Inventory Management of Equipment Maintenance Materials

The case study of Zagope

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Abstract

Zagope is an international Portuguese construction company specialized in developing public constructions that operates predominantly in Africa. The equipment's maintenance is a crucial aspect to the company to ensure a continuous execution of the construction operations. The present study focuses on the most important type of inventory concerning equipment's maintenance (spare parts), and develops an inventory management methodology to better manage these materials. This methodology aims to improve the inventory efficiency and, more importantly, to reduce inventory costs in three current Zagope's constructions.

In order to achieve the previously referred goals, the methodology developed entails the three most important steps of inventory control: inventory classification, forecasting methods and stock control policies. Typically spare parts are characterized for being slow moving items or items with intermittent demand - the forecasting methods employed were the most frequently found in the academic literature, specifically for intermittent demand. Due to the impossibility of estimating with accuracy the exact fitting distribution and determining the optimal inventory levels, heuristic procedures were also applied. These heuristics are periodic stock control policies that provide the most adequate inventory levels.

In this empirical study, the results show that the Naddor's heuristic is the most suited to reduce the total cost. However, it is less efficient in terms of backorder volumes than other heuristics, at the same inventory levels. For all heuristics applied/studied, the demand forecasting method SES (Single Exponential Smoothing) outperforms the SBA (Syntetos-Boylan Approximation) variant as well as the TSB method. The application of this methodology allows to achieve a maximum potential reduction, for intermittent and non-intermittent items, equal to 84.7%.

Keywords: intermittent demand, classification, forecasting, stock control heuristics

1. Introduction

Portugal's financial crisis has affected all economic activities and the construction sector is no exception. As a way to overcome this problem, Portuguese construction companies have extended their activities beyond borders. Zagope is one of these companies. With a turnover of more than 545 million euros, Zagope was the second biggest Portuguese construction company exporter in 2013. With operation predominantly in Africa, the complexity of its supply chain turned bigger. Adding to this, over the last years Zagope has suffered financial constraints due to the recessive juncture of the world economies. For these reasons, the company felt the need to improve its activities efficiency to reduce costs and to increment operations accuracy.

This paper will study the inventory linked to one of the most expensive areas in Zagope's supply chain - equipment's maintenance. In this sector the materials are very important and quite expensive. The maintenance costs are proportional to the unavailability of parts to repair equipment's when they are needed. Zagope has about 4800 equipment's and the challenges to manage this type of inventory are extremely large. Therefore, the inventory management of this type of stock represents a potential opportunity for costs reduction that is analyzed throughout this paper.

This paper focus on the development of a methodology that concurrently classifies this special type of inventory, spare parts, and selects appropriate policies for each product examining the interactions between demand forecasting methods and stock control systems applied. Due to the typical lumpiness of intermittent demand and lack of historical demand, difficulties in forecasting and controlling this type of inventory arises (Teunter et al., 2010).

The remain of the paper is organized as follows: In section 2 the most relevant literature is reviewed. Section 3 presents the case study through empirical data exhibition. In section 4 a short description of the developed methodology, its implementation and the intermediate results are presented. In section 5 the main results are exhibited and discussed. Finally in section 5 the main conclusions are drawn.

2. Research Background

The parts used for equipment's maintenance represent a different type of inventory, identified in literature as spare parts. Spare parts are common inventory stock items, which exist for satisfying the need of maintenance of plant systems (Kennedy et al., 2002) and replacement of operating plant items. From an inventory management point of view, it is well known that the management of spare parts differs from other manufacturing inventories such as work-in process and finished products in several ways (Wang, 2012). Kennedy et al. (2002) in their review described that the unavailability of the required spare parts may prolong the downtime of the plant and incur in unnecessary costs. But overstocked spare parts may also be costly in terms of total inventory cost.

Spare parts often exhibit intermittent demand and are particularly prevalent in the aerospace, automotive, military, and IT sectors (Johnston et al., 2003). Intermittent demand is random demand with a large proportion of zero values (Silver, 1981) and appears randomly, with some periods having no demand at all. When demand occurs, it is not necessarily for a single unit or a constant demand size (Syntetos and Boylan, 2006).

An effective inventory control system involves two problems: classification of inventory items in groups and finding appropriate strategies for each group previously identified (Mohammaditabar et al., 2012).These aspects are going to be developed in the next sections.

