Analysis and Improvement of the Management of Stocks in 'Vasco da Gama' Frigates - A Practical Study

José Miguel Aragão Celestino Soares, ISEG Lisbon School of Economics & Management, Universidade de Lisboa, Portugal
Fernanda Maria de Almeida Santos Mendes, European University/Laureate International Universities, Portugal

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Abstract
Vessels, as an autonomous system, require the provision of maintenance needs, and transport the spare parts necessary to meet those needs. The existence of stocks and the type of lots on board are intertwined with the type of mission assigned, and according to the duration of the mission, often the ship cannot be supplied by land. For this reason, the normal time in the supply chain requires stocks, since in the Portuguese Navy, and in particularly on ships during its voyages, it is not possible to implement the 'Just-in-Time' system, which limits the time factor. Thus, in order to guarantee the autonomy of the missions with the supply cycle available, board batches to 'Vasco da Gama' frigate's engines, allow the ship's systems to be permanently operational. This study includes, in a first phase, an estimate of the maintenance needs of the main propulsion engines of the 'Vasco da Gama' Class Frigates using the arithmetic mean method and the least squares method. This is followed by an approach to stock management using the ABC analysis to determine which spare parts require more detailed control. Finally, the optimum quantity of spare parts per board batch, to be used for autonomous navigation missions up to a maximum of one year, is determined. The aim of this study is to reduce maintenance costs by calculating the optimal size of on-board batches, and also to improve sustainability by reducing the impact on the environment by not overloading the vessels with too many spare parts.

Keywords: Maintenance needs; stocks management; Portuguese navy; on-board batches; costs reduction.

Introduction

In 1976 the Portuguese War Navy entered a new stage of its history, turning to the North Atlantic and to the participation in NATO missions. The adoption of this new course soon made evident the need to re-equip the Navy with surface ships.

A proposal for the construction of three MEKO 200 frigates was then made by a German consortium, which included special support from the German government. Finally, on July 25, 1986, a contract was signed between the Portuguese state and the German consortium for the construction of the three frigates.

In terms of logistics, Vasco da Gama class frigates have significant capabilities. Spare parts are available for 365 days, and these parts are stored in 23 warehouses throughout the ship. There are also several workshops equipped with machines and tools, and a documentation and database center with computer support that helps the exchange of information on board.

Maintenance on board the ships is one of the basic functions of the Portuguese Navy's logistics system, and its main objective is to ensure levels of availability of equipment and systems that are compatible with the established operational usage programs. After the entry of equipment and materials and during their usage, it is aimed to maximize their operational availability and minimize their maintenance costs. Hence, the maintenance of the first step relates to maintenance work involving the replacement of materials, and the replacement of spare parts that are damaged, or in the end of their life cycle, including adjustments or refinements within the technical services of the ship itself.

The present work addresses the thematic of management of stocks, with the research focused on the definition of board lots, in the context of the maintenance of the main propulsion engines of the "Vasco da Gama" class frigates. The frigate-type ship in which this study is based will be the NRP “Corte-Real” that participated in the NATO mission "Noble Mariner", which corresponds to the reference time period used to calculate the optimal quantity of a board lot.

We intend to determine the optimal quantity of a board lot in the context of the maintenance of the main propulsion engines, which guarantee the operation during a maximum time of 12 months of autonomous navigation (365 days), with the objective of ensuring the existence on board of a stock of equipment, materials and accessories essential to the proper and efficient maintenance of the engines during the participation in NATO missions with a maximum duration of one year.

This will be the basis to develop this study, addressing issues that arise at the operational subsystem level and at the management of indispensable material resources. We seek the equilibrium between divergent forces that tend to increase the stock and the cost of holding that stock. It is also intended to define an economic board lot (the optimal quantity of spare parts to be carried on board each mission), and to determine which of these spare parts require more thorough control in order to minimize the total cost of storage.

Literature review and research questions

Logistics Mission

Logistics and the supply chain are not new ideas. Throughout the development history of global economies, the principles governing the efficiency of flows of materials and information following logistical requirements have changed over time (Bloomberg, LeMay & Hanna, 2002).

As a management philosophy, supply chain management makes a system approach to show the supply chain as a whole. All organizations contribute to the individual performance of chain members as well as to the global chain (Cooper, Douglas & Janus, 1997). According to Christopher (2005), the goals of logistics management are to plan and coordinate all the activities of an organization that are necessary to achieve the desired levels of performance and quality, at the lowest possible cost. Adam and Foster (2000) argue that the extent of logistics goes from material management to the delivery of the final result.

Ballou (2004) defines logistics as the process that strategically manages the needs, movement and storage of materials, and the information about its flow through the organization, so that current and future performance are maximized by increasing the efficiency/cost ratio of processes and orders. In their new concept, for Bai and Zhong (2008) logistics encompasses purchasing, stock management, and the physical distribution itself, and each activity in the chain must contribute to the common goal with a constant improvement (Handfield & Nichols Jr., 2002).

For the case under study, the relevant logistic activities are forecasting, planning maintenance needs, managing warehouses, handling materials, planning distribution, and the processing of orders.

