Spare Parts Inventory Planning In The Aircraft MRO Industry By Integrating Demand Categorization And The RPA (s,S) Policy Method

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Abstract.
Air transportation in Indonesia has experienced significant growth in passenger traffic over the past few years, driven by factors such as travel distance, time efficiency, safety, and service quality. From a safety perspective, one critical aspect that must not be overlooked is the availability of spare parts during Maintenance, Repair, and Overhaul (MRO) activities, as it directly affects aircraft airworthiness and flight safety. Demand for spare parts in the MRO industry is influenced by maintenance schedules and aircraft utilization, resulting in varying demand patterns characterized by different levels of demand variability and demand frequency. This study focuses on inventory planning in an Indonesian aircraft MRO company using the Revised Power Approximation (RPA) (s,S) policy. The proposed inventory policy is evaluated by comparing its performance with the company's existing inventory management approach in terms of total inventory cost and customer service level. The results demonstrate that the RPA (s,S) policy can effectively reduce inventory-related costs and improve service performance, thereby enhancing spare parts availability to support maintenance operations and flight safety.
Keywords: *Promotions, Discounts and Purchase Interest.*

I. INTRODUCTION

The main heading of each section should be written in capital letters and numbered using Arial Narrow font In the aircraft industry, the availability of spare parts for MRO activities is crucial. Companies face a dilemma: when spare parts are unavailable at the time they are required for flight operations, the aircraft may enter Aircraft on Ground (AOG) status, which indicates that the aircraft is not airworthy and cannot be operated [10]. Spare-parts demand patterns may vary depending on maintenance schedules and aircraft utilization, and demand for spare parts classified as intermittent demand represents one of the major challenges in spare parts availability management [5]. This condition may result in substantial backorder costs, reduced service levels, and difficulties in meeting customer demand. On the other hand, excessive spare parts inventory will significantly increase holding costs [9].

According to the National Aviation Academy [12], aircraft maintenance processes consist of light maintenance, such as line maintenance and A-checks, as well as heavy maintenance, including B-checks, C-checks, and D-checks. Aircraft maintenance schedules and the spare parts required have been strictly regulated. Meanwhile, aircraft utilization depends on passenger demand. Companies tend to schedule major maintenance activities during the low season to ensure operational readiness during the high season.

The International Air Transport Association (IATA) [6] classifies aircraft spare parts into three categories: expendable, repairable, and rotable. Expendable spare parts have a 100% scrap rate and are intended for single use only; therefore, they are treated as inventory items. Repairable spare parts have a scrap rate between 1% and 100% and can be repaired when damaged. Meanwhile, rotable spare parts have a near-zero scrap rate because their service life is maintained and they are also repairable. Both repairable and rotable spare parts are generally classified as company assets.

This study applies demand categorization to categorize expendable spare parts that are routinely used in MRO activities by employing the method proposed by Syntetos, Boylan, and Croston [14], focusing specifically on the intermittent demand category. After categorization, an inventory planning model is developed under a periodic-review inventory system using 24 periods of historical demand data. The total inventory cost is calculated based on holding costs and backorder costs incurred within 12 periods and then compared with the actual total costs generated under the company's current inventory management practice. The customer service level is calculated based on the probability of stockout for each spare part. The results are expected to provide practical guidance for MRO planners in determining reorder thresholds that minimize AOG-related risk.

Numerous studies have been conducted to classify demand patterns using the method developed by Syntetos, Boylan, and Croston [14]. This method has been widely applied across various industries for demand categorization, including the heavy-duty vehicle industry [7], the retail industry [15], and the aviation industry [13]. The method classifies demand based on the variance and interval of demand occurrences within a given period, resulting in four demand categories: smooth, erratic, intermittent, and lumpy.