2.1 Demand Classification

In order to build an efficient control of the huge amount of inventory items, the inventory management traditional approaches classify the inventory into different groups. Different inventory control policies can then be applied to different identified groups (Ng, 2007).

The ABC analysis is an efficient and most widely employed technique for inventory classification in organizations (Simchi-Levi, et al., 2003). This technique is based on the Pareto principle and is easy to understand. The associated method divides inventory items into three classes according to specific criteria. In class A, commonly are those items of high importance but few in quantity, in class C, are the less important but large in number items and in class B are the items between this two classes (Torabi, et al., 2012).

This traditional method is based on solely annual money usage, reflecting the principle that a small proportion of SKUs accounts for the majority of money usage (Chen, et al., 2008).

Flores and Whybark (1986), for instance, proposed a multiple criteria framework to handle ABC analysis, beginning with selecting another critical criterion, in addition to the money usage. This criterion, which depends on the nature of the industry, may be obsolescence, lead time, substitutability, reparability, criticality or commonality (Flores and Whybark, 1986).

2.2 Intermittent Demand Forecasting

The traditional forecasting techniques (such as simple exponential smoothing or simple moving average) ignore the fact that intermittent demand patterns are built from two elements: demand size and demand interval.

The Croston (1972) method uses the intermittent nature of the demand by singly updating the demand size and the demand interval after each period with a positive demand (using exponential smoothing).

Syntetos and Boylan (2005) proposed a modification of the Croston method in order to eliminate its positive bias. As such, the authors applied a deflating factor that is linear in the smoothing constant to the Croston method. Their method is called Syntetos-Boylan

Approximation (SBA). However, some (negative) bias remains and there are indeed cases when the SBA method may be more biased than the original Croston method (Teunter, et al., 2011).
More recently, Teunter et al. (2011) proposed a new method that is unbiased and updates the demand probability instead of the demand interval, in every period, attempting to take into account the risk of obsolescence.
Having in mind that different spare parts are associated with different underlying demand patterns, which in turn require different forecasting methods. Consequently, there is a need to classify spare parts and apply the most appropriate method in each class (Velagić, 2012). Syntetos et al. (2005) proposed four demand pattern classes to perform this classification: intermittent, erratic, slow moving, and lumpy demand, according to two variables: the average inter-demand interval and the variability of the demand sizes.

2.3 Stock Control Model

Periodic stock control policies have been used in stock control for intermittent demand items.
Under the (T,s,S) periodic stock control system, the inventory position is reviewed at the end of a fixed period T and if it is less than the re-order level s, enough is ordered to bring it up to the replenishment level S.
Babai et al. (2010) point out that the exact demand distribution is impossible to estimate in practise. Using heuristics rather than use a exact algorithm to achieve the optimal levels is a way to overcome this fact.
The three heuristics with a major contribution in literature are periodic stock control policies (T, s, S): the power approximation (Ehrhardt & Mosier, 1984), the normal approximation (Wagner, 1975) and the Naddor's heuristic (Naddor, 1975).
Having analyzed the relevant literature within the inventory management of spare parts the following section will describe the case-study that is going to be addressed along this paper.

3. Case-study

This work was developed in the constructor company Zagope, one of the biggest Portuguese exporters.
Most of its operations run in Africa. In the African continent, economic operations are more difficult to perform due to the underdevelopment expressed by social instability and lack of infrastructures. These difficulties lead to a more complicated inventory management, being long lead times one of these consequences.
Furthermore, in Zagope there is not a culture of inventory management and stock control. Consequently, there is no control methodology over any kind of materials, including spare parts. Spare parts control is based on empirical knowledge of mechanical engineers (the equipment's maintenance managers), because there is not an integrated faults system capable to forecast equipment's failures and to help the engineers. With this type of tool, it would be possible to overcome the great lumpiness attached to spare parts demand. Typically, the demand of this kind of inventory is triggered by equipment's needs becoming which are more unpredictable than the demand of the final customer.
In addition, the technical specificity of spare parts is usually large. In this sense, Zagope has accumulated large quantities of spare parts throughout the development of different projects. At the end of each work the number of obsolete spare parts has been growing largely as well as the costs associated.
This raises the need for an appropriate inventory management system that aims to reduce stock and inventory costs while simultaneously meeting the equipment's needs.
In this work it is developed and applied an inventory management methodology that focuses on Zagope's spare parts.
This methodology is composed of three phases: inventory classification, demand forecasting and stock control policy. The outputs of each phase are inputs to the next phase until the inventory levels are found in the final phase.
In the next subsection the details of Zagope's available data are presented.