Stock Management

According to Chopra and Meindl (2016), logistics are concerned with the stock as a whole, and more than 50% of an organization's assets are normally invested in stocks. Thus, organizations' policy regarding inventory levels and their locations will have a considerable impact on the size of the stocks (Gonçalves, 2006).

Logistics also has functions of monitoring, managing and implementing operational strategies that allow the minimization of stock levels. Effective and efficient stock management is essential in the operation of any organization, with stocks being created by storing materials along the logistics channel. The cost of having these stocks can represent 20% to 40% of their value, and thus the management of stock levels makes economic sense (Bassin, 1990).

Significant Costs of Stock Management

Lalonde and Masters (1999) and Russell and Taylor III (2011) argue that there are three important cost classes in determining inventory policies: the costs of purchasing spare parts, the costs of having spare parts and the stockout costs of spare parts.

Purchasing costs are costs associated with the purchase of goods to replace on-board inventory, and those that are mostly taken into account when deciding order quantities or maintenance planning within the 1st level. These costs may vary according to the quantities ordered and the type of organization (Ptak & Smith, 2011).

Ownership costs result from the storage, maintenance and possession of spare parts in a given time interval, and, usually, costs are directly proportional to the quantity stored (Goldsby & Martichenko, 2005). These costs are divided into 4 classes:

• Space costs (costs and fees charged for the use of the volume within the storage building (Shang, Tadikamalla, Kirsch & Brown, 2008));

• Capital costs (refer to the value of the cost of money invested and assigned to the inventory (Slack, Brandon-Jones & Johnston, 2013));

• Inventory service costs (include insurance and fees, and depend on the quantity in stock (Silver, Pyke & Peterson, 1998), which represent a low percentage of the total costs of stock management (Simchi-Levi, Kaminsky & Simchi- Levi, 2004));

• Inventory risk costs (costs related to material deterioration, theft, damage, or obsolescence (Coyle, Langley Jr., Novack & Gibson, 2017)).

Forecasting Concept

According to Van Horne and Wachowicz Jr. (2009), forecasts are visions about the future. Predictions about sunrise and sunset can be made without great error, but this is not the scenario concerning forecasts of the main engines maintenance needs of the "Vasco da Gama" class frigates.

The conditions surrounding organizations change over time, and therefore forecasts generate errors. Mentzer and Moon (2005), describe forecasts as a future projection for the expected maintenance needs, knowing a set of conditions of the current environment, and according to Zermati (2000) the maintenance planning process should not be confused with the process of forecasting maintenance needs.

Chopra and Meindl (2016) summarize the characteristics of forecasts:

1- Forecasts are always wrong, and as such, errors must be expected;

2- Long-term forecasts are usually less accurate than short-term forecasts;

3- Aggregate forecasts are usually more accurate than disaggregated forecasts;

4- The greater the distortions of information in the supply chain, the higher the errors in forecasts.

Therefore, a forecast that is as close as possible to the reality will be decisive to accomplish a correct maintenance planning of the operational systems of the ship.

Forecasting Methods of Maintenance Needs

In choosing the method to be used, we first have to choose whether we opt for quantitative or qualitative methods. In this study, quantitative methods were chosen, as they provide the information required for the development of the project. Also, the choice of method should be based on the data and time interval available to analyze the forecast of maintenance needs, as well as to adapt to the organization's expectations (accuracy, margin of error, cost of the method). According to Slack et al. (2013), the first question is to know the time period to be analyzed, and also Roldão and Ribeiro (2014) mention that the choice of method is based on the following points:

1- Possibility of collecting data that satisfy the input requirements;

2- Intended rigor;

3- Applicability of each of the methods;

4- Cost of the method.

Courtois, Pillet and Martin-Bonnefous (2007), still add the following points:

5- The time available to make the forecast;

6 – Availability of historical data on the considered articles or family of articles.

There are several quantitative methods to be used in study this, which can be grouped into two categories: Time Series Models and Associative Models (Heizer, Render & Munson, 2017) or Causal Models (Jacobs & Chase, 2014; Slack et al., 2013).

These authors assert that time-series models attempt to predict the future based on past data, and that associative or causal models incorporate all variables or factors that may influence the quantity being predicted.

This study will be based on the methods with lower implementation costs and that are adequate to the data available in the Portuguese Navy, as well as to the time period of the project (the arithmetic averages method and the least squares method).

ABC analysis

According to Grosfeld-Nir, Ronen and Kozlovsky (2007), the ABC Analysis (also known as Pareto rule) consists of three steps: Classification, Differentiation, and Affectation of resources. The ABC analysis indicates that approximately 20% of the total number of spare parts in storage correspond to approximately 80% of the value invested in stocks (Figure 1).

