Decision Support System for Optimizing Spare Parts Forecasting for Training Aircrafts

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Abstract:- The sporadic nature of demand pattern of aircraft maintenance repair parts renders the forecasting of these spares an immensely complicated task. This research effort deals with techniques applicable to predicting spare parts demand for the training aircrafts. The experimental results of 3 forecasting methods, including those used by aviation companies, are examined and validated through statistical analysis. Actual historical data of 118 training aircrafts for hard-time and condition-monitoring components from the Aviation Flying Training School was used, in order to compare different forecasting methods when facing intermittent and lumpy demands. The results confirm continued superiority of weighted moving average and exponential smoothing method for intermittent demand, whereas most commonly used naive methods used Aviation Flying Training School was found questionable. A new approach has been devised for forecasting evaluation; formulation of a comparative analysis matrix to isolate most critical parts in terms of their prices and quantities followed by a predictive error-forecasting model which compares and evaluates forecasting methods based on their factor levels when faced with intermittent demand. This research is useful to identify parts/spares critical to the operation of a training aircraft in terms of both their prices and quantities and application of reliable and robust forecasting method to predict the future demand requirements, thereby optimizing the logistic supply chain and aircrafts operational performance over the life cycle. These findings may be applied to other aircrafts with similar demand patterns. In this research, it has been assumed that all spares/components are non-repairable and are replaced upon failure.
Keywords:- Logistics, Inventory optimization, Spare part, Forecasting methods, Aviation, Demand patterns

1 Introduction

The lack of technology and other compelling factors in the design phase makes it impossible to design a product that will fulfill its expected function completely during its entire life cycle. Therefore, the need for support is becoming vital to enhance system effectiveness and minimize unplanned stoppages. Product support, also commonly referred as after sales service, consists of the different forms of assistance and support that manufacturers offer customers to help them gain the maximum value from products. This assistance can be provided in different forms and in different stages of the product life cycle. Product support falls into two broad categories, namely support to the customer and support to the product. In fact, reliability is a function of time/load and the operational environment of a product, which comprises factors such as the surrounding environment (e.g. temperature, humidity and dust), condition-indicating parameters (e.g. vibration and pressure), and human aspects (e.g. the skill of the operators). The variables related to these factors are referred to as covariates (Ghodrati, 2005). In order that any system may be able to perform their expected function, some of the typical technical forms of support needed include installation, maintenance, repair services, and provision of spare parts. Such forms of support are supplied by Original Equipment Manufacturers (OEM)/suppliers, and are characterized as product support. Product support includes all the activities that ensure that a product is available for trouble-free operations over its useful life span (Loomba, 1996).

Spare parts management and logistics is an aspect of product support management which influences the product life cycle cost. The availability of spare parts upon demand decreases the product down-time and increase the utilization of the system/ machine and consequently the profitability of the project. If the optimum number of spare parts is stored in the inventory, it will minimize the product life cycle cost as a goal function. Optimal spares provisioning is a prerequisite for all types of maintenance tasks, such as inspections, preventive maintenance, and repairs. With the exception of preventive activities, spare parts for maintenance tasks are usually required at random intervals. Thus, the fast and secure coordination of the demand for spare parts with the supply of spare parts at the required time is an important factor for the punctual execution of the maintenance routines. Missing materials are one of the most frequently cited reasons for delay in completion of maintenance tasks. As spare parts for aircrafts are often of a very high quality, this problem cannot be solved simply by an increased warehouse stock. Therefore, spare parts management is naturally an important area of inventory research (Huiskonen, 2001).

The need to have a large stock of spare parts makes management of aircraft fleets difficult. Safety issues and the costs of having planes out of service while being maintained necessitate efficient maintenance policies when inspection and preventive maintenance are carried out. Therefore, there must be a policy for coping with unanticipated mechanical problems when the aircrafts are away from base. Spare part inventory management becomes a significant issue in this context. In particular, good forecasts of consumption are important and influence both fleet performance and economic returns on capital.

The demand for aircraft spare parts is partly irregular and may be seen as “intermittent or lumpy.” This complicates the challenge of inventory management that requires balancing of component inventories with their holding costs. To achieve this inventory management, models require accurate forecasts. The intermittent nature of demand can be traced to four underlying features (Ghobbar and Friend, 2002).

- *Slow moving demand* with no great variation in inter-demand intervals and quantities for each requirement;
- *Strictly intermittent demand* with no extreme variations in quantity but with demand absent in many time periods;
- *Erratic demand* is highly erratic in scale rather than per unit time period; and
- *Lumpy demand* is random with zero demand in many time periods but significant demands if other demand values can vary greatly.