3.1 Characterization of Historical Data Sample

Throughout this study are analyzed the spare parts stocks available in three current representative Zagope's constructions in 27 February 2014. These are three road construction works: BMX, NGOL and MECC.
BMX is the more recent and has the least dimension. NGOL is located in Luanda and the shipyard (the place through which all imported material, ordered by all Zagope's constructions in Angola, pass before being delivered to the works) is located inside NGOL construction site. MECC is located in south interior of Angola (Menongue) and BMX is located north of Luanda (about 6 hour drive from Luanda), being the latest construction and the one with the least dimension.
The selection of these three constructions was based on: the prospect of being able to study (in the available literature) the possibility of parts exchange between works belonging to the same market; and further, based on the immense stock volumes of them.

As of 27 February 2014 (the last date that the data were taken from the system), the inventory of each work analyzed had a large amount of spare parts both in terms of volume and in terms of value (USD), as can be seen in Table 1.

Table 1 – Stock quantification on February 27 2014

Work Constructions	BMX	NGOL	MECC
Total number of references* in stock(1)	1.174	4.397	5.221
Total number of part references in stock (2)	873	3.925	4.856
Representativeness of the total number of parts in stock (2)/(3)	74,36%	89,27%	93,01%
Total value in stock (USD) (3)	473.418	3.453.724	4.127.793
Total value in parts stock (USD) (4)	383.080	2.130.768	3.400.550
Representativeness of the total value in parts stock (4)/(3)	80,92%	61,69%	82,38%

* Item Reference is a primary key of a given item. Example: The reference of CAT 8T4189 screw is the number 1051957.

This study just accounts for the present stock in the warehouse. Thus, the stock present in Angola's shipyard (where the items belonging to each work are requested) is not accounted.
The database considers the individual spare parts demand present in stock at the date of analysis, covering 14 consecutive periods (months) from January 2013 to February 2014.
Descriptive statistics related to data demand of the stock items in each of the works were calculated. Through the analysis it was possible to verify that, as in NGOL (results in the Table 2), in the other works it is possible to deduce that the average demand sizes and the demand per period are almost zero for more than half of the sample. On the demand request intervals, the average is also of approximately 8 months for more than half of the sample, what is a high value.

Table 2 - Descriptive statistic of the NGOL's stock on February 27 2014

3925 References	Demand Sizes		Demand Intervals		Demand per period	
	Mean	**S. D.***	**Mean**	**S. D.***	**Mean**	**S. D.***
Min.	0,00	0,00	1,07	0,25	0,00	0,00
25% ile	0,00	0,00	7,07	4,22	0,00	0,00
Median	0,00	0,00	8,00	4,32	0,00	0,00
75% ile	1,00	0,26	8,00	4,32	0,07	0,26
Max.	935,0	683,05	8,00	4,32	467,5	683,05

* S. D. – Standard Deviation

From the data analysis it can be concluded that the items demands are predominantly intermittent. Also it was observed that464, 2868 and 3721 items respectively in BMX, NGOL and MECC constructions are associated with no demand within the period considered.
The following characterizes each phase of the methodology in terms of structure, assumptions and intermediate results. Finally, the final results are presented and discussed in order to understand if the main objective of this methodology was achieved. The conclusions and suggestions are briefly discussed in the last section.

4. Development and Implementation of the Methodology

Based on the previous analysis of the state of the art the methodology developed to improve the stock management of spare parts involves three main phases (Figure 1):

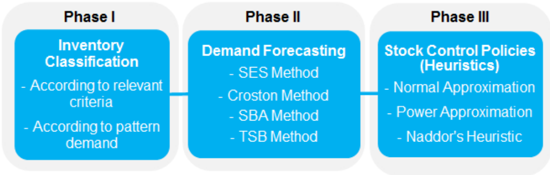

Figure 1 - The scheme of the methodology

- The first phase, divided into two steps, classifies the items according to two relevant criteria to Zagope's inventory management and according to pattern demand.
- In the second phase, demand forecasting methods are applied to achieve the demand parameters applied within the stock control policy.
- And in third phase, three periodic inventory control heuristics are applied to calculate the inventory levels s and S for all assumed periodic reviews over the period analyzed.