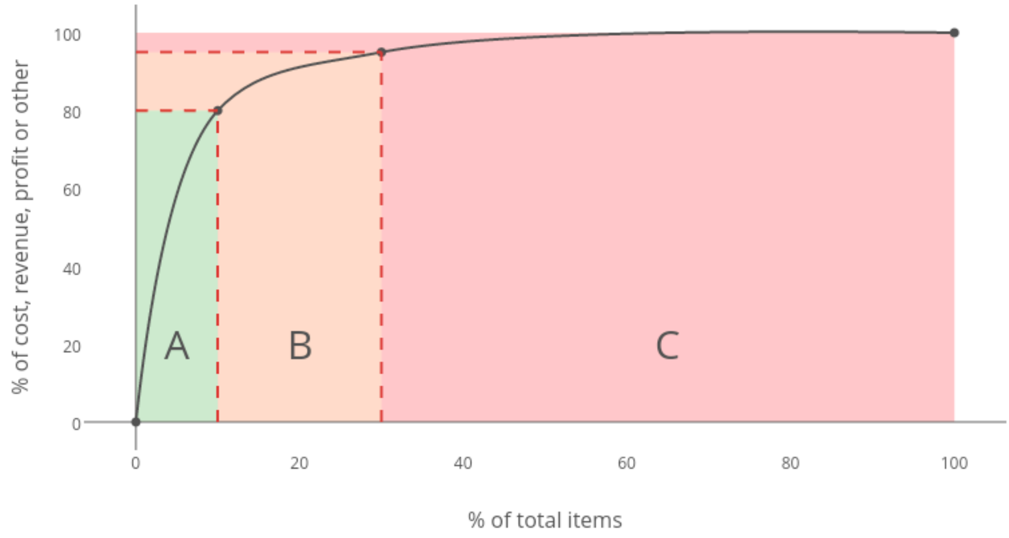


Figure 1: ABC analysis curve
Source: ABC Analysis – The Ultimate Guide to Inventory Classification, (2017)

Reis (2008) mention that if the majority of management resources (material, human, and time) are concentrated in those spare parts, results are much more relevant than they would be if such resources were dispersed equally or indiscriminately by all articles.

Heizer et al. (2017) classify classes A, B and C as follows: Class A, containing the items representing between 70% and 80% of the financial value and 15% of the total inventory; Class B containing 30% of the inventory and representing 15% to 25% of the financial value; Class C containing 55% of the total inventory and only representing 5% of the financial value of the total inventory.

Reis (2008) also states that another advantage of using the ABC Analysis is to allow the detection of non-moving articles (articles in the base of class C), which can be taken from the global stock as their storage increase the costs.

Research questions

In order to the Portuguese Navy know the performance of its operational units, in particular of the system that drives the mobility of each of its frigates (main propulsion engines), it is imperative to forecast the maintenance needs for one, or more, short, medium, or long-term malfunctions. Therefore, this study aims essentially to answer two research questions:

• What is the optimal composition of a board lot to be transported in each autonomous navigation mission for a maximum period of 12 months, in the context of the maintenance of the main propulsion engines of the "Vasco da Gama" class frigates?

• What are the most important spare parts that ensure the effectiveness and efficiency of on-board maintenance of "Vasco da Gama" Class Frigates?

Methodology

For this study the forecasts of extreme relevance are the short and medium term forecasts, since these are the ones that allow to elaborate the 1st level maintenance planning, and allow on board management of stocks.

The forecasting of malfunction maintenance needs of the main propulsion engines of the "Vasco da Gama" class frigates is based on the NRP "Corte-Real" failure history for the period from Year X to Year X + 1 (for Confidentiality reasons it is not allowed to identify the actual dates). The historical data on the consumption of spares, and on malfunctions referring to this period, support the forecasting of maintenance needs.

Two methods were used to calculate the forecasts: the arithmetic mean method, and the least squares method. Based on historical data for Year X and Year X+1 (Table 1), the following forecasts were calculated.

Table 1: Number of faults on main propulsion engines for Year X and Year X+1
Source: Authors

Months	Year X	Year X+1
	Number of faults	
Jan	1	3
Feb	3	2
Mar	7	5
Apr	9	8
May	5	6
Jun	1	2
Jul	2	2
Ago	3	3
Set	1	2
Oct	8	9
Nov	7	7
Dec	6	10
Total	53	59
Average	4	5

The final formula for the trend line is determined by the following formula:

$$x - x_1 = \frac{x_2 - x_1}{t_2 - t_1} (t - t_1)$$

Where:

x - Number of malfunctions to be determined;

x1 - Monthly average of malfunctions verified in time period 1;

x2 - Monthly average of malfunctions verified in time period 2;

t1 - Date corresponding to half of time period 1;

t2 - Date corresponding to half of time period 2;

t - Month corresponding to the number of malfunctions to be determined.

By determining the trend line, we can determine the demand forecast for the period we want.

The number of failures divided into 2 periods for Year X is now determined (Table 2).

