Chain Management: A Focus on Manufacturing Supply Chains	(I. Lee, Mangalaraj, & computing, 2022)	The study explores the use of big data to enhance quality control in factories.	Improved product quality and reduced costs.	Big data, quality control

**Table 3: Axis 2: Improving Demand Forecasting Accuracy and Determining the Optimal Reorder Point**

No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
1	Machine Learning-Driven Demand Prediction to Minimize Supply Chain Costs	(Ahmed, 2023)	This study focuses on leveraging machine learning to enhance demand forecasting accuracy across industries.	Significant improvement in forecasting accuracy and inventory optimization.	Machine learning, demand forecasting
2	Artificial intelligence-based inventory management: a Monte Carlo tree search approach	(Preil & Krapp, 2022)	The study introduces a novel AI-based approach to inventory management, focusing on real-time data and adaptive systems.	Increased inventory efficiency and better demand matching.	AI, real-time data, adaptive systems
3	Reorder point for the EOQ inventory model with imperfect quality items	(Nobil, Sedigh, & Cárdenas-Barrón, 2020)	The study focuses on dynamically calculating reorder points using AI techniques.	Improved inventory turnover and reduced stockouts.	AI, dynamic reorder point
4	Enhancing Supply Chain Agility and Sustainability through Machine Learning: Optimization Techniques for Logistics and Inventory Management	(Pasupuleti, Thuraka, Kodete, & Malisetty, 2024)	This study applies statistical learning methods to optimize reorder points in complex supply chains.	Improved reorder point calculation accuracy and reduced stockouts.	Statistical learning, reorder point optimization

No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
5	Development of Predictive Analytics for Demand Forecasting and Inventory Management in Supply Chain using Machine Learning Techniques	(Seyedan, 2023)	The study reviews the application of predictive analytics to improve inventory management.	Reduced excess inventory and improved storage efficiency.	Predictive analytics, inventory management
6	Machine learning demand forecasting and supply chain performance	(Feizabadi & Applications, 2022)	The study explores the use of predictive analytics to improve demand management in companies.	Increased forecasting accuracy and reduced waste.	Predictive analytics, demand management
7	Demand Forecasting Optimization with Machine Learning	(Li et al., 2022)	The study discusses optimizing demand forecasting processes using machine learning algorithms.	Enhanced accuracy and efficiency in demand planning.	Machine learning, demand forecasting
8	Predictable inventory management within dairy supply chain operations	(Huerta-Soto et al., 2023)	The study reviews the use of AI to enhance inventory management in supply chains.	Improved forecasting accuracy and cost reduction.	AI, inventory management
9	Effective Demand Forecasting Model Using Business Intelligence Empowered with Machine Learning	(Khan et al., 2020)	The study reviews the use of deep learning to improvedemand forecasting accuracy.	Increased forecasting accuracy and reduced excess inventory.	Deep learning, demand forecasting



No.	Study Title	Researchers and Year	Study Summary	Key Findings and Recommendations	Variables Covered
10	Machine learning demand forecasting and supply chain performance	(Feizabadi & Applications, 2022)	The study reviews the use of neural networks to analyze data and improve demand management.	Enhanced forecasting accuracy and increased efficiency.	Neural networks, demand management
11	Demand forecasting in retail operations for fashionable products: methods, practices, and real case study	(Ren, Chan, & Siqin, 2020)	The study reviews advanced forecasting models and their application in inventory management.	Enhanced accuracy and reduced operational costs.	Forecasting models, inventory management
12	Improving Reorder Point Using Statistical Analysis	(Laeiddee, 2010)	The study reviews the use of statistical analysis to determine the optimal reorder point.	Cost reduction and efficiency improvement.	Statistical analysis, reorder point

**B. Study tools and details**

- **AI algorithms:** algorithms designed to process and analyze large data sets to identify patterns, predict outcomes, and improve decision-making processes.
- **Machine learning models:** statistical models that learn from historical data to predict future events, such as demand forecasting.
- **Data analysis programs:** tools used to analyze data, visualize trends, and extract actionable insights. Common examples include specialized analytics platforms, the most important of which are statistical package programs.
- **Inventory management systems:** programs that help track inventory levels, orders, sales, and deliveries and ensure that the right amount of inventory is available at the right time.
- **Simulation programs within Internet of Things sensors:** represented by the tools used that collect real-time data about inventory levels, conditions, and movement, and feed this information into AI systems for analysis to create a digital twin of the inventory management process to test different scenarios and predict the outcomes of different strategies.