This section is divided into three subsections that correspond to implementation of the constituent's phases of the developed and applied methodology. Throughout the presentation of these subsections are also showed the application of the methodology and the intermediate results obtained.

4.1 Inventory Classification

Inventory classification is the first step to implement in order to solve the problem.

4.1.1 Classification according to relevant criteria to Zagope's inventory management

The inventory classification is made according to relevant criteria of Zagope's inventory management- A list of possible relevant criteria for implementation was analysed. Along with Zagope's equipment director, three criteria were selected: inventory value, inventory turnover and lead time.
Criticality is also a relevant criterion to inventory classification of the spare parts, mainly when there are expectations for its application in a stock control policy. However, criticality cannot be used in this context as there is not a centralized and integrated maintenance system in Zagope that would allow its application. In addition, the criticality

criterion definition for spare parts varies between construction works or even within the same work depending of its features.

4.1.1.1 Inventory Value Criterion

Regarding the inventory value criterion, an ABC analysis of spare parts in stock was performed, on 27 February 2014. The inventory value for each reference was computed as the multiplication between the moving average price of the part and its unitary quantity in stock. The output reflected the Pareto's Principal, is shown in Table 3 (where the NGOL's outputs of this classification are presented).

Table 3 - Results of the ABC analysis in NGOL

	Inventory Value (USD)	Percentage of the sample	Number of items	Percentage of the sample
Group A	1.704.869	80,01%	829	21,12%
Group B	344.098	16,15%	1212	30,88%
Group C	81.802	3,84%	1884	48,00%
Sample	2.130.768	100%	3925	100%

4.1.1.2 Inventory Turnover Criterion

The inventory turnover criterion was analyzed in terms of the number of occurrences of demand per time period. Thus, the items were divided into four groups:

- Group D: Items that are treated as slow moving items – obsolete; includes the items in stock that have not registered any demand occurrence for more than 6 months (assumption validated with the director of the Zagope's equipments maintenance)
- Group C: Items that are in danger of becoming obsolete; this group includes items in stock since September and October 2014 but that have not registered any demand occurrence since October and November 2014, respectively.
- Group C: items that registered demand occurrences for more than 6 months, but since its last occurrence until 27 February 2014 have had null inventory levels in some periods.
- Group B: Items that are relatively new in stock (new entries in stock between November and January 2014) but that have not registered any demand occurrence since then.
- Group A: Items that registered demand occurrences over the last 3 and/or 6 months on 27 February 2014. In this group are the items with "large" inventory turnover, that is, with enough demand occurrences for analysis.

The items belonging to group D represent a very significant part of the total value of the spare parts in each warehouse analyzed (40,45%, 66,17% e 66,83% of stock value in BMX, NGOL and MECC works, respectively), confirming the notion that there are a lot of obsolete items in inventory for each analyzed work. Items belonging to group A, also represent a very significant part of the total value of the spare parts in each warehouse (38,92%, 26,71% and 23,62% of stock value in BMX, NGOL and MECC works, respectively). Thus, these two groups are the most representative in terms of inventory value.

4.1.1.3 Lead Time Criterion

For the calculation of this criterion historical data of the stock item's purchasing processes, in the analyzed date, was used. From the data analysis it was possible to conclude that the application of this criterion was unfeasible because there was not enough historical data of the purchasing processes for approximately 50%, 85% and 73% of the items references in stock on 27 February 2014 in the works of BMC, NGOL and MECC, respectively.

For the existing data the lead time was calculated and it was possible to verify that: the average lead time for the local purchasing processes (in each country) was of 19 days for BMX and NGOL works and 32 days for MECC work, when items pass through Angola's shipyard; for the local purchasing process. Without passing through Angola's shipyard, the average lead time calculation was 12 days for BMX work, 10 days for NGOL work and 8 days for MECC. For the imported items by Angola (that involve Zagope in Portugal as the exporter) that mandatorily pass through Palmela's shipyard and Angola's shipyard, the average lead time computed for the items with historical purchasing data was 121, 131 e 135 days for BMX, NGOL and MECC works, respectively.