Table 2: Number of faults in main propulsion engines divided into 2 periods for Year X+1
Source: Authors

Number of faults			
Period 1	**t1**	**Period 2**	**t2**
1	3	7	2
2	2	8	3
3	5	9	2
4	8	10	9
5	6	11	7
6	2	12	10
Total	26		33
Average	4		6

From Table 2, the following values are obtained:

$$x1=4; x2=6;$$

$$t1=3; t2=9.$$

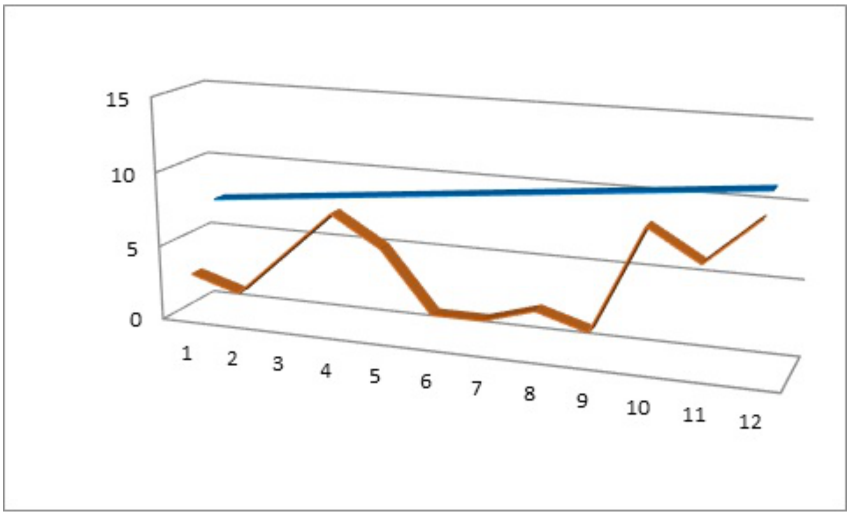
And the demand forecast for Year X + 2 is then (Table 3):

Table 3: Prediction of the number of faults in main propulsion engines for Year X+2 (Arithmetic Mean Method)
Source: Authors

Year X+1	Faults	Year X+2	Prediction
1	3	13	7
2	2	14	8
3	5	15	8
4	8	16	8
5	6	17	9
6	2	18	9
7	2	19	9
8	3	20	10
9	2	21	10
10	9	22	10
11	7	23	11
12	10	24	11
Total	59		110

It is, therefore, possible to determine the following trend line (Figure 2):

$$x - 4 = \frac{6-4}{9-3}(t-3) \Leftrightarrow x = \frac{t}{3} + 3$$



Year X+1; Year X+2

Figure 2: Trend line (Arithmetic Mean Method)
Source: Authors

By analyzing the trend line in Figure 2, it can be seen that the method predicts an increasing trend during Year X+2, which is explained by the degradation of the auxiliary systems of the ship as the number of hours of operation increases.
By analyzing the values referring to the Year X+1 it is verified that there is the need for seasonal maintenance of malfunctions, with 2 peaks, which are directly related to the adverse weather and navigation conditions during the respective periods.

Least Squares Method

The final formula for the trend line is determined by the following formula:

$$x = a + bt, \ \ where \ \ a = \bar{x} - b.\bar{t}\,, \ \ and \ \ b = \frac{\sum(t\,.x) - \bar{x}.\sum t}{\sum t^2 - \bar{t}\,.\sum t}$$

Where:

x - Number of malfunctions to be determined;

t - Month corresponding to the number of malfunctions to be determined.

Determination of the trend line for the number of malfunctions in the main propulsion engines, based on Table 1.

Calculation of a: a = 5-0.47*7 = 1.71

Calculation of b: b = (439-5*78)/(650-7*78) = 0.47

The trend line will be given by:

$$x = a + bt \Leftrightarrow x = 1.71 + 0.47t$$

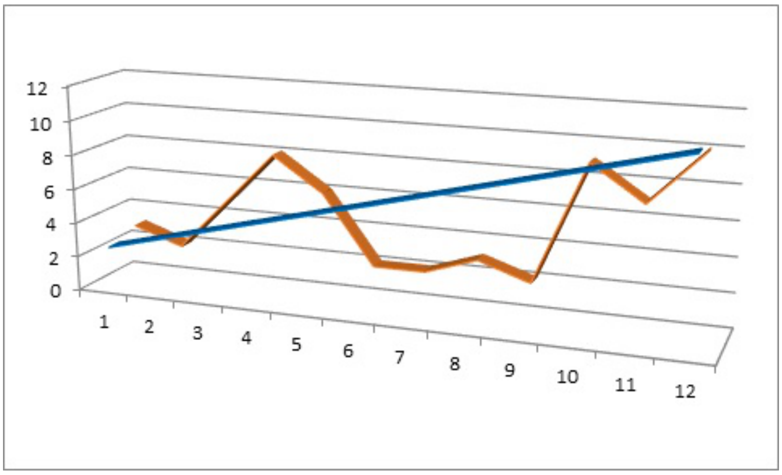
And the demand forecast for Year X+2 is presented in Table 4:

Table 4: Prediction of the number of faults in main propulsion engines for Year X+2 (Least Squares Method)
Source: Authors