**III.METHODOLOGY**

- **Sampling methods:** Selecting a random set of products to collect data. This method ensures that each product has an equal chance of being selected, which reduces selection bias and provides a representative sample by relying on a descriptive approach in understanding the data used and how it is collected and analyzed, as well as leaning towards a stratified sample based on specific characteristics (e.g., industry type and company size). Samples are then randomly selected from each stratum. This method ensures representation from all relevant subgroups and can lead to more accurate and reliable results, in addition to relying on case studies by knowing the comparisons to explain the AI tools and techniques used and their applications
- **Predictive analytics tools:** These are tools that use historical data and machine learning algorithms to predict future demand and improve inventory management. A deductive questionnaire for the procedural and methodological application to describe the steps for integrating AI techniques into spare parts management. Analysis of results and recommendations to improve the accuracy of demand forecasting and

determine the optimal reorder point. According to the set of elements, programs and application mechanisms that contribute to producing the achieved results and linking the relationships that clarify the research outputs.

- Study Design: refers to the overall plan for conducting a research study. In the context of integrating AI in spare parts management, a case study or quasi-experimental design might be suitable.
  - Case study: Involves an in-depth examination of a specific organization or system to understand the impact of AI implementation.
  - Quasi-experimental: Compares an intervention group (where AI is implemented) with a control group (without AI) to assess the effects.
  - Sample Size: Sample size determines the number of data points or observations required for the study. In this case, it would depend on factors such as:
    - Population size: The total number of spare parts or products managed by the organization.
    - Data availability: The amount of historical data available for analysis.
    - Desired level of precision: The desired accuracy of the results.

Statistical power: The ability to detect a significant effect of AI implementation. A power analysis can be conducted to determine the optimal sample size.

Types of Devices: In this context it would refer to the AI tools and technologies used that might include:

- Machine learning algorithms: Such as random forests, support vector machines, neural networks, etc., for demand forecasting and pattern recognition.
- Data mining tools: For extracting valuable insights from large datasets.
- Optimization algorithms: For determining optimal reorder points and inventory levels.
- Simulation software: To model different scenarios and evaluate the impact of AI interventions.
- Data visualization tools: For presenting results and findings effectively.

Case studies: studies involve the detailed examination of specific instances or scenarios, often within a real-world context, to understand how theories or concepts are applied in practice. In this context, the case studies refer to practical examples of how XYZ Company can utilize the data and strategies discussed in the two papers to enhance its spare parts inventory management. These studies provide actionable insights by demonstrating the effectiveness of using AI for demand forecasting, optimizing reorder levels to reduce inventory costs, and improving supplier management to ensure timely availability of spare parts.

The numbers and data mentioned in the tables used in this research are sourced exclusively from the company's database. These data represent detailed analyses conducted on the operational and business processes of the company, and have been utilized to assess and enhance performance in spare parts management and demand forecasting. Relying on this precise and comprehensive data strengthens the validity of the results and supports the feasibility of the recommendations presented in the study. Through advanced analytics, the company was able to identify strengths and weaknesses in supply chains and various management systems, enabling the development of sustainable strategies to improve efficiency and effectiveness at all operational levels.

#### IV. EXPERIMENTAL RESULTS

##### Reorder Point Calculation:

Calculate the reorder point by following these practical steps:

##### Reorder Point Formula

The Reorder Point (ROP) is calculated as follows:

$$ROP = (d * LT) + SS$$

Where:

- **ROP:** Reorder point
- **d:** Average daily demand
- **LT:** Lead time (in days)
- **SS:** Safety stock

In order to greatly improve the management of spare parts inventory, in order to improve the accuracy of forecasting under the use of AI to analyze historical data and predict future demand more accurately Reducing Inventory appropriate reorder levels and minimizing the need for safety Procurement supplier performance and optimizing lead times to ensure parts are available when needed.