4.1.1.4 Multicriteria Classification

Having performed individual classifications, a multicriteria classification was developed. For that, were taken into account only two criteria: inventory value and turnover.

A new classification was developed, resulting from the junction of the ABC classification according to inventory value outputs and the ABC classification according to inventory turnover. The new results are presented above:

- Items with high inventory value (USD) and turnover (group A in ABC classification, and group A in classification according to inventory turnover) were classified as group AA in a bicriteria classification.
- Items with a high inventory value and a low turnover (group A in ABC classification and groups C and D in classification according to inventory turnover) were classified as groups AC and AD in a bicriteria classification.

Together these two groups represent a high inventory value, confirming the robustness of the classification and the high volume of obsolete parts in stock (with a significant percentage of group AD's inventory value) of the work's warehouses (see Table 4).

Table 4 - Results of the Multicriteria Analysis

	Works		
	BMX	**NGOL**	**MECC**
Group AA	31,53%	22,85%	20,60%
Group AD	33,01%	51,74%	52,52%
Group AC	4,29%	0,10%	4,16%
Group AC	0,49%	0,67%	0,24%
Total	69,32%	75,36%	77,52%

The items references classified in group AA show demand occurrences and represent a high inventory value. As such, it is important for the stock of this representative group to be planned and controlled with a control policy that does not accentuate the costs.
The items presented in Table 4 (group AA) were the analyzed items in the next phases of the developed methodology (phase II – Demand Forecasting and phase III – stock control policies).

4.1.2 Classification according to demand pattern

This classification was performed according to the scheme in Figure 2 (based on Velagić (2012) and Syntetos et al. (2005)). In this method the cut-off values are the squared coefficient of variation of the demand sizes (CV^2) and the average inter-demand interval (ADI).

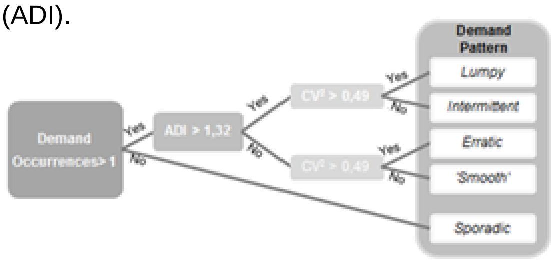

Figure 2 - The scheme to classify the items with respect to demand forecasting

Five groups were achieved, after using the pattern of demand classification. These groups were attached into three types: intermittent items (lumpy and intermittent items), non-intermittent items (erratic and smooth items) and sporadic items (items with a very high average inter-demand interval – only one demand occurrence or none).
The intermittent items have a high average inter-demand interval – low demand frequency; and the non-intermittent items have a low average inter-demand interval – high demand frequency.
Finally, after crossing the outputs of the multicriteria classification showed in section 3.2.1.3, it shows that: the number of parts references with sporadic demand in BMX, NGOL and MECC works are 644, 3443 and 4318, respectively; most of the items belonging to bicriteria group AA are intermittent items (see Table 5).

Table 5 - Quantification of the demand pattern for items belonging to group AA to all works

Demand pattern for items belonging to group AA with the number of demand occurrences > 1	BMX	NGOL	MECC
Erratic Items	1	2	4
Intermittent Items	53	121	111
Lumpy Items	4	18	31
Smooth Items	0	1	3

The subsequent phases of the methodology were applied to all items belonging to bicriteria group AA (with the exception of sporadic item without demand occurrences). However, the implementation of these two phases was carried out by separating the intermittent items, the non-intermittent items and sporadic items (with only one demand occurrence). Therefore, the results were achieved separately according to this analysis option (Ferreira and Póvoa, 2014).

4.2 Demand Forecasting

In this phase of the methodology the objective was to achieve the forecasting demand parameters to apply within the stock control policy.
Firstly, the demand forecasting methods were applied. The methods applied were: Croston method, Syntetos-Boylan Approximation method (SBA) and TSB (aiming to address lumpiness characteristics of intermittent demand), and the traditional method, Simple Exponential Smoothing (SES).