Several inventory planning methods for intermittent demand have also been investigated in previous studies. Tian et al. [14] compared several forecasting and inventory planning methods in the retail sector, including simple exponential smoothing, the Croston method, the Markov-combined method, and the Syntetos–Boylan approximation, to identify the method with the lowest forecasting error. Their findings indicated that the Markov-combined method provided superior performance. Similarly, Sahin et al. [13] compared several methods suitable for non-smooth demand patterns, including intermittent demand, such as Croston, exponential smoothing, naïve, and Syntetos methods. Their results showed that exponential smoothing was the most appropriate method for expendable spare parts because it resulted in the lowest inventory cost. Kenzhevayeva et al. [10] also investigated intermittent demand for aircraft spare parts by comparing an order-up-to inventory model combined with a negative binomial distribution and an (s, S) inventory model. The results demonstrated that the (s, S) inventory model generated the optimal inventory level for repairable and rotable spare parts. In a stochastic inventory context, Zhu et al. [16] integrated minimum order quantity (MOQ) and batch ordering mechanisms into (s, t) and (s, S) inventory policies. Their findings showed that the (s, S) policy resulted in the lowest total inventory cost.

Although previous studies have investigated intermittent demand forecasting and inventory policies in aviation spare parts, few studies have integrated demand categorization with the RPA (s, S) policy for expendable spare parts in Indonesian MRO operations. The RPA (s, S) policy was selected because it is suitable for aircraft spare-parts planning involving single-item independent demand, backorder fulfillment, fixed lead times, and stochastic demand environments characterized by measurable means and variances.

II. METHODS

The data required for inventory planning in this study consist of historical demand data for stock keeping units (SKUs) of expendable spare parts obtained from one of the largest aircraft MRO companies in Indonesia.

2.1 Demand Categorization

The first stage of inventory planning in this study is to determine the demand categorization based on historical demand data over the last two years. Demand categorization is performed using the method proposed by Syntetos, Boylan, and Croston [14], which divides demand into four categories: smooth, erratic, intermittent, and lumpy.

The categorization is based on two criteria: coefficient of variation (CV^2) and average demand interval (ADI). The calculation follows the equations provided by Kaya et al. [8]:

$$ADI = \frac{\sum_{i=1}^{N} t_i}{N} \quad (1)$$

$$CV^2 = \left(\frac{\sqrt{\frac{\sum_{i=1}^{N} (D_i - \bar{D})^2}{N}}}{\bar{D}} \right)^2 \quad (2)$$

The demand categories are illustrated in Figure 1.

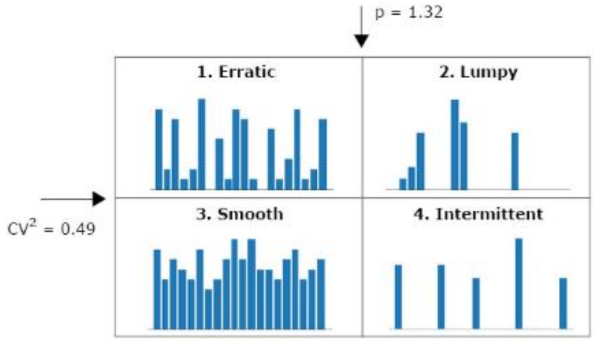

Fig. 1. Syntetos, Boylan & Croston (2017) Demand Categorization

Erratic demand with high variation with relatively regular intervals, Lumpy demand with high variation with irregular intervals, Smooth demand with low variation with regular intervals, and Intermittent demand with low variation with irregular intervals. In this study, the focus is placed on the intermittent demand category, as it represents the most critical inventory issue in aircraft spare parts management

2.2 Revised Power Approximation (s,S) Policy

The Revised Power Approximation (RPA) (s, S) policy is an inventory planning method developed by Ehrhardt and Mosier [4] as an improvement of the original Power Approximation (s, S) policy introduced by Ehrhardt [3]. Under the RPA (s, S) policy, when the available inventory level plus outstanding orders (y) is less than or equal to the reorder point (s), a replenishment order is triggered with an order quantity of S − y. In this study, we present inventory planning under a periodic-review inventory system using 24 periods of historical demand data.

