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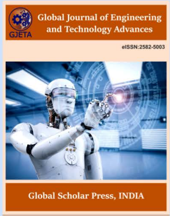

(Review Article)

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Utilizing industrial engineering methods and strategies to determine optimal inventory levels of spare parts: A review

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Abstract

A shortage of maintenance spare parts can lead to significant problems for the company, and sometimes even result in the disruption of operations. On the other hand, excess inventory will lead to increased storage costs and financial losses, as the monetary value over time diminishes due to financial inflation. The aim of this study is to determine the industrial engineering methods and strategies used to improve the effective management of spare parts inventory. To address the challenges and improve the efficient management of spare parts inventory, this study will review various industrial engineering techniques. These may include demand forecasting methods, inventory optimization models, supply chain management strategies, and data analysis techniques. By implementing these approaches, the company aims to achieve a balance between inventory levels and demand variability, thereby minimizing stockouts, reducing excess inventory, and optimizing financial resources. This will lead to improved operational efficiency, cost savings, and increased customer satisfaction by ensuring timely availability of spare parts for maintenance.

Keywords: Spare parts inventory; Six Sigma DMAIC; ABC classification; Intermittent demand forecasting; Bootstrap method; Supply Chain Management

1. Introduction

Nowadays, many companies focus on efficient and effective inventory management to achieve a distinct competitive advantage and improve their market position [1]. In this regard, the management of inventory plays a major role in the global economy. As stated by Prempeh [2], inventory management is a fundamental asset of the company with an economic value. Better inventory management can ensure high growth and profitability. The control over level of inventory and positioning of inventory has been considered as the two main purposes of inventory management. The importance of inventory management is the most vital task for the companies. Inventory control is a difficult task and has complex structures in many supply chains. The main question of inventory that needs to be addressed has been as to how to control the stock efficiently and ensuring the availability of spares. Hold the spares in stores tie up capital and resources of company that in result limit sales growth. Also, the stocking level of parts decline with period of time. Therefore, storing high levels of inventory can lead to financial burden [3-6]

Efficient inventory management is a main goal for both traditional or forward companies and for reverse logistics providers. Controlling and optimally managing the inventory in reverse logistics becomes complicated due to high uncertainties with regard to returned parts and products. In these companies, the collection of returned products is driven by supply rather than market demand. Therefore, as it cannot be controlled directly by the company, high uncertainties arise in terms of quality, time and quantity of returned products [7].

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Often, companies face a trade-off between maintaining low levels of stock or high levels of stock in inventory. The first option is to buy only when necessary, which means low costs but high risks in the event of a lack of stock. The second option is to hold high stock levels with high costs (high ordering costs, more inventory, more storage costs, high obsolescence, high working capital) but with a low risk of stock out [8]. To address this problem and to ensure optimal inventory management, companies should adopt different reordering policies for different classes of spare parts in order to keep low inventory levels while guaranteeing high efficiency and effectiveness.

2. Problem Description

Companies encounters significant complexities in effectively managing its spare parts inventory. The primary challenge lies in reconciling inventory levels with unpredictable demand fluctuations, aiming to avert both surplus stock and critical shortages. To address this multifaceted challenge, our approach involves utilizing the 5 Whys analysis method to uncover underlying causes. Through Fig (1), it was identified that excessive storage incurs heightened retention costs, constraining financial resources and physical storage capacity. Conversely, insufficient inventory leads to operational disruptions, resulting in production delays and operational halts.