Here, we primarily focus on the intermittent and lumpy demand forecasting problem that involves the challenge of meeting extremely irregular demands both in terms of the temporal irregularity of demand cycle and its intensity. Intermittent demand is random demand with a large proportion of zero values (Silver, 1981). There are two broad approaches to spare parts selection: the first is based on the operational experience of an airline and the second on the application of forecasting techniques. (Ghobbar and Friend, 2004) found that only 9–10% of companies use forecasting models. Airline operators usually base predictions on their operational experience, on annual budgets, and information from aircraft manufacturers that prepare lists of recommended spare parts.

When new types of aircraft are introduced, the airframe and engine manufacturers normally provide a list of recommended spare parts, which is based on the projected annual flying hours of the new aircraft. The original equipment manufacturers also provide overhaul manuals for aircraft components aimed at supporting assessment of required replacements, i.e. data on the operational life of components. Consequently, the forecast of spare part inventories is based on past usage patterns and the experience of company personnel. Accurate forecasting of demand is important in inventory control (Buffa and Miller, 1979, Hax and Candea, 1984 and Silver et al., 1998), but the intermittent nature of demand makes forecasting especially difficult for service parts (Swain and Switzer, 1980, Tavares and Almeida, 1983 and Watson, 1987). Using historical demand data on selected inventory parts of a fleet of 118 training aircrafts of an Aviation Flying School and a database spread over the past 8 years, some of the most reliable forecasting methods have been applied to predict spare parts requirements and finally selecting the optimum values based upon the minimum Mean Absolute Deviation (MAD)/ Mean Absolute Percentage Error (MAPE) calculations for all applied forecasting techniques. In the past, naïve forecasting methods such as recommended list of parts provided by the supplier, previous data, suggestions of technicians and experience were being used to predict part quantities. In this research efforts have been made to develop a decision support system by not only scientifically forecasting spare parts but also identifying the group of most critical parts in terms of parts prices and quantities in which they are required. With each passing year, the results of this research shall continue to refine and shall continue to bridge the gap between the forecasted values and actual demands. A group of most critical parts to the aircraft operation, in terms of their prices and quantities, has been identified for continuous/top priority focus to optimize inventory and parts procurement budget. Few high priced parts have been selected which showed seasonality. For these parts, the seasonality indices have been calculated and their demands/requirements on monthly basis have also been worked out.

2 Research Questions

The operational reliability and performance characteristics of an aircraft determine the degree and type of product support that it needs e.g. the estimation of the required number of spare parts. The identification, classification and quantification of the effects of few critical parts may help in forecasting, calculation and managing the quantity of required spare parts with respect to minimizing the product life cycle cost.

At present Aviation Flying Training School is using naïve approach to predict future requirement of spare parts based on the number of allotted flying hours for the next year, past experience, competence of technical personnel and the list of recommended spares provided by the OEM. Even the simplest of forecasting techniques are not being employed. The ultimate effect of such a rudimentary approach is incorrect estimation of spare part quantities. Besides above, no effort has been made to identify and segregate a group of parts which have the most significant impact on spares support budget in terms of their prices and required quantities. These parts are termed as "critical parts "and therefore, correct estimation of critical parts quantities by applying latest and robust forecasting methods is essential to optimize spares support budget. Hence there is a need to develop a technique to scientifically forecast the future requirements as well as to identify the group of most critical parts for close and continuous monitoring. This can be done by developing an approach and a decision model for the classification and forecasting of spare parts to optimize the spare parts logistics. This research is concerned broadly with development of improved methods and techniques that enable the effective analysis and planning of spare parts.

3 The Significance of Research

This research work uses fundamental and other related experimental knowledge and provides practical solutions and results for spare parts estimation and inventory management performed to avoid a shortage when a part is required. The idea is to identify and segregate those parts/components which are critical to the smooth aircraft operation both in terms of price and quantities. These parts shall represent the major chunk of procurement budget and optimizing these parts would indirectly mean optimizing the spare parts procurement budget. Also an error-predictive forecasting model has been developed to predict demands of parts by applying modern and robust forecasting methods in lieu of previously used traditional naïve forecasting approaches such as list of recommended parts provided by the OEM, allotted flying hours, past experience and competence of personnel which resulted in incorrect prediction of the quantities of parts and ultimately procurement of parts in surplus or deficient quantities.