The main assumptions of the RPA (s, S) policy are as follows:

1. Lead time is constant
2. Demand is independent
3. Demand follows a statistical distribution with a measurable mean and standard deviation
4. Holding cost and backorder cost are calculated at the end of each period

The calculation is based on the equations developed by Ehrhardt and Mosier (1984)

$$D_p = 1{,}30\mu^{0{,}494}\left(\frac{K}{h}\right)^{0{,}506}\left(1+\frac{\sigma_L^2}{\mu^2}\right)^{0{,}116} \quad (3)$$

$$S_p = 0{,}973\mu_L + \sigma_L\left(\frac{0{,}183}{z} + 1{,}063 - 2{,}192z\right) \quad (4)$$

$$z = \left[\frac{D_p}{\sigma_L \frac{p}{h}}\right]^{\frac{1}{2}} \quad (5)$$

$$\mu_L = (L+1)\mu \quad (6)$$

$$\sigma_L^2 = (L+1)\sigma^2 \quad (7)$$

In the study by Kenzhevayeva et al. (2021), the RPA (s, S) policy was applied to manage spare parts inventory in the aviation industry by integrating the approach of Wagner (1965) to determine the values of S and the setup cost (K).

If $D_p/S_p > 1.5$:

$$s = S_p \quad (8)$$

$$S = S_p + D_p \quad (9)$$

If $D_p/S_p < 1.5$:

$$s = \min\{s_p, s_0\} \quad (10)$$

$$S = \min\{s_p + Q, S_0\} \quad (11)$$

$$S_0 = (L+1)\mu + \theta\sigma\sqrt{L+1} \quad (12)$$

$$K = \left(\frac{\text{Average size} \times h^{0{,}506}}{1{,}3 \times \text{Average Demand}^{0{,}494} \times \left(1+\frac{\sigma^2}{\text{Average Demand}}\right)^{0{,}116}}\right)^{1{,}97} \quad (13)$$

2.3 Total Inventory Cost

The total inventory cost for periodic review inventory is calculated based on two main components [2]:

1. holding cost, representing the cost of maintaining inventory at the end of the period
2. backorder cost, representing the additional cost incurred when stock is unavailable at the time demand occurs

In the aviation industry, backorder costs are generally much higher than regular purchasing costs because stock shortages may lead to Aircraft on Ground (AOG) conditions, which must be resolved immediately to avoid operational disruption.

The total inventory cost generated by the RPA (s, S) policy is then compared with the total cost generated by the company's current inventory management method.

2.4 Customer Service Level

Customer service is defined as a company's ability to meet customer requirements. In inventory management, customer service reflects the availability of the products needed by customers at the time demand arises and has a direct impact on customer satisfaction [11]. One commonly used measure of customer service level is the fill rate, which represents the percentage of customer demand that is fulfilled directly from available inventory. The fill rate can be calculated as follows [1]:

$$Fr = 1 - \frac{\text{Jumlah Stock Out}}{\text{Jumlah Demand}} \qquad (14)$$

III. RESULT AND DISCUSSION

The results of the demand categorization were obtained by calculating CV² and ADI, where the intermittent demand category was identified using the criteria $CV^2 \leq 0.49$ and $ADI \geq 1.32$. These values indicate that the demand variation is relatively low, while the time interval between demand occurrences is considerably large. Out of a total of 1,177 Out of the 1,177 expendable spare-part SKUs analyzed in this study, 628 SKUs were classified as intermittent demand (Figure 2). This is consistent with the study conducted by Ghobbar and Friend [5] which stated that the most significant inventory problems in aircraft maintenance operations are largely associated with intermittent demand patterns.

After identifying the intermittent demand items, the inventory parameters were calculated using the RPA (s, S) policy to determine the values of s and S.

- s represents the reorder point, indicating the inventory level at which replenishment must be initiated.
- S represents the order-up-to level after replenishment.