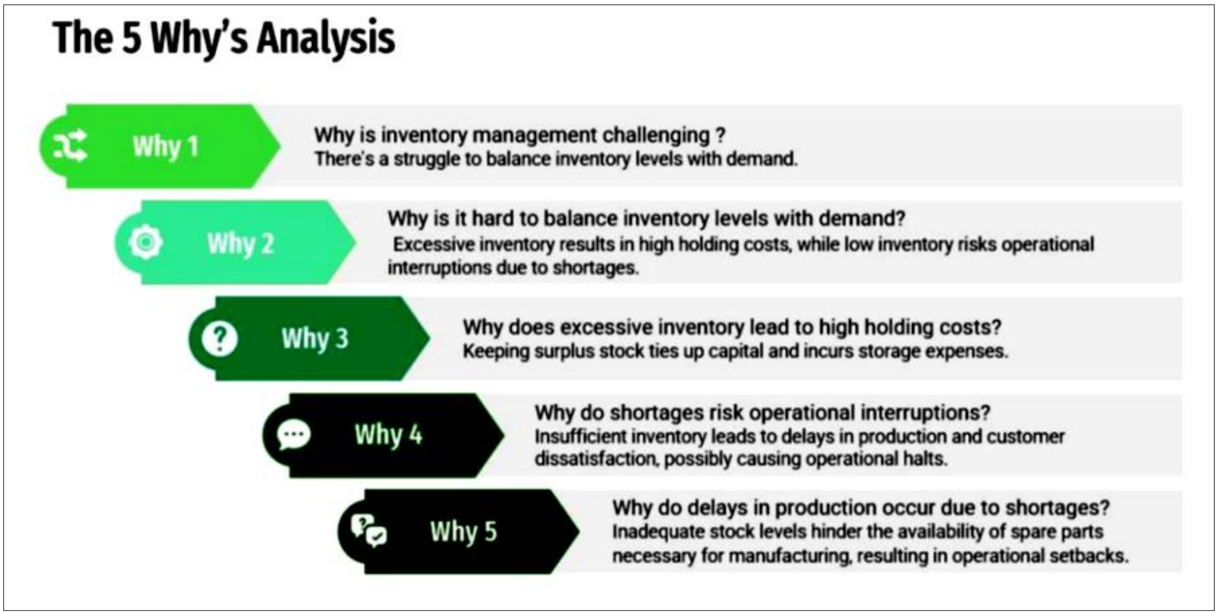

Figure 1 The 5 Whys Analysis

2.1. Proposed Solutions

- **Inventory Management Techniques:** Perform a comprehensive analysis of historical data to implement advanced and effective strategies such as ABC classification for spare parts costs and EOQ strategy to determine optimal quantities for critical spare parts and set the reorder point.
- **Inventory Organization Improvement:** Implement the 5S methodology to enhance the efficiency and organization of spare parts storage. This includes sorting, organizing, cleaning, establishing standardized processes, and maintaining these practices to improve overall inventory management.
- **Forecasting Intermittent Demand:** Utilize repeated sampling of historical data using the bootstrap strategy to forecast intermittent demand for spare parts. This approach provides a range of potential demand scenarios, aiding in better decision-making regarding inventory levels and order quantities.
- **Supply Chain Management:** Streamline the supply chain for valve repair spare parts through strong supplier relationships and contingency plans.
- **Inventory Management System:** Implement ERP system for efficient inventory management, integrating data and processes, providing real-time visibility, and enabling informed decision-making. Streamline workflow, optimize inventory control, and enhance operational efficiency.
- **Integration of Sustainability Practices:** Implement eco-conscious practices across the entire inventory lifecycle, encompassing responsible sourcing and environmentally friendly disposal methods.

3. Methods and Strategies

3.1. Warehouse impact on SC

Warehouses play an important role in the supply chain by serving as a link between producers and end consumers. Warehouses not only serve as a place to store goods, but also have other important functions. Operational efficiency and logistics control in finished goods warehouses are increasingly becoming an urgent need for companies in various industries. However, ineffective warehouse management can lead to negative impacts such as decreased profits and customer dissatisfaction. Therefore, efforts are needed to manage warehouses with good efficiency and structure [9].

Warehouses are considered a strategic component of supply chains in the literature (e.g., Mahalakshmi et al., [10]; Soundararajan and Reddy, [11]; Oey and Gabriella, [12]; Valmohammadi and Dadashnejad, [13]). They play an integrative role, interfacing with production lines, markets, suppliers, customers, and the broader business environment [14]. Warehousing operations are vital to the business strategy of manufacturing organizations allowing for the timely shipping and receiving of essential stocks for replenishing shelves or manufacturing plants [15,16]. The Warehouse Management System (WMS) is crucial in the innovation and development of businesses, encompassing processes like order picking, handling, loading, palletizing, and stacking [17].

