A MODEL TO SELECT A PORTFOLIO OF MULTIPLE SPARE PARTS FOR A PUBLIC BUS TRANSPORT SERVICE

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ABSTRACT

This study proposes a model for managing spare parts in urban passenger bus transport companies so as to support maintenance planning decisions. This is alsoknown as an MRO inventory (Maintenance, Repair and Operations). Spare parts play a significant role in the assets of these companies because inappropriate management of these inventories can cause serious losses to the business. As a typical portfolio problem, in which there are “n” items, separated into critical and non-critical, while competing for the same resources, a new model and algorithm was developed to aid the inventory management of spare parts in corrective maintenance through a cost-benefit analysis which considers the level of service versus the cost of each item. The model was tested in an urban passenger bus transport company in the city of Natal, Brazil.

KEYWORDS. inventory management. spare parts. urban bus.

1. Introduction

MRO inventories consist of non-productive materials, such as office supplies and parts used in maintenance, simply known as spare parts. In materials management, spare parts are divided into two main categories: repairable items and consumable or disposable items. Normally MRO inventories have low (or very low) consumption and forecasting demand is difficult and erratic. They have high unit costs, long lead-times, and are of high criticality for the operation (missing cost). It is common for enterprises to relegate these items to the background, but in some companies – such as steel, mining, petrochemical and automotive ones, where in the latter alone, the annual costs of opportunity, storage, depreciation, insurance and handling of spare parts range from 25% to 35% of the book value of all stocks in any company – spare parts are a significant part of all product inventories, and therefore, need to be better controlled. Cheng and Prabhu (2010) confirmed this when they showed that managing MRO inventories represents 36% of the overall costs while the procurement process represents 25% of them.

This is what happens especially in companies offering an urban passenger bus transport service: for them, spare parts are critical and have relevant value for the business. In Brazil, among the modalities of urban passenger transport, travelling by bus is the primary means of transportation for people within their cities and metropolitan areas. This is evidenced by IDET/FIPE (2009) which demonstrates that urban transportation by bus was 11.4 billion passengers in 2009, while railroad transportation, the second placed, carried 2.1 billion passengers in same period. For this, buses ran 6.9 billion kilometers in 2009. Given that the average cost of a ticket was R$ 2.50, this sector of the economy produced revenue of about R$ 28.5 billion, only from this source of revenue. So, faulty parts and/or lack of spare parts possibly needed for replacement purposes, as well as vehicles being laid up for these reasons, can result in serious losses to any transportation company. Thus, good inventory management of spare parts certainly has a positive influence on maintenance management, since this leads to the higher reliability and greater availability of equipment and therefore has a direct impact on business profitability.

There are some studies on this topic, although many fewer when compared to studies on other kinds of inventory such as work in process (WIP) and finished goods. Kennedy at al. (2002) shows many differences between inventories for spare parts, WIP and finished goods and due to this the policies that govern spare parts inventories are sharply distinct from the other two. Their relevance in forming part of maintenance costs for buses and managing them is one of the most critical tasks of maintenance departments because they impact on a company's profits.

This study covers spare parts, with a failure rate and purchase cost, classified into critical and non-critical items which compete for the same funds of a budget that may or may not have constraints. The model proposed identifies for purchase the spare part that has the best cost-benefit ratio, i.e., the spare part that offers the minimum cost and the maximum service level. It is important to emphasize that only spare parts used in corrective maintenance, the demand for which is random, are dealt with in this paper rather than parts used in preventive maintenance for which consumption can be defined by a periodic replacement strategy.

Chang et al. (2005) dealt with this topic when they proposed a (r, r, Q) inventory model for spare parts where some of the stock is reserved for critical demand and they determined the reorder point r, which is equal to the critical level, and the reorder quantity Q. Almeida (2001) presented a spares provisioning model that considers a multicriteria approach based on total spare cost, but without forgetting the risk of the system being interrupted. Sun et al. (2008) introduced a dynamic order strategy (R, st, ST) that enables the goal based on a target service level to be achieved and ensures the total average inventory cost is minimized. Vaughan (2005) addressed inventory policy for spare parts, when demand for the spare parts arises due to regularly scheduled preventive maintenance, as well as random failure of units in service, and he made use of a stochastic dynamic programming model to characterize an ordering policy which addresses both sources of demand in a unified manner. Similarly Diallo et al. (2008) showed a model which takes into account the lifetime distribution of the system, the preventive and corrective maintenance costs and time intervals between different forms of preventive maintenance review, as well as the total costs of spare parts inventory management. This model aims at maximizing the system's availability under a budget constraint.