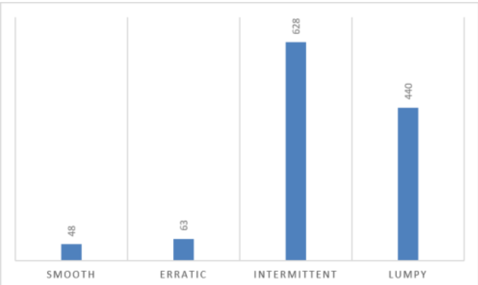

Fig. 2. SKU demand Categorization

Thus, whenever the inventory level reaches or falls below s, the company places an order to restore the stock level up to S. The calculated (s, S) values were then applied to the actual demand data for the subsequent period to estimate the resulting holding cost and backorder cost. These costs were then compared with the costs generated by the company's current inventory management method.

3.1 Total Invemtory Cost Analysis

The results show that the implementation of the RPA (s, S) policy led to an increase in total holding cost by 5.2% compared with the company's existing method. However, in terms of backorder cost, the RPA (s, S) policy demonstrated a significant reduction of 38.7%. Although the holding cost increased by 5.2%, the increase is relatively small compared with the 38.7% reduction in backorder cost. In the aircraft MRO industry, stock shortages may result in Aircraft on Ground (AOG) events, which generate substantially higher operational and financial consequences than inventory holding costs. Therefore, maintaining additional inventory can be justified as a risk-mitigation strategy. Overall, the total inventory cost decreased by 12.9%, from $433,213.01 to $377,195.92 (Figure 3). This indicates that the proposed method provides better cost efficiency despite the increase in inventory holding cost.

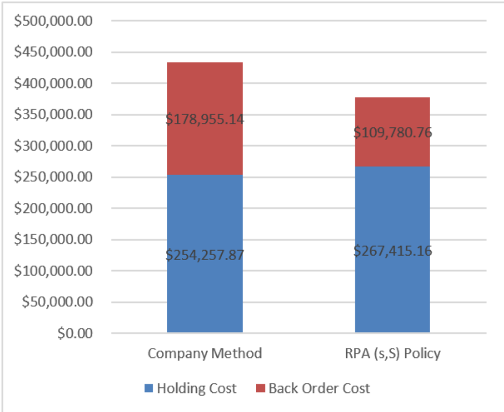

Fig. 3. Inventory Cost with company's current inventory management method and RPA (s,S) Policy

3.2 Holding Cost Analysis

The initial holding cost at the end of 2024 was $177,060.19 for both the company's current method and the RPA (s, S) policy. At the end of 2025, the holding cost under the RPA (s, S) policy is 5.2% higher than that of the company's current method. The increase in holding cost occurred because the RPA (s, S) policy requires maintaining the inventory level of each SKU at or above the predetermined reorder point (s). This increase was particularly significant at the beginning of the implementation period due to the adjustment from the company's existing inventory method to the RPA (s, S) policy. As a result, any SKU with stock equal to or below s had to be replenished immediately up to the level S, and this inventory level was maintained throughout the period. Although this resulted in higher storage costs, it reflects the necessity of maintaining spare parts availability in the aviation MRO industry.

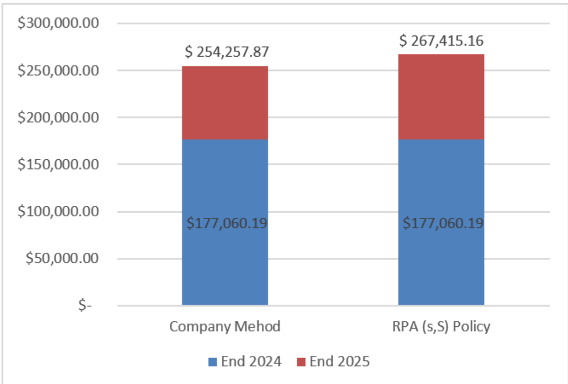

Fig. 4. Holding Cost with company's current inventory management method and RPA (s,S) Policy

3.3 Backorder Cost Analysis

A substantial reduction in backorder cost was observed because spare parts availability was maintained at a safer stock level. This finding aligns with the main objective of inventory planning in the aircraft MRO industry, which is to minimize the cost associated with Aircraft on Ground (AOG) conditions caused by stock unavailability.