Based on a survey conducted by McCrea [18] more than half (56%) of the companies surveyed use WMS, inventory management, etc. WMS aids inventory management with real-time stock data, preventing shortages or excesses. Successful implementation demands proper strategy, tech utilization, planning, system integration, and employee training. Thus, WMS implementation can bring about positive changes in warehouse operational efficiency, inventory optimization, and meeting customer needs.[9].

In today's competitive environment, continuous improvement in warehouse operations is essential, given warehouses' role as nodes connecting the flow of materials between suppliers and customers [17].

3.2. DMAIC methodology and its application

The DMAIC (Define, Measure, Analyze, Improve, Control) framework is a pivotal element of Six Sigma methodologies, offering a systematic, structured approach to problem-solving across various sectors [19,20]. Figure (2) Table (1) cover the five phases of the DMAIC methodology and what tools are used in each phase.

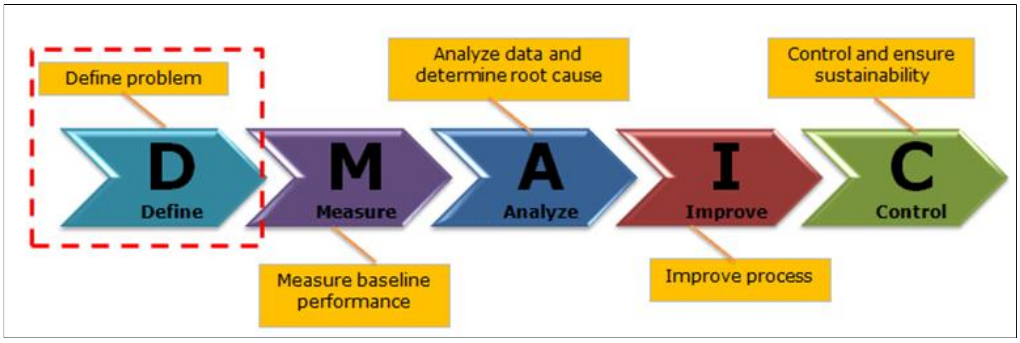

Figure 2 The DMAIC methodology

Table 1 DMAIC method

Phases	Tools
Define the problem, improvement activity, opportunity for improvement, the project goals, and customer (internal and external) requirements	Project charter SWOT Analysis Process map
Measure process performance	Data Collection Interview method.

Analyze the process to determine root causes of variation and poor performance (defects).	SMART method Issue tree Prioritization matrix Pivot table
Improve process performance by addressing and eliminating the root causes.	ABC Strategy EOQ model Bootstrap method 5S method
Control the improved process and future process performance	Failure Mode and Effects Analysis

In the Define phase, the problem is identified and mapped with precision, setting goals based on customer expectations, and ensuring alignment with the project's real value [21]. This initial phase lays the groundwork for all subsequent steps, emphasizing the importance of clarity and focus on customer-centric objectives [22].

In the Measure phase, the emphasis is on data collection to quantify the identified problems, which forms the foundation for a thorough analysis. This step is essential for establishing the metrics that will guide the analysis and improvement phases [19,22]. The Analyze phase then takes center stage, utilizing the collected data to pinpoint the source of the problem and quantify the gap between the current and desired states. This phase employs graphical and analytical tools to elucidate deviations and inefficiencies [19]. The Improve phase is where solutions are not only defined but also rigorously tested to ensure their effectiveness before implementation. This stage is crucial for translating insights into actionable changes that can have a significant impact on the process [22]. Finally, the Control phase serves as the capstone of the DMAIC process, monitoring the implemented solutions to ensure they deliver sustained improvements and align with the project's goals. This last step is vital for maintaining the gains achieved and ensuring that the solutions continue to meet the desired objectives over [19,23].