	Number of faults in main propulsion engines				
	Months *(t)*	Faults *(x)*	*t*x*	t^2	Prediction
	1	3	3	1	2,45
	2	2	4	4	3,19
	3	5	15	9	3,93
	4	8	32	16	4,67
	5	6	30	25	5,41
	6	2	12	36	6,15
	7	2	14	49	6,89
	8	3	24	64	7,63
	9	2	18	81	8,37
	10	9	90	100	9,11
	11	7	77	121	9,85
	12	10	120	144	10,59
Total	78	59	439	650	78,24
Average	7	5	37		

It is, therefore, possible to determine the following trend line (Figure 3):

Figure 3: Trend line (Least Squares Method)
Source: Authors



Year X+1; Year X+2

Analyzing the trend line in Figure 3, and comparing both methods, it can be concluded that the method of the least squares results in a forecast that is closer to reality.

For this specific study, which analyzes the history of malfunctions in the main propulsion engines of the NRP "Corte-Real", the arithmetical mean method tends to make forecasts "above" the expected number of failures in the propulsion systems of the ship during the navigation hours of Year X+2.

Results analysis and discussion

Currently the increasing need to reduce costs, makes it necessary to save in all areas. Since stocks of materials are one of organizations' assets with the greatest weight in treasury, it is imperative to determine the best way to keep the stocks at their minimum cost without running out of stock on board.

It is therefore imperative to know the quantity of spare parts to be ordered annually in order to determine the optimal composition of a board lot, with the objective to provide the stocks of Vasco da Gama class frigates at the lowest possible cost, aiming effective and efficient maintenance of the main propulsion engines.

In order to better understand the spare parts in stock and to determine which are most important, or those that require a more detailed management by the command of each frigate, we will use ABC Analysis, which tells us that about 20% of the total number of articles correspond to approximately to 80% of the financial value invested by the organization.

In Table 5 we will define which spare parts are directly allocated to maintenance operations of the main propulsion engines of NRP "Corte-Real".

Table 5: List of spare parts under analysis
Source: Authors

Article	System	Designation	Value of Total Consumption (Euros)	Total Consumption (units)	Unit Cost (Euros)
1		Bloco armado completo	224,28	84	2,67
2		Camisa Gola Sup.2ªRect Saia STD	2.307,44	4	576,86
3		Aros para camisas com rect. no assentamento 6,5mm	2.753,52	4	688,38
4		Aros para camisas com rect. no assentamento 7mm	31,44	2	15,72
5		Cadeira Interior STD	72,96	1	72,96
6		Prisioneiros de aperto das cadeiras	24.635,15	5	4927,03
7		Porca de aperto das cadeiras	45.728,72	17	2682,92
8		Braço de articulação com rotulas nos extremos	1.218,10	10	121,81
9		Ponta com rotula	18.218,56	1.065	17,11
10		Veio de Manivelas completo	1.610,96	4	402,74
11		Capas de Apoio Ext.2ªRect - Int.STD	1.492,80	2	746,40
12		Casquilho de apoio Ext.STD - Int.1ªRect.	3,21	1	3,21
13		Amortecedor de vibrações (VIBRATION DAMPER)	252,18	32	7,88
14		Embolo completo	586,81	12	48,90
15		Tirante completo	3.484,57	36	96,79
16		Cabeça completa	3.923,45	5	784,69
17		Casquilhos dos balanceiros	48.688,30	48	1014,34
18		Veios dos balanceiros	244,81	1	244,81
19		Veio de excentricos (esquerdo)	1.351,16	1	1351,16
20		Amortecedor de vibrações (DAMPER)	24.771,72	19	1303,77
21		Regulador de velocidades (completo)	5.323,65	12	443,64
22		Turbo ZR 170 (Completa)	56.698,61	61	929,49
23		Injector (completo)	54,96	2	27,48
24		Bomba Injectora (completa)	98,28	2	49,14
25		Bomba elevatória de combustivel (completa)	43,52	2	21,76
26		Caixa de válvulas	88,52	2	44,26
27		Bomba de água Doce (completa)	904,44	12	75,37
28		Bomba de água Salgada (completa)	1.387,68	12	115,64
29		Arrefecedor de água doce (completo)	706,08	4	176,52
30		Válvula termoestática (completa)	180,92	4	45,23
31		Bomba de reposição nivel óleo, acoplada ao veio de ressaltos (completa)	842,16	4	210,54
32		Electrobomba de óleo de prélubrificação (completa)	1.254,45	5	250,89
33		Bomba de oleo principal (completa)	197,22	2	98,61
34		Filtro de oleo lado esquerdo (completo)	64,88	4	16,22
35		Cardan Voith Tripod (completo)	2	2	1,00
36		Acoplamento Geislinger (completo)	0,01	1	0,01
37		Acoplamento TEK (completo)	26,5	2	

Based on Table 5, we can do the ABC Analysis (Table 6), and draw the ABC Analysis curve (Figure 4).