Croston Method:

$$z'_t = z'_{t-1} + \alpha(y_t - z'_{t-1}) \tag{1}$$

$$k'_t = k'_{t-1} + \alpha(q - k'_{t-1}) \tag{2}$$

$$y'_t = \frac{z'_t}{k'_t} \tag{3}$$

SBA:

$$y'_t = \left(1 - \frac{\alpha}{2}\right) \times \frac{z'_t}{k'_t} \tag{4}$$

TSB:

Se $p_t = 0$:

$$p'_t = p'_{t-1} + \beta(0 - p'_{t-1}) \tag{5}$$

$$z'_t = z'_{t-1} \tag{6}$$

$$y'_t = p'_t \times z'_t \tag{7}$$

Se $p_t = 1$:

$$p'_t = p'_{t-1} + \beta(1 - p'_{t-1}) \tag{8}$$

$$z'_t = z'_{t-1} + \alpha(1 - z'_{t-1}) \tag{9}$$

$$y'_t = p'_t \times z'_t \tag{10}$$

SES:

$$y'_t = y'_{t-1} + \alpha(y_t - y'_{t-1}) \quad (11)$$

Considering the following notation:

y_t: Demand for an item in period t
y'_t: Estimative of mean demand per period at the end of period t for period t+1
z_t: Actual demand size in period t
z'_t: Estimative of mean demand size at the end of period t
q_t: Actual demand interval between transactions
k_t: Number of months since the last positive demand at the beginning of month
k'_t: Forecast in month of number of months between consecutive positive demand
p_t: Demand occurrence indicator for period t (1 if demand occurs at time t; 0 otherwise)
p'_t: Estimative of the probability of a demand occurrence at the end of period t
α, β: smoothing constants

Three variation factors were considered in the implementation: the method itself, the choice of the smoothing constants α and β and the initiate method. This phase aims to understand the method with the best performance under experimental conditions (from the application of different scenarios) so as to then select its results and apply them in the next phase.
As there were variation factors, the four forecasting methods were applied as many times as were the different combinations of the smoothing constants and initiate method.
The smoothing constant α varied in 0, 05 increments (between 0,05 and 1), and the smoothing constant β varied in 0,01 increments (between 0,01 and 0,04) and 0,05 increments (between 0,1 and 1).
To find the initiate values equations 12, 13, 14 and 15 (Velagić, 2012) were applied, as the initiate formulas used by the ERP (Enterprise Resource Planning) - SAP. After, the methods of Croston and SBA were used, in the absence of formulas by the same source for the remaining methods applied in this methodology.
The average formulas applied according to Velagić (2012) are as follows:

$$y'_t = \frac{1}{n}\sum_{1}^{n} y_t \quad (12)$$

$$k'_t = \frac{n}{|T|} \quad (13)$$

$$p'_t = \frac{|T|}{n} \quad (14)$$

$$z'_t = \frac{1}{|T|}\sum_{t \in T} y_t \quad (15)$$

As for ERP, SAP, the calculations for the initial values to be applied in the forecasting methods are calculated according to (SAP SE, 2014):

$$\text{If } \; y_1 \neq 0 \Rightarrow z'_0 = y_1 \wedge k'_0 = 1 \quad (16)$$

$$\text{If } \; y_1 = 0 \Rightarrow z'_0 = 1 \wedge k'_0 = 2 \quad (17)$$

n: number of months of analyzed period
T: the set of months in n months with a positive demand

Once applied to different scenarios with the above changes of variation factors for the data of the three works a performance computation was developed using two measures: one that estimates the variance of the forecasting method - Error Mean Square Error (MSE) and another that measures the bias of the same - Mean Error (ME).

$$MSE = (y'_t - d_t)^2 \quad (18)$$

$$ME = y'_t - d_t \quad (19)$$

Regarding the values of the smoothing constant, there was not found a pattern in the results obtained, as they also deviated from the expected results (for demand processes hardly known, such as those which occur for intermittent items, it would be expected that the demand process approached a non-stationary demand pattern (Babai, et al., 2011). As such, the forecasting method should adapt quickly through "sufficiently large" smoothing constant, showing better performance in these cases, which is not always found).
Finally, in order to obtain the demand forecasts to apply to periodic stock control policies in the following phase of the methodology, the methods of demand forecasting which showed better overall performance were selected. So for the items belonging to the bicriteria group AA with more than one occurrence of demand in the last six months, it was decided to obtain the respective demand forecasts from the SBA and SES methods. Items belonging as well to the group AA but with a sporadic demand pattern, it was decided to apply the TSB and SES methods. In applying these methods, the initial values (equations 12, 13, 14 and 15) were calculated though the average formulas due to the best results of the forecasts using this method. As for the smoothing constant, given the variability and the deviation from the expected results, an intermediate value of 0.5 was selected for the constant α, and a value of 0.3 was selected for the smoothing constant β.