Fig. 5. RPA (s,S) Policy Backorder Cost

At the beginning of the period, the increase was caused by the transition from the company's previous inventory policy to the RPA (s, S) policy, where several SKUs had stock levels below the reorder point and therefore required immediate replenishment. At the final quarter of the period, another significant increase in backorder cost was observed. Based on the demand data, this was caused by an increase in aircraft maintenance activities, which led to higher demand for spare parts.

This suggests that the values of s and S should be recalculated periodically to reflect operational changes, especially planned maintenance workloads in future periods. Such periodic adjustments would help further reduce the risk of backorders.

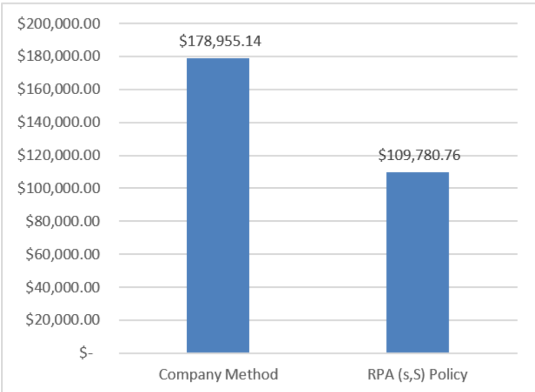

Fig. 6. Backorder Cost with company's current inventory management and method RPA (s,S) Policy

The backorder cost under the RPA (s, S) policy decreased significantly by 38.7% compared with the company's current method. This reflects the trade-off between higher holding costs and lower backorder costs in aviation MRO inventory management.

3.4 Service Level Analysis

Fill rate is used as a measure of customer service level, which represents the percentage of customer demand that is fulfilled directly from available inventory for each SKU obtained from inventory planning using the RPA approach and the company method.

Figure 7 shows that there is an improvement in the CSL level when inventory planning uses the RPA method compared to the current method by 2.4%. This represents a significant improvement because the customer service level achieved under the company's current method is below the company's target service level of 95%. This is also reflected in the reduction of backorder values.

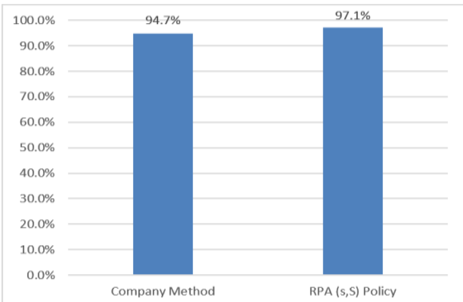

Fig. 7. Fill rate company's current inventory management and method RPA (s,S) Policy

IV. CONCLUSION

The inventory planning approach using the RPA (s, S) policy demonstrated a reduction in total inventory cost and an improvement in customer service levels, although this improvement came with the consequence of increased holding cost. The increase in holding cost requires further evaluation, particularly regarding the company's storage facility capacity and warehouse readiness.

The most significant improvement was observed in the backorder cost, which decreased substantially due to the higher minimum stock level maintained under the proposed method. From the perspective of the aircraft MRO company, this outcome is highly beneficial because it helps prevent AOG events resulting from spare-part shortages during maintenance operations.

This study also highlights the importance of periodic inventory planning evaluation, both in terms of the planning horizon and adjustments based on future maintenance workloads. Such adjustments can reduce the potential impact of backorder costs.

In addition, several SKUs in the company's procurement process are subject to minimum order quantity (MOQ) requirements. Therefore, MOQ can be considered as an additional criterion in determining the value of S in future inventory planning models.

V. ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to all individuals and organizations who supported the data collection process at the company where this study was conducted.

VI. AUTHORS CONTRIBUTION

Raga C. A. Pambudi contributed to Conceptualization, Data curation, Formal analysis, Methodology, Writing - Original Draft

Yuri M. Zagloel contributed to Supervision, Writing - Review & Editing.

VII. DECLARATION OF COMPETING OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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