3.3. ABC strategy

The ABC strategy is an inventory management approach that classifies items into different categories based on their value or importance Fig.(3). It helps to allocate resources effectively, optimize inventory levels, and improve overall operational efficiency. Initially, extract historical data of spare parts including their cost and inventory quantity. Using Excel functions, these parts are then classified based on their costs to identify high-cost critical spare parts, focusing on ordering them in an economical quantity to reduce costs and avoid unnecessary stockpiling of non-critical high-cost spare parts.

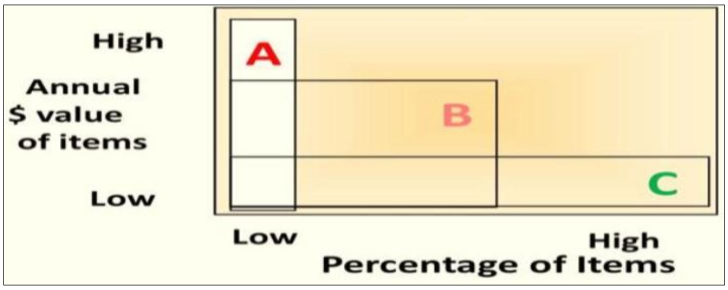

Figure 3 ABC strategy

In his article [24], Ramanathan proposed to implement multi-criteria ABC classifications with weighed linear optimization. Chen proposed in [25] the use of case-based multiple-criteria ABC analysis by accounting for additional criteria, such as lead time and criticality of stock-keeping units. Also, Partovi and Anandarajan proposed in the reference [26] the use of the ABC-analysis integrated with Artificial Neural Networks for stock-keeping units. On the other hand, Boylan uses the variability of demand and the control frequency through a two-dimensional matrix in his classification in [27].

Categorizing spare parts into A, B, and C groups facilitates spare parts inventory management, especially for companies which have tens of thousands of spare parts. Nevertheless, most research on ABC classification has concentrated on developing classification methods, and only three contributions (Mohammaditabar et al [28], Zhang et al. [29] Teunter et al. [30] addressed linking ABC classification to the selection of a stocking strategy. Mohammaditabar et al. [28]

proposed an integrated model that concurrently classifies inventory items and selects appropriate policies for each product group with the objective of effective inventory performance. The proposed model was compared with annual dollar usage (ADU), AHP weighted score, the method proposed by Zhang et al. [29] and optimal inventory score, and exceeded all of them in minimizing both dissimilarity and total inventory value. Two other papers classified spare parts into ABC groups incorporating selection of stocking strategies. Zhang et al. [29] developed a new ABC classification criterion, which is a ratio taking into account expected demand per year, lead time, and unit cost. Based on the new criterion, the determination of reorder points and reorder quantities was investigated. A numerical study showed that the proposed ABC scheme did not introduce large errors. Teunter et al. [30] proposed a further new cost criterion for ABC classificationThe criterion takes four system parameters into account, namely demand rate, holding cost (purchase price), shortage cost (criticality), and average order quantity. Based on classification results using the new criterion, the cycle service level for each class can then be fixed, where the A group should have the highest service level, followed by B and then by C. A numerical experiment using three real life datasets showed that the proposed criterion outperformed the criterion proposed by Zhang et al. [29].

3.4. EOQ model in inventory managment

The Economic Order Quantity (EOQ) model Fig.(4) is a fundamental inventory management tool that optimizes order quantity to minimize the sum of holding and ordering costs. This model is particularly effective in spare parts management, where maintaining an optimal inventory level is crucial for operational efficiency and cost reduction. The EOQ formula, which takes into account factors such as annual demand, ordering cost, and holding cost, provides a decision-making framework for inventory management across various industries. In the context of spare parts management for oil drilling companies, the EOQ model, when combined with ABC analysis for inventory classification and forecasting methods for demand prediction, can significantly streamline inventory levels (Sato & Jauhari, 2024). This approach ensures the availability of critical components, minimizes the risk of stockouts and excess inventory, and leads to a more economical and environmentally friendly operation. The application of EOQ in retail environments further demonstrates its versatility, aiding companies in maintaining a competitive advantage by reducing stockouts and associated costs while satisfying customer demand [31].