4 Research Methodology

The research work began with the collection of data. Consolidated parts supply-demand data was not available at one location and therefore, data regarding the demands for parts was collected from the field maintenance units and data regarding the supply of parts was collected from the Aviation School Central Supply Depot. The next step was transformation of data into an interpretable form by developing criteria, based upon the prices of parts and their quantities, for subsequent useful analysis. This was followed by the formulation of (3x3) price/quantity comparative analysis matrices to identify and isolate a group of critical parts on the basis of parts prices and their quantities. The matrices formation also allowed segregation of sample population of 90 parts for detailed analysis. As such "Most Critical Parts" to the aircrafts operation in terms of their accumulated prices and quantities were identified. Next, a predictive error-forecasting model, which compares and evaluates few of the most reliable forecasting methods, was developed and the sample population, already selected, was subjected to the model to predict future demands of parts. Also, monthly demand patterns for few high dollar value parts were observed on the basis of historical data and their monthly seasonality indices were calculated which were then used to forecast even the monthly demands of these most critical parts/ assemblies.

Apparently, the control and management of spare parts is a complex operation and common inventory control models lose their applicability, because the demand process is different from that assumed due to varying operating conditions and unpredictable events during operation. An essential element in many models is forecasting demand, which requires some historical demand figures, which are unavailable or invalid for new and/or low consumption parts. Moreover, the shorter life cycles of products and better product quality further reduce the possibility of collecting historical demand figures. Unfortunately, the pragmatic approaches of spare parts inventory management and control are not validated in any way, and then controllability and objectivity are hard to guarantee (Fortuin and Martin, 1999). There are some operational characteristics of maintenance spare parts that can be used for estimation of the spare parts need and control of the inventory. The most relevant control characteristics are: criticality, demand and value (Huiskonen, 2001).

5 Results and Discussion

5.1 Price Based Analysis for Single Aircraft

In this analysis, total number of parts out of the sample population belonging to each price category i.e. low, medium and high was determined. Total price impact, total number of parts and total number of units of each category were calculated by adding up prices, number of parts and units belonging to their respective sub-categories. The relationship between the prices and quantities of spare parts for a single aircraft is plotted below in Figure 1. Total number of parts belonging to each price category has been plotted on X-axis whereas total price contribution of each corresponding price category has been plotted on Y-axis. It is evident that there is a negative correlation between the prices of parts and their quantities e.g. high price parts are lesser in quantity and vice versa.

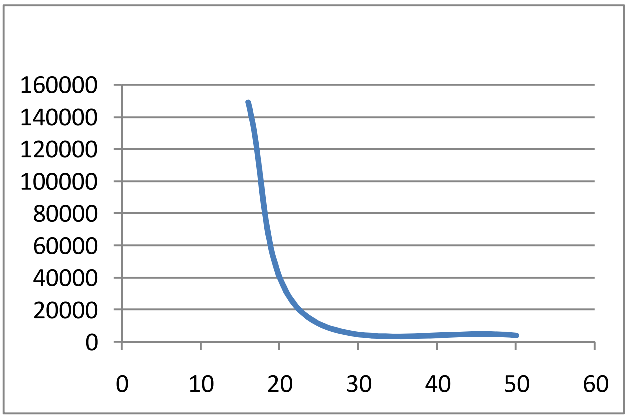

Fig. 1 Price/Quantity relationships for a single training aircraft

It is evident that although low price parts/units constitute a major bulk of training aircraft spares (81.8%), yet they have the lowest cumulative effect on the overall aircraft spares support budget (i.e. 2.3% of the total expenditure). Only 16 parts (4.5%) fall in the high price parts category but they have the most significant impact on the overall spares procurement budget (i.e. 87.3% of the total expenditure). It can, therefore, be deduced that special emphasis should be laid on ascertaining/forecasting high price & small quantity (HS category) spares. Narrowing or bridging the gap between forecasted quantities vis-à-vis the actual required quantities of spares belonging to HS category (High Price & small quantity) can result in high amount of foreign currency saving and ensuring optimum utilization of spares support budget.