Table 6: ABC analysis
Source: Authors

Article	Value of Article	Number of Exits	Total (€)	Accumulated Value (€)	Accumulated Articles	Class
22	€ 929,49	61	€ 56 698,89	€ 56 698,89	22,74%	A
17	€ 1 014,34	48	€ 48 688,32	€ 105 387,21	42,26%	A
7	€ 2 682,92	17	€ 45 609,64	€ 150 996,85	60,55%	A
20	€ 1 303,77	19	€ 24 771,63	€ 175 768,48	70,49%	A
6	€ 4 927,03	5	€ 24 635,15	€ 200 403,63	80,37%	A
9	€ 17,11	1065	€ 18 222,15	€ 218 625,78	87,68%	A
21	€ 443,64	12	€ 5 323,68	€ 223 949,46	89,81%	B
16	€ 784,69	5	€ 3 923,45	€ 227 872,91	91,38%	B
15	€ 96,76	36	€ 3 483,36	€ 231 356,27	92,78%	B
3	€ 688,38	4	€ 2 753,52	€ 234 109,79	93,89%	B
2	€ 576,86	4	€ 2 307,44	€ 236 417,23	94,81%	B
10	€ 402,74	4	€ 1 610,96	€ 238 028,19	95,46%	B
11	€ 746,40	2	€ 1 492,80	€ 239 520,99	96,06%	B
28	€ 115,64	12	€ 1 387,68	€ 240 908,67	96,61%	B
19	€ 1 351,16	1	€ 1 351,16	€ 242 259,83	97,15%	B
32	€ 250,89	5	€ 1 254,45	€ 243 514,28	97,66%	B
8	€ 121,81	10	€ 1 218,10	€ 244 732,38	98,15%	C
27	€ 75,37	12	€ 904,44	€ 245 636,82	98,51%	C
31	€ 210,54	4	€ 842,16	€ 246 478,98	98,85%	C
29	€ 176,52	4	€ 706,08	€ 247 185,06	99,13%	C
14	€ 48,90	12	€ 586,80	€ 247 771,86	99,36%	C
13	€ 7,88	32	€ 252,16	€ 248 024,02	99,47%	C
18	€ 244,81	1	€ 244,81	€ 248 268,83	99,56%	C
1	€ 2,67	84	€ 224,28	€ 248 493,11	99,65%	C
33	€ 98,61	2	€ 197,22	€ 248 690,33	99,73%	C
30	€ 45,23	4	€ 180,92	€ 248 871,25	99,80%	C
24	€ 49,14	2	€ 98,28	€ 248 969,53	99,84%	C
26	€ 44,26	2	€ 88,52	€ 249 058,05	99,88%	C
5	€ 72,96	1	€ 72,96	€ 249 131,01	99,91%	C
34	€ 16,22	4	€ 64,88	€ 249 195,89	99,94%	C
23	€ 27,48	2	€ 54,96	€ 249 250,85	99,96%	C
25	€ 21,76	2	€ 43,52	€ 249 294,37	99,97%	C
4	€ 15,72	2	€ 31,44	€ 249 325,81	99,99%	C
37	€ 13,25	2	€ 26,50	€ 249 352,31	100,00%	C
12	€ 3,21	1	€ 3,21	€ 249 355,52	100,00%	C
35	€ 1,00	2	€ 2,00	€ 249 357,52	100,00%	C
36	€ 0,01	1	€ 0,01	€ 249 357,53	100,00%	C