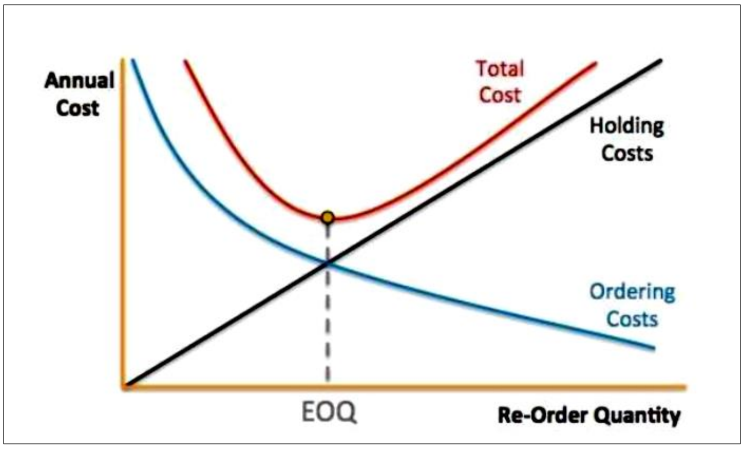

Figure 4 EOQ Model Graph

3.5. Demand Forecasting and the bootstrap method

Forecasting spare parts demand is a complex task due to the intermittent nature of the demand, which traditional time series forecasting methods often fail to address effectively. The bootstrap method Fig.(5) has been recognized as a robust approach to tackle this issue, as it employs resampling techniques to create empirical distributions from historical data, allowing for the prediction of future demand without the need for a predefined parametric model of the data. This method's practicality is particularly evident in its ability to handle large datasets and simulate demand values not present in historical data, which is a significant advantage over other forecasting methods like exponential smoothing and Croston's method [32].

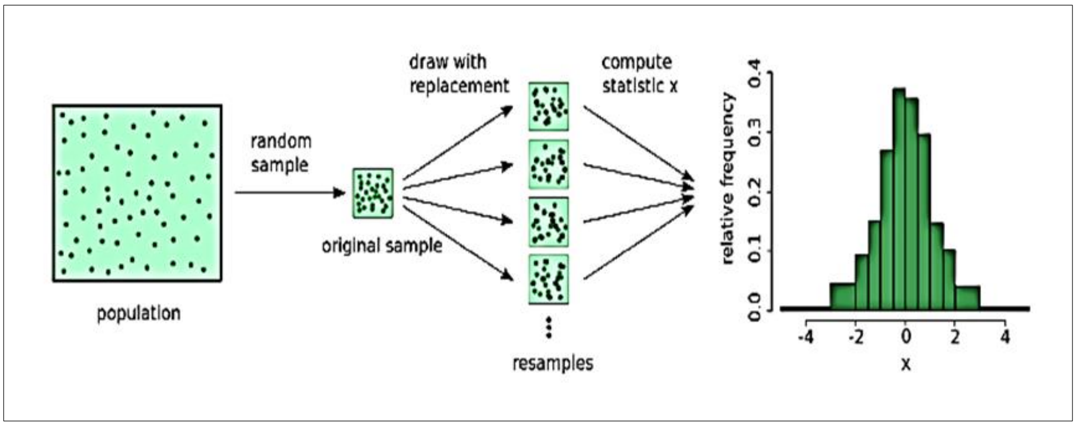

Figure 5 Process of Bootstrap method

In recent literature, there has been a shift towards integrating machine learning and transfer learning techniques to enhance the accuracy and stability of demand predictions. For instance, Fan & Song [33] propose a transfer learning-based method that adapts to the intermittent features of demand series, enhancing prediction stability and accuracy Fig.(6).