4.3 Periodic Stock Control Policies

This is the last phase of the inventory management methodology. In this point the assumptions taken and the results achieved from the application of the chosen periodic policies are presented.

Power Approximation, Normal Approximation and Naddor's Heuristic were the three periodic inventory control heuristics used as the ones identified in the literature as more adequate.

One of the fundamental aspects in the application of these heuristics regards the definition of values considered in inventory costs, including backordering and ordering charges. To Zagope the holding costs per item are valued at 13% of the moving average price of the item. For the remaining costs, given the lack of information for its calculation, values near the reality of the company were chosen (from an empirical analysis). As such, and based on the study of Teunter et al. (2011), the backordering costs (b) were defined as a function of holding costs (h) through the h/b ratio.

Given the impossibility of calculation for the value of this ratio, 4 values were assumed for all items, h/b = 1%, h/b = 5%, h/b = 10% and h/b = 20%. Together with the Zagope's equipment director, it was concluded that this simplification would lead to increased inventory levels for some items and sub-orders for other items. However, it is expected that these two faults could be compensated and that their influence in inventory costs was almost nullifying. Finally, for the order costs, it was possible to identify a set of factors that alter these values, namely: the purchasing process, eg, local or with an exporting entity; type of transport , aircraft or ship; type of request, urgent or non-urgent; type of logistics contract with the supplier. Thus, the costs for ordering an item may vary within the same work at different ordering times. For the worst case scenario, it was predicted (by equipment director) that this value approaches 20% of the moving average price of the item. However it is known that this value may be exaggerated for certain situations, and so this was one of the parameters studied in the sensitivity analysis performed.

Another assumption was based in fitting the demand to the Gamma probabilistic distribution, for the application of Naddor's heuristic (to compute the probability of no demand per time unit).

Finally, the lead time assumed was 3 months and the periodic review 1 month.

Considering these assumptions, the inventory levels s (reorder level) and S (replenishment level) were achieved for all items references studied, for all assumed periodic reviews over the period analyzed and for all considered scenarios (each one of the three heuristics were applied the achieved parameters through each one of two selected forecasting methods to intermittent and non-intermittent items and sporadic items belonging to group AA, considering h/b=1%, h/b=5%, h/b=10% and h/b=20% and the ordering cots=20%).

Next, with the application of the results from the inventory levels, the expected backorders, the expected on-hand inventory, the expected on-order inventory and the inventory position, were calculated, for each periodic review. As such, it was possible to calculate the inventory cost for each scenario obtained from the methodology.

$$\begin{aligned}\text{Custo de inventário} &= \sum_{i=1}^{n} \text{IM em armazém do item}_i \times \text{Ordering Charge} + \\ &+ \text{IM em armazém do item}_i \times \text{Holding Charge} + \\ &+ \frac{\text{IM em armazém do item}_i \times \text{Holding Charge}}{\dfrac{\text{Holding Charge}}{\text{Backordering Charge}}}\end{aligned} \quad (20)$$

Where:

IM = Average Inventory

5. Main Results and Discussion

The final results were found through the fixation of the variables described in the previous sections varying only the h/b ratio. For each scenario, the h/b ratio took the following values: 1%, 5%, 10% and 20%.

The results presented in this section were based on the comparative analysis between the costs and the efficiency of inventory that would be reached if the inventory management methodology would be applied the current inventory situation (see example in Table 6).

In terms of costs, this comparison was performed through the analysis of the following indicator:

$$Potencial\ de\ \text{Re}dução = \frac{Custo\ \text{Pr}evisto - Custo\ \text{Re}al}{Custo\ \text{Re}al} \quad (21)$$