Analyze inventory data from multiple Excel files to calculate the Economic Order Quantity (EOQ) and Reorder Point for different items. These metrics will help optimize inventory levels and reduce costs.

Table 4: Relationship between reorder point and infinite value

Material	Material Description	Reorder Point	Price
X1	Heater clamp 1x	11	715025.36
X2	Heater clamp 2x	2	715025.06
X3	PC Pump	11	694346.36
X4	Rotor	1	401766.73
X5	Forming Clamp	3	399831.39

Relationship between Reorder Point and Material

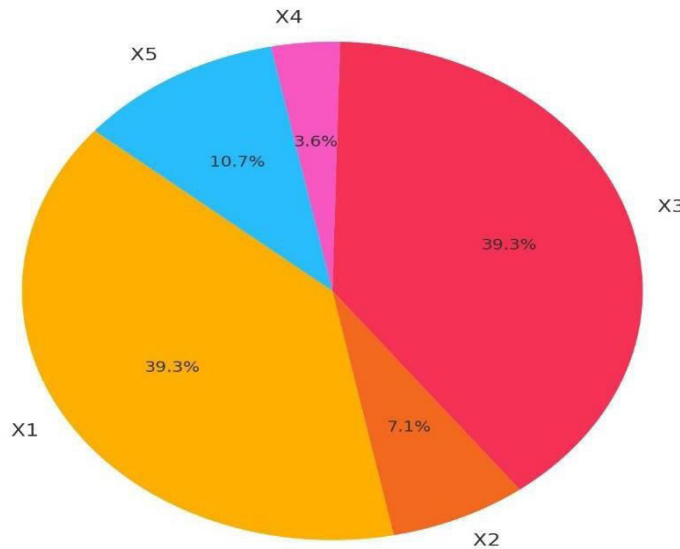


Figure 1: Relationship between Reorder Point and Material

**Safety Stock Calculation:** Understanding the Formula

The safety stock calculation involves two key steps:

Calculating standard deviation of lead time demand ( $\sigma_{LT}$ ), This measures the variability in demand during the lead time.

The formula is:

$$\sigma_{LT} = \sigma_D * \sqrt{LT}$$

Where:

- $\sigma_{LT}$  is the standard deviation of lead time demand
- $\sigma_D$  is the standard deviation of daily demand
- LT is the lead time in days

**Calculating safety stock (SS):**

This is the extra inventory held to buffer against demand uncertainty.

The formula is:

$$SS = Z * \sigma_{LT}$$

Where:

SS is the safety stock, Z is the number of standard deviations corresponding to the desired service level.

Table 5: Relationship between safety stock and material

Material	Material Description	Safety Stock
X1	Heater clamp 1x	10
X2	Heater clamp 2x	1
X3	PC Pump	10
X4	Rotor	0
X5	Forming Clamp	2

## V.CONCLUSION

### Discussion of Results:

Based on the analysis of the data and the tables presented, we find that:

**Descriptive Statistics:** The mean, median, and standard deviation of key measures such as unbound value and safety stock provides an overview of the central tendency and variance within the data set.

Unbound value and price per unit have high mean and median, indicating that the values are relatively large and that the distribution is centered around these values with some variation.

**Economic Order Quantity and Reorder Point:** The calculated economic order quantity values for each item are relatively close, indicating a constant economic order quantity required to minimize total inventory costs. The reorder points vary slightly, reflecting the different delivery times and order rates for each item.

### Recommendations:

**Inventory optimization:** Based on the calculated EOQ and Reorder Point, suggest optimal order quantities and reorder times.

**Safety stock:** Consider adding a safety stock to account for uncertainty in demand or lead time.

**ABC analysis:** Classify items into A, B, and C categories based on their value and usage to focus on the most critical items.

**Forecasting:** Use forecasting techniques to improve demand prediction and reduce forecast errors.

**Integrate AI Tools:** Continuously update AI models with new data for consistent forecasting accuracy. Use AI to analyze historical data and improve demand forecasting accuracy.

**Regular Reviews:** Periodically reassess EOQ, safety stock, and reorder points as demand patterns change.

**Training:** Ensure staff is trained to use AI tools effectively for inventory management. Train staff to effectively use tools and techniques to improve inventory management.

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