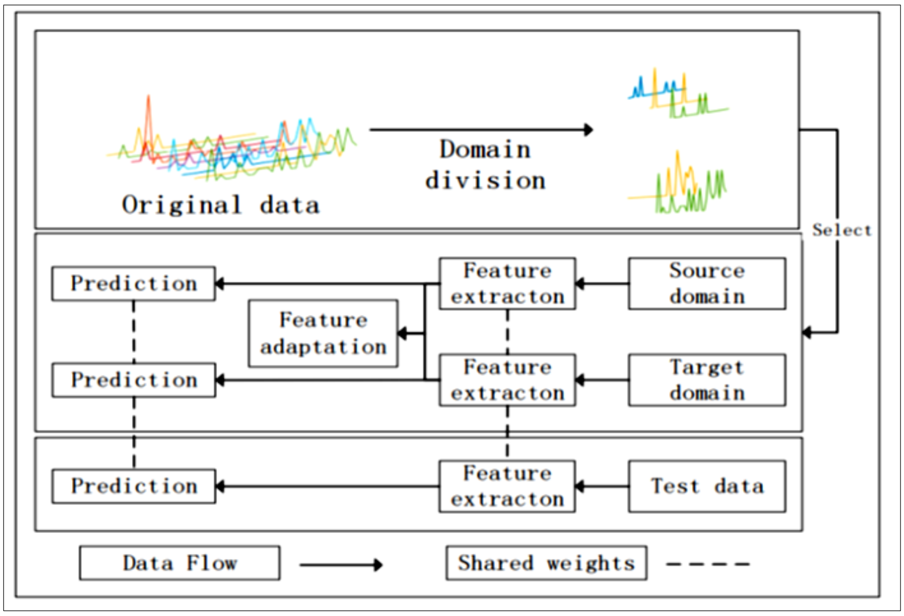

Figure 6 Flowchart of Intermittent Feature Adaptation-Based Spare Parts Demand Forecasting Method

This method involves partitioning the time series domain using a hierarchical clustering algorithm, constructing a weight vector that combines intermittent and temporal characteristics, and learning common information across domains by weighting the output feature distances of each cycle. Such advancements indicate a growing recognition of the need for models that can incorporate the intermittent characteristics of spare parts demand to improve forecasting performance. The integration of temporal and intermittent characteristics into a weight vector facilitates the learning of common evolutionary laws among spare parts demand, offering a promising direction for future research and application in the field [33].

According to the literature review, the use of the bootstrap method is variable. The method has been of interest in academia and focused on intermittent part forecasting [34]. It is combined with tools such as neural networks [35] and the Markov chain [36]. It can be said that the bootstrap approach using the Markov chain is the best method for predicting intermittent demand for spare parts since it gives better results compared to traditional methods, such as, simple exponential smoothing and Croston [34-36].

3.6. 5S method

The 5S strategy is a systematic approach to workplace organization and efficiency. It involves five key steps Fig (7): Sort, Set in Order, Shine, Standardize, and Sustain. The 5S strategy is a powerful tool that we are implementing to enhance our inventory management for spare parts. This methodology, aims to achieve efficient housekeeping practices and improve overall operational effectiveness. The 5S strategy will not only optimize the storage space and streamline processes but also significantly contribute to the enhancement of our maintenance operations. By organizing and categorizing maintenance spare parts, it can ensure easy accessibility and minimize downtime. The systematic arrangement of spare parts will enable quick identification and retrieval, facilitating timely maintenance activities and preventing unnecessary disruptions.