5.2 Quantity Based Analysis for Single Aircraft

This analysis was performed to determine the number of parts (units) having maximum impact on the spares support budget in terms of their quantities. Parts of sample population were distributed amongst nine boxes (sub-categories) of 3x3 matrixes on the basis of pre-determined/aforementioned criteria. Hence a total number of 374 units belonging to a sample population of 89 parts have an accumulated price impact of 1, 70,728.53 $ US on the spares support budget. The relationship between the quantities of spare parts and their prices for a single aircraft is plotted below in Figure 2. Total number of units belonging to each quantity category has been plotted on X-axis whereas total price contribution of each corresponding quantity category has been plotted on Y-axis. It is evident that the small quantity category represents the biggest price contribution and therefore has the maximum financial impact on spares support budget. Quantity based analysis, therefore, re-emphasizes the deduction made through price based analysis i.e. it is the small quantity (parts/units) category which has the maximum financial impact on Aviation spares procurement budget.

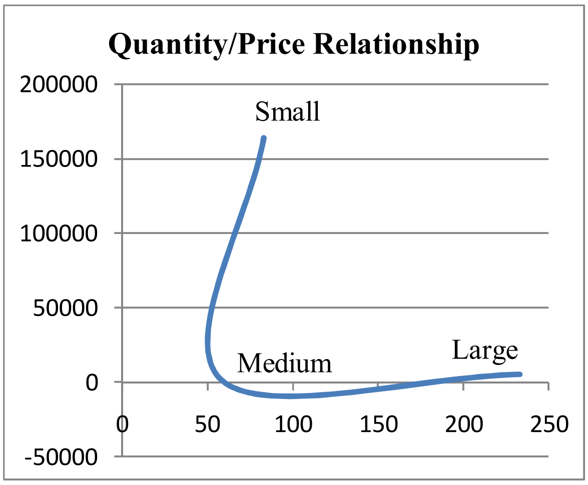

Fig. 2 Price contribution of each quantity category drawn through quantity based analysis for a single Training aircraft.

It can be seen that high price parts in small quantities (22% of small quantity parts represent 96% of price contribution) are the most critical parts and require maximum monitoring/attention during predictive planning/forecasting of aviation spares support/logistic support plan (LSP). Such an effort shall ensure optimization and effective utilization of aviation spares support budget.

Again, a sample population of 89 parts was segregated for detailed analysis in line with the previous calculations for a single training aircraft. This time, the data for analysis pertained to spare parts required to support flying activities of a fleet of 118 Training (flying training) aircrafts. Based upon already established price criteria, adding the number of parts along the horizontal of the matrix revealed that 30 parts got included in the low price category (Lo), 35 parts were identified in medium price category (M) and 24 parts in high price category. Similarly, adding the number of parts along the vertical revealed that 52 parts belonged to the Small quantity category (S), 15 parts were identified in medium quantity category (M) and 22 parts in large quantity category (L).

5.3 Price Based Analysis – 118 Aircrafts

A total number of 15999 (8560+5986+1453) units belonging to a sample population of 89 parts have an accumulated price impact of 4.21 Million (20830.95 + 1,94,411.32 + 3.99 Million) US dollars on the spares support budget for a fleet of 118 training aircrafts. The relationship between the prices and quantities of spare parts required for a fleet of 118 Training aircrafts is plotted in Figure 4. Again, it is evident that there is a negative correlation between the prices of parts and their quantities even when the accumulated prices and quantities of parts required to support training flying of a fleet of 118 aircrafts is used i.e. the higher the price, the lesser the quantity and vice versa. Close tracking and continuous monitoring of high price parts can even be narrowed down to this HS (High Price and Small Quantity) category-matrix number 7 of the nine matrices, to which only 3.6% of the units belong but they represent 92.5% of budget spending on spares procurement.

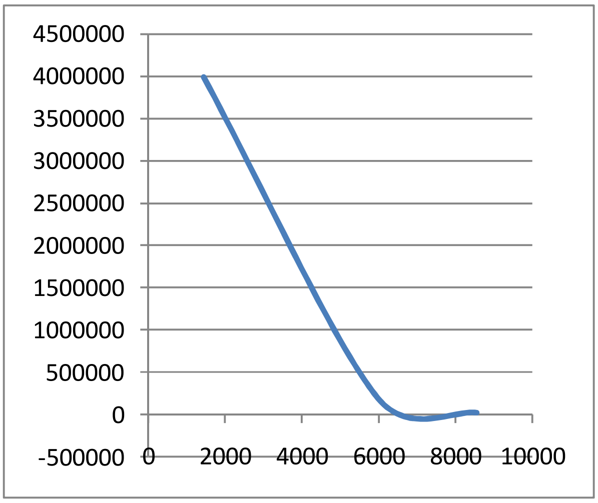

Fig. 3 Price/Quantity relationship between the prices/number of spare parts required for the fleet of 118 Mushshak aircrafts

5.4 Quantity Based Analysis – 118 Aircrafts

The relationship between the quantities of spare parts and their prices for a single aircraft is plotted below in Figure 5. The small quantity category represents the biggest price contribution and therefore has th Small ncial impact on spares support budget. Quantity based analysis, therefore, re-emphasizes the deduction made through price based analysis i.e. it is the small quantity (parts/units) category which has the maximum financial impact on Aviation spares procurement budget.