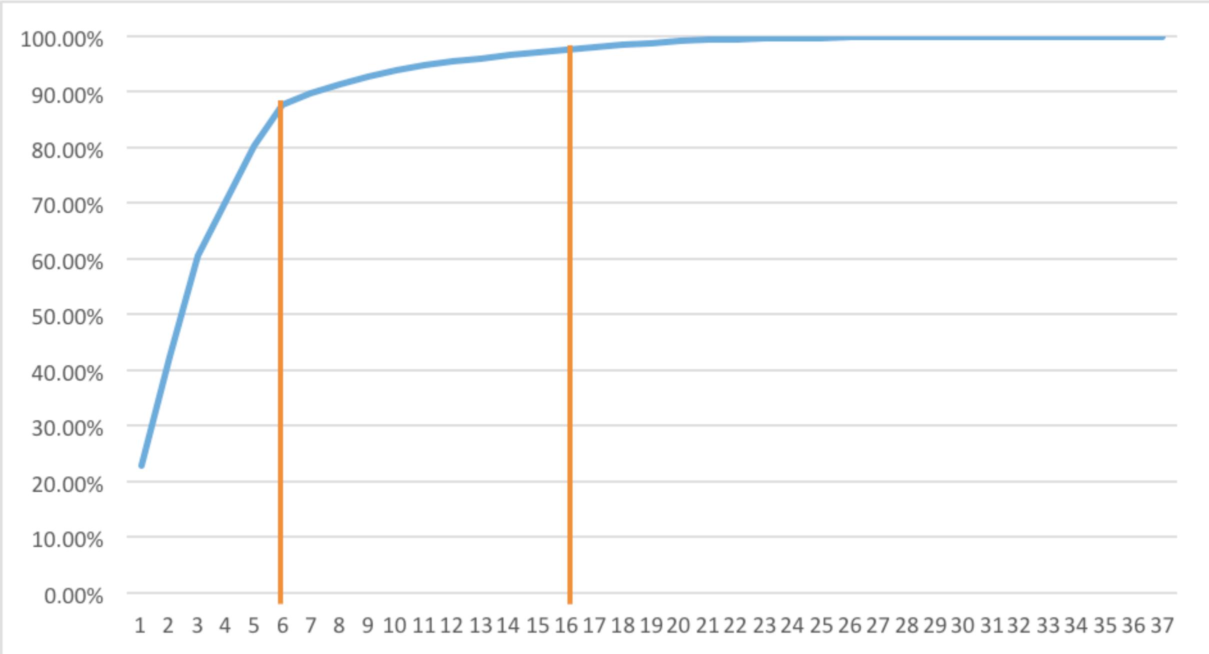


Figure 4: ABC analysis curve
Source: Authors

As we are in the presence of a small amount of spare parts (37), the values for the division are approximations, still fulfilling the objectives of this study, since this analysis intends to define the classes of the spare parts.

Class A and some class B spare parts are the most important, and those requiring more detailed management by the command of each of the "Vasco da Gama" class frigates. It is in these spare parts that the management should focus, giving more attention to their control.

Total Cost of Inventory and Onboard Economic Lot

Following Heizer et al. (2017), the Total Cost of Inventory (TCI), is the sum of product costs (C1), setup (order) costs (C2) and holding (carrying) costs (C3).

$$TCI = C1 + C2 + C3$$

Purchasing costs include all the costs related to the purchase process of a spare part (requisitions, human resources, computer equipment, etc.), and its calculation formula is as follows:

$$C1 = D \times p$$

(D) is the number of spare parts purchased for use in missions with a maximum duration of one year, and (p) the unit price.

The setup (order) cost (C2), includes the cost of making an order (S) (sum of the direct and indirect costs of completing the order). To determine (C2) we multiply (S) by the annual number of orders, which is obtained by dividing the annual consumption of spare parts (D) by the economic lot onboard (EL).

$$C2 = S \times (D/EL)$$

The holding (carrying) cost (C3) involves the overall carrying cost (I), which includes all the costs of storing the spare parts inside the ship's warehouses, such as warehousing costs, and the interest on the fixed assets used in spare parts.

$$C3 = I \times (EL/2) \times p$$

The Economic Lot on Board (EL) is calculated using the following formula:

$$EL = \sqrt{\frac{2DS}{Ip}}$$

Based on the previous formulas, and considering the overall carrying cost of 1%, and an order cost (S) equivalent to 7% of the unit price of the spare part (these values are defined by the Portuguese Navy), the Economic Lot on Board (EL) and the Total Cost of Inventory (TCI) were calculated for each item (Table 7).

Table 7: Total Cost of Inventory (TCI) and Economic Lot on Board (EL)
Source: Authors