Regarding items with intermittent and non-intermittent demand pattern, it was possible to see that: the potential reduction that arises from the application of the forecasting method SES to the inventory control heuristic, is greater than that which occurs when applying the TSB method to the same heuristic. The consequent potential reduction of the application of the inventory management methodology in relation to the current situation, increased for all scenarios with increments of the h/b ratio, due to the decreased backordering costs when the h/b ratio increased, considering constant holding costs. The results obtained from the scenarios where the ratio h/b is fixed at 10% are similar between themselves. Furthermore minimal potential reduction in absolute value, happened when applied the heuristic Power Approximation for h/b = 1%, been equal to 31% for the forecasting method SES and 25.1% for the SBA, in the work of BMX. The

maximum potential reduction found of 84.7% for intermittent and non-intermittent items was verified in the work of NGOL, for the results obtained from the application of SES method to Naddor's heuristics when h / b = 20%. All other scenarios showed a potential reduction between these two values.
As for sporadic items, it was possible to verify that: the potential reduction in absolute value, obtained by applying the forecasting method TSB is always greater than the potential reduction obtained by the application of the forecasting method SES when applied to Naddor's heuristic; in most cases, the potential reduction is greater either when the results of the forecasting method SES are applied to Power Approximation heuristic or to Normal Approximation heuristic. In BMX for h / b = 1%, there is an increase of the estimated cost with the application of the inventory management methodology in relation to the current situation, either with the application of the Power Approximation heuristic or Naddor's heuristic.
Finally, it appeared that the minimum potential reduction happed in the application of Naddor's heuristic when h/b = 1%, was equal to 6.3% for the forecasting method TSB, in the BMX work. For the maximum potential reduction achieved for sporadic items, its minimum was achieved when the results of the forecasting method SES were applied to the Normal Approximation, being around 88% when h/b = 20 % in the NGOL work. All other scenarios analyzed to all works exhibited a potential reduction between these two values.
For intermittent and non-intermittent items: the Naddor's heuristic generally allowed to achieve a greater potential of cost reduction. However, the results obtained from the Normal Approximation were similar to those obtained from Naddor's heuristic; and in terms of inventory efficiency, Naddor's heuristic is the one that presented the lowest total cost due to the less efficient inventory policy because its application resulted in a lower volume of annual inventory, reflected in an increased value of backorders in relation to the other two heuristics. Although for all scenarios considered it was found that the increase of h/b ratio (leading to lower backorders costs) implies a decrease in the volume of inventory and an increase in the number of backorders, it is possible to conclude that the number of backorders obtained from the application of Naddor's heuristic were always larger than the other two heuristics.
For sporadic items, the results obtained from the Normal Approximation showed the increased cost reduction at the expense of inventory efficiency, either in volume or in backorders. This efficiency was almost always better than that achieved in scenarios where the other two heuristics were applied.
Finally, a sensitivity analysis was performed for the following parameters: smoothing constant α, lead time and ordering costs. From the sensitivity analysis it was possible to conclude that: The method was relatively robust to changes in the constant smoothing parameter α; the methodology was sensitive to the parameters lead time and ordering costs and the results are less robust to the variation of the lead time parameter.

6. Conclusions

As main conclusion it should be pointed out that the initial proposed objective to reduce inventory costs with equipment maintenance materials was reached. For that, a methodology of inventory management was developed and implemented along this study.
The tool developed consists of three important phases of inventory control: inventory classification, forecasting methods and stock control policies, applied to historical data of spare parts stocks available in three current Zagope's works.
The first phase, divided into two steps, entails a classification according to two relevant criteria to Zagope's inventory management (inventory value and turnover) and a classification according to pattern demand. From this step resulted a selected group to be analyzed in the next phases.
The second phase consisted on the application of demand forecasting to achieve the demand parameters applied within the stock control policy. The methods applied were: Croston method, Syntetos-Boylan Approximation method, TSB and Simple Exponential Smoothing. For its applications and from the assessment of the obtained results, the methods and characteristics that enable the achievement of the best parameters were selected.
Finally, in third phase the Power Approximation, the Normal Approximation and the Naddor's Heuristic were the three periodic inventory control heuristics applied. In this phase were taken into account some assumptions related to inventory costs.
From these assumptions, the inventory levels s (reorder level) and S (replenishment level) were achieved for all items studied, for all assumed periodic reviews over the period analyzed and for all considered scenarios.
Regarding the final results, for intermittent and non-intermittent items: the Naddor's heuristic generally allowed to achieve a greater potential of cost reduction due to less efficient inventory policy. For sporadic items, the results obtained from the Normal Approximation showed an increased cost reduction at the expense of

inventory efficiency, either in volume or in backorders.

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