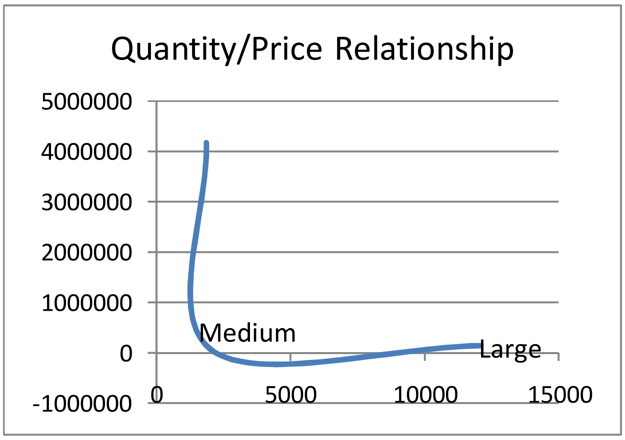

Fig. 4 Price contribution of each quantity category drawn through quantity based analysis for a fleet of 118 Training aircrafts.

From the above analysis, it is evident that small quantity category represents only 12 % of the total number of spares (units) procured annually but constitutes a major 95% of the total foreign currency expenditure on spares procurement. Medium quantity category represents again a 13% of the total annual procurement of spares (in terms of units) but constitutes only 1.2 % of the total foreign currency expenditure on spares procurement whereas large quantity category represents a major 75.5% of the total quantity (in terms of units) of spares but constitutes only 3.3% of the total foreign currency expenditure on spares procurement.

5.6 Results of Analysis

1. The price/quantity comparative analysis matrices for both single Training aircraft and for a fleet of 118 Training aircrafts have been analyzed in detail. The quantitative findings/graphic representations indicate that both matrices show almost similar prices versus quantity patterns. Parts belonging to a similar sub-category (high price and small quantity category) have been segregated and identified as the group of most critical parts for both the matrices.
2. Quantity based analysis re-emphasized the deduction made through Price based analysis which was to closely track and continuously monitor high price and small quantity parts (HS category) since they constitute the biggest chunk of aviation spare support budget. Parts belonging to HS category require maximum monitoring/attention during predictive planning/forecasting of aviation spares support/logistic support plan (LSP). Estimation of HS parts in correct quantities, followed by a close and continuous tracking of these parts throughout the year, can ensure optimization and effective utilization of aviation spares support budget.
3. Forecast for the year 2008 for each part of the sample population was determined by applying all three selected techniques. This resulted in providing three forecasts per part for the year 2008. Next, MAD was calculated for each forecasting method using historical data along with the newly determined forecast values for 2008. The final forecast for the year 2008 for each part amongst all three competing methods was picked on the basis of minimum MAD/MAPE of the historical data. Out of a selected population of 90 spare parts, 20.9% parts have been forecasted using Weighted Averages Method, forecasts for 72.5% have been obtained using Exponential Smoothing Method and forecast for 6.6%) have been generated using Trend Projection Method (by applying a program developed in MS Excel). The contribution made by each of the forecasting techniques to forecast future demands of the sample population of about 90 parts is shown in figure 5.

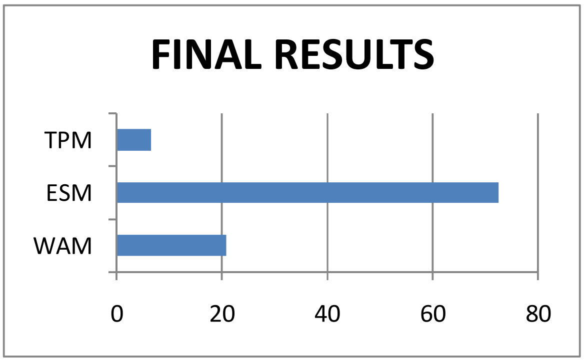

Fig. 5 Percentage contributions of forecasting methods to predict future requirements of spare parts