Article	Value of Article (p)	Number of Exits	C1	S	C2	C3	TCI	EL
22	€ 929,49	61	€ 56 698,89	€ 65,06	€ 132,30	€ 139,42	€ 56 970,61	30
17	€ 1 014,34	48	€ 48 688,32	€ 71,00	€ 131,08	€ 131,86	€ 48 951,27	26
7	€ 2 682,92	17	€ 45 609,64	€ 187,80	€ 199,54	€ 214,63	€ 46 023,82	16
20	€ 1 303,77	19	€ 24 771,63	€ 91,26	€ 102,00	€ 110,82	€ 24 984,45	17
6	€ 4 927,03	5	€ 24 635,15	€ 344,89	€ 191,61	€ 221,72	€ 25 048,47	9
9	€ 17,11	1065	€ 18 222,15	€ 1,20	€ 10,37	€ 10,52	€ 18 243,04	123
21	€ 443,64	12	€ 5 323,68	€ 31,05	€ 28,67	€ 28,84	€ 5 381,18	13
16	€ 784,69	5	€ 3 923,45	€ 54,93	€ 30,52	€ 35,31	€ 3 989,28	9
15	€ 96,76	36	€ 3 483,36	€ 6,77	€ 10,60	€ 11,13	€ 3 505,09	23
3	€ 688,38	4	€ 2 753,52	€ 48,19	€ 24,09	€ 27,54	€ 2 805,15	8
2	€ 576,86	4	€ 2 307,44	€ 40,38	€ 20,19	€ 23,07	€ 2 350,70	8
10	€ 402,74	4	€ 1 610,96	€ 28,19	€ 14,10	€ 16,11	€ 1 641,17	8
11	€ 746,40	2	€ 1 492,80	€ 52,25	€ 17,42	€ 22,39	€ 1 532,61	6
28	€ 115,64	12	€ 1 387,68	€ 8,09	€ 7,47	€ 7,52	€ 1 402,67	13
19	€ 1 351,16	1	€ 1 351,16	€ 94,58	€ 23,65	€ 27,02	€ 1 401,83	4
32	€ 250,89	5	€ 1 254,45	€ 17,56	€ 9,76	€ 11,29	€ 1 275,50	9
8	€ 121,81	10	€ 1 218,10	€ 8,53	€ 7,11	€ 7,31	€ 1 232,51	12
27	€ 75,37	12	€ 904,44	€ 5,28	€ 4,87	€ 4,90	€ 914,21	13
31	€ 210,54	4	€ 842,16	€ 14,74	€ 7,37	€ 8,42	€ 857,95	8
29	€ 176,52	4	€ 706,08	€ 12,36	€ 6,18	€ 7,06	€ 719,32	8
14	€ 48,90	12	€ 586,80	€ 3,42	€ 3,16	€ 3,18	€ 593,14	13
13	€ 7,88	32	€ 252,16	€ 0,55	€ 0,80	€ 0,87	€ 253,83	22
18	€ 244,81	1	€ 244,81	€ 17,14	€ 4,28	€ 4,90	€ 253,99	4
1	€ 2,67	84	€ 224,28	€ 0,19	€ 0,45	€ 0,47	€ 225,20	35
33	€ 98,61	2	€ 197,22	€ 6,90	€ 2,30	€ 2,96	€ 202,48	6
30	€ 45,23	4	€ 180,92	€ 3,17	€ 1,58	€ 1,81	€ 184,31	8
24	€ 49,14	2	€ 98,28	€ 3,44	€ 1,15	€ 1,47	€ 100,90	6
26	€ 44,26	2	€ 88,52	€ 3,10	€ 1,03	€ 1,33	€ 90,88	6
5	€ 72,96	1	€ 72,96	€ 5,11	€ 1,28	€ 1,46	€ 75,70	4
34	€ 16,22	4	€ 64,88	€ 1,14	€ 0,57	€ 0,65	€ 66,10	8
23	€ 27,48	2	€ 54,96	€ 1,92	€ 0,64	€ 0,82	€ 56,43	6
25	€ 21,76	2	€ 43,52	€ 1,52	€ 0,51	€ 0,65	€ 44,68	6
4	€ 15,72	2	€ 31,44	€ 1,10	€ 0,37	€ 0,47	€ 32,28	6
37	€ 13,25	2	€ 26,50	€ 0,93	€ 0,31	€ 0,40	€ 27,21	6
12	€ 3,21	1	€ 3,21	€ 0,22	€ 0,06	€ 0,06	€ 3,33	4
35	€ 1,00	2	€ 2,00	€ 0,07	€ 0,02	€ 0,03	€ 2,05	6
36	€ 0,01	1	€ 0,01	€ 0,00	€ 0,00	€ 0,00	€ 0,01	4

Conclusions and recommendations

Despite the recognized usefulness and importance of the study carried out concerning the implementation of a more precise methodology for management of stocks, and the definition of the onboard lots of the "Vasco da Gama" class frigates, due to bureaucratic reasons it was not possible to implement this methodology.

Therefore, the conclusion is restricted to the analysis made and the information obtained, being limited to a policy suggestion aiming the improvement of the stock management practiced on board the "Vasco da Gama" class frigates of the Portuguese Navy.

Concerning the first research question, the optimal board lot, to be carried in each autonomous navigation mission for a maximum period of 12 months, was defined for the maintenance of the main propulsion engines of the "Vasco da Gama" class frigates.

Each board lot consists of the number of units of each spare part, indicated in Table 7 (Total Cost of Inventory (TCI) and Economic Lot on Board (EL), column 'EL'.

For the management of stocks, the focal point of the whole process ends up being the logistics of placing the spare parts on board the ships, but because this is assigned to entities subcontracted by the Portuguese Navy, the Navy can only define which spare parts are the most important to ensure the effectiveness and efficiency of onboard maintenance of the "Vasco da Gama" Class Frigates.

To do so, and addressing the second research question, an ABC analysis (Table 6 - ABC analysis) was performed, defining 3 classes of articles, and concluded that class A spare parts are indeed the most important. However, some spare parts of Class B are also important, and the control of the remaining spares should not, obviously, be neglected.

A number of proposals to improve the stock management on board the "Vasco da Gama" class frigates in the context of the maintenance of their main propulsion engines are now presented.

In the future, it would be possible to define the critical values for each spare part under analysis, which could provide data to make spares' control even more effective and efficient, thus defining the Safety Stock, The Minimum Stock and the Maximum Stock.

Concerning the physical space of the frigate warehouses, some simple changes, that would certainly improve the management of stocks, could be made. For example, the space inside the warehouses should be resized by changing the different shelves. There are shelves with little space to store larger materials, and more shelves should be created, with greater space and visible dividers that differentiate the different articles and materials in stock.

Since stocks in the Portuguese Navy are responsible for a large part of the capital allocation, a good stock management will optimize the use of capital and reduce the costs associated with stocks, presented in Table 7.

A suggestion for future studies will be the reproduction of this study in other classes of ships in the Portuguese Navy, in order to also determine the possibilities of improving the stock management in those ships.

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Contact email: josesoares@iseg.ulisboa.pt