Figure 7 5S method

3.7. Some models of spare part inventory management system.

Nagarur et. al.[37] studied the spare part inventory system of a computer industry. The aim of this study was to relate stock quantities accordingly to demand that may avoid overstocking and understocking of spares. They classified spares into four categories depending upon their cost and lead time. Forecasting models with high degree of accuracy were implemented, demand forecasting was determined and ordering points and safety stock were computed. Kumar and Knezevic [38] gave the optimization model in spare part for both series and parallel structures. The study presented optimization model in spares for both series and parallel system and concluded the objective which maximize the availability with respect to minimizing the space. The problem was solved with the help of simple algorithms. The model helped in predicting the spare requirements to achieve specified availability of stores with minimum space. Kobbacy and Liang [39] proposed an intelligent inventory management system that assisted in decreasing the gap connecting practice and theory of inventory management. Authors proposed an automatic demand and lead time detection to validate the model. The empirical evaluation of this system with real data of manufacturing industries showed that system could lead to considerable saving of inventory cost. Braglia et al.[40] implemented a multi attribute classification technique for spares inventory management for a paper industry The authors proposed the Inventory policy matrix that linked with different classes of spares which were used for identifying best control strategy of spare parts. The purpose of study was to develop the decision support tool for maintenance managers and adjust the basic approach to validate the policy of inventory for each spares in easy and quick manner. Ahn and Seo[41] proposed a model for ordering in inventory system. Also, authors introduced the ordering range (s, S) in inventory system. 's' was considered as the ordering point of inventory and 'S' was considered as maximum level of inventory The model proposed in the study has dealt transportation lead time that was a transportation constraint. This model was tested with the help of numerical example and showed computational results that concluded the effectiveness of this model. Gebauer et.al.[42] aimed to offer recommendation in increasing spares logistic. The paper suggested that recommendations for, increasing spares logistics had been rare despite of the proved benefit of high performing spares logistic. The study analyzed that necessary changing achieved a cutting-edge logistics solution which showed how companies should implement their solution. Ghodrati et.al.[43] studied the product support improvement of spare parts by considering the environment of operating system. The authors suggested also said that forecasting of spares on basis of reliability and maintainability along with environmental conditions could be most effective strategy for untimely stoppages. It was generalized from the research that system operating environment should be considered while spare parts estimation was done. After studying the various factors which influenced product support the spares management software was used for checking the result. Oguji Nnamdi [44] in his study explores operations and inventory strategies for reducing and controlling excess inventory. The paper proposes managerial tool-box that includes both Strategic: (ownership and key performance indicators, strategic policy on reverse logistics, customer buy-backs, large purchase volumes for sourcing savings, leveraging Big Data and Analytics). Reactive: (lateral transshipment, scraping & disposal of excess inventory, sales discounts, spare parts dismantling into sub spare parts). Proactive: (Croston/SBA forecasting, exception management for data errors, tool/algorithm for new spare parts forecasting, part replacement control measures, forecasting sudden decrease in demand and part life-cycle pricing) measures on how excess inventory can be controlled and reduced. Lukitosari et.al [45] developed a strategy comprising a model for obtaining the best choice based on inventory cost and spare part availability. We developed four scenarios for addressing spare parts supply and evaluated them in terms of costs and the duration of downtime. Scenarios were built on modules with combinations of onsite stock, redundant configurations, and fast supply from external sources. The results suggest that the best scenarios in terms of costs are those that do not hold inventory and those that do not use standby components as redundant parts installed in the system.

4. Conclusion and Recommendation

This review discusses the optimization of spare parts inventory management. It introduces some fundamental methods and storage strategies. These methods aim to improve inventory levels, maintenance processes, and mitigate risks associated with shortages and surplus inventory. By implementing these approaches, the company aims to achieve a balance between inventory levels and demand variability, thereby minimizing stockouts, reducing excess inventory, and optimizing financial resources. It can enhance the accuracy of spare parts forecasting by investing in the development of historical data records. This data will enable informed decision-making and better anticipation of future spare parts requirements. Implement the Economic Order Quantity to determine the optimal order quantity that minimizes total inventory costs and achieves a balance between ordering and holding costs. Identify reorder points to efficiently replenish inventory and avoid stockouts. Using the Bootstrap method to estimate inventory parameters, allowing for better forecasting accuracy, and reducing uncertainties in demand estimation.Employ the ABC analysis to classify inventory items based on their monetary value and prioritize management efforts accordingly. This helps focus resources on high-value items while improving inventory control for low-value items. Organize the inventory using the 5S methodology to streamline operations, improve visibility, and reduce waste in the warehouse. Regularly review the inventory to identify obsolete parts and remove them, saving space and reducing the risk of unnecessary inventory carrying.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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