6 Forecasting to Cater for Seasonal Variations in Data

Seasonal Variations are regular up and down movements in a time series that relate to recurring events. Demand for coal and fuel oil, for example, peaks during cold winter months. Seasonality may be applied to hourly, daily, weekly, monthly, or other recurring patterns. Many aircraft major assemblies/ parts show similar demand surges and need to be precisely predicted and supplied on monthly basis to optimize both aircraft operation as well as aviation budget. To achieve this end, monthly seasonality indices for TBO parts have been worked out and the demand pattern of all these TBOs have been calculated on monthly basis. Forecast of TBO parts for the year 2008 has been obtained through the application of the mathematical model employing afore mentioned forecasting techniques. These forecasted quantities of TBO parts are then used to determine monthly requirements of TBO parts, on the basis of monthly seasonality index calculated by using historical monthly demand data for the period 2005-2007. This can enable the buyer to raise a timely demand and the supplier to arrange an in time delivery of the part in question. Also periods (months) of peak requirement can easily be identified.

7 Conclusions

Aviation is a highly expensive and a dicey business. Being dicey does not imply that we are left with no other options but to take chances while conducting aviation related businesses. We, therefore, cannot afford to create inventories by incorrectly predicting spares continuously thus adding undesired handling, transportation, storage and inventory costs. The use of own experience, suggestion of supplier, traditional and naïve forecasting techniques in the past resulted in wrong predictions of quantities of parts. In this research, three of the leading and most reliable of the forecasting techniques as recognized by the researchers, have been used to predict the quantities of a sample population of 90 parts of Training aircraft. The results of the research have proved the dominance of the selected forecasting techniques by finding that all methods perform reasonably well; exponential smoothing sharing 72.5 % of predicted parts, weighted averages sharing 20.9% and trend projection method providing 6.6% of parts forecasts. If these forecasting methods are used to predict the quantities of parts in the future, the results shall continue to be refined as the gap between the forecasted and demanded quantities shall continue to bridge over a period of time. Again, segregation of a group of most critical parts in terms of their prices and quantities, by formulating (price/quantity) comparative analysis matrix, can help us to closely track and monitor the supply-demand pattern of this group, thus ensuring efficient and effective utilization of aviation resources and optimizing spares support budget. The results of the research can be replicated across the board to include other fixed and rotary wing aircrafts and even industrial databases which show similar patterns of intermittency and lumpiness of demands.

8 Recommendations

The following recommendations have been made on the basis of results drawn from this research work. These recommendations are likely to have positive contributions on the existing system:

1. Comparative analysis matrix is formulated for all types of aircrafts and helicopters of Army Aviation to identify and segregate the group of “Most Critical” spare parts. Formulation of (price/quantity) comparative analysis matrix is a simple yet a potent tool to isolate those parts which have the most significant impact on the overall spares support budget.
2. In this research work, a group of 20 parts belonging to “High Price and Small Quantity” (HS) category has been identified to be the most critical parts group, sharing a major 92.5 % of the net foreign exchange spent upon procurement of spare parts to support training flying of a fleet of 118 Training aircrafts. Close and continuous tracking/monitoring of this category alone can help optimize the biggest chunk i.e. 92.5 % of aviation logistics support budget.
3. During comparison of both 3 x 3 matrices i.e. for a single aircraft and for a fleet of 118 aircrafts, it was noticed that 12 parts were common to the most critical group category (HS group) for both matrices. 4 parts which appeared to be most critical for single aircraft analysis were left out of the same category for 118 aircrafts matrix whereas another 8 parts joined the most critical

parts category on the basis of their accumulated cost effects for 118 aircrafts.

4. Three of the most reliable, latest and best acclaimed forecasting techniques were used to predict the quantities of a sample population of 90 parts for the year 2008. These techniques included Weighted Averages Method, Trend Projection Method and Exponential Smoothing Method. The results confirmed the continued dominance of exponential smoothing method (Regattieri & Manzini, 2005) [43], providing estimates for 72.5% of parts, followed by weighted averages method (Ghobbar & Friend 2003) [42] sharing 20.9% of predicted parts and trend projection method contributing 6.6% of forecasts.
5. A paradigm shift from the use of naïve and traditional methods to predict future quantities of aviation spares to the application of the latest, robust and reliable forecasting techniques can continuously help bridge the gap between required/demanded and forecasted quantities of spares. With each passing year, the results of the research shall continue to refine until the demanded and forecasted quantities shall finally match.

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