The content of this paper is organized as follows. Section 2 describes the model with its structure, flowchart, mathematical formulation and algorithm. Section 3 presents a case study and Section 4 provides the main results and a conclusion.

2. The structure of the model

The analysis model for analysing the stock of spare parts was thought of as a mathematical model that may quantify the cost/benefit obtained when trying to decide on which part to buy and keep in stock, based on some important variables which contribute to this decision. The cost/benefit (CB) in this case stems from a relationship between the purchase cost and the increase in the level of service (ΔLS) for each purchase transaction: the component that offers the lowest purchase price (least cost) and greatest increase in the level of service (greatest benefit) by purchasing it, will represent the lowest CB index and is the one that will be purchased and kept in stock for use in due time. Figure 1 shows the flowchart of the model.

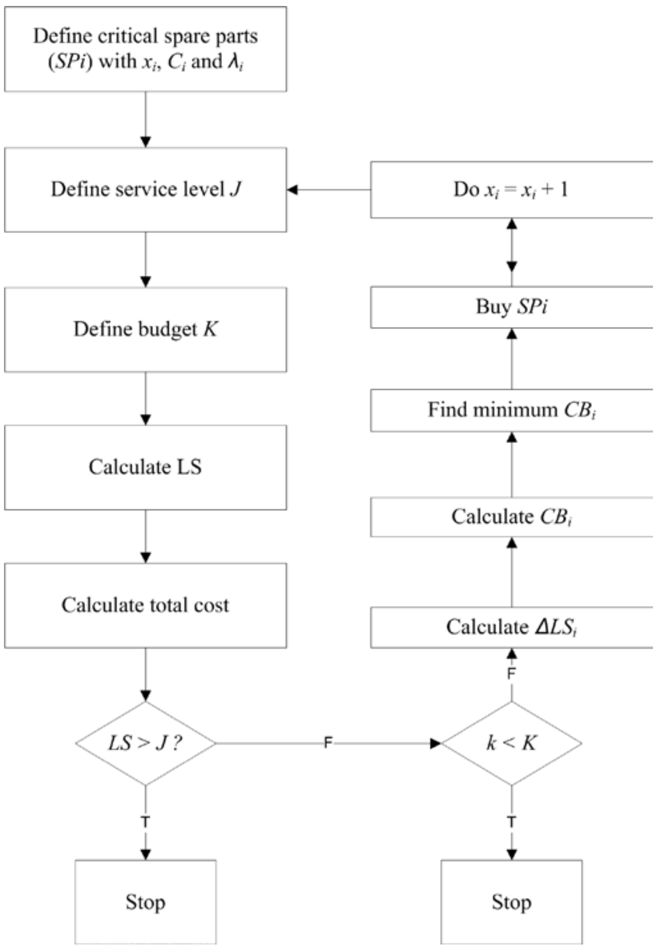

Figura 1 - Flowchart of Analysis Tool

The flowchart demonstrates the logic of the model which considers a budget and a level of service previously defined in accordance with the company's strategy. In Figure 1 it can be seen that the level of service has a certain priority within the budget (see boxes where "$\overline{LS} \geq J$" and "$k < K$"), i.e. if the answer is true in the first question about whether the average level of service is greater than or equal to the level of the service pre-defined, the program stops, no matter at what value the total cost of inventory "k" lies at that moment. This order of priority between the service level and the budget can be inverted by the company in line with its strategy. The flowchart also shows the model dealing with critical parts, while non-critical parts can be analysed by the same method.

Data analysis reveals a typical problem of a portfolio of assets, where each of these (in this case, the spare parts) vies for the resources available such that preference is given to purchasing the one that is based on the maximum return (or benefit) and at the least risk that it could cause for the "investor", in this case, the manager of the stock. Markowitz (1991) showed that the basic elements of his portfolio theory were based on these two criteria - the expected return and the risk - with which the investor seeks to choose the optimal point (the "efficient frontier", in the words of that author) at which to apply his resources.

It is worth noting that the model was designed to make use of consumable parts, used only in corrective maintenance, which if broken, will be replaced immediately if available in stock.

The model aims to answer the main question inherent in any process of inventory management: what is the ideal inventory level for a spare part that guarantees the minimum cost and maximum availability by means of the Poisson distribution.

As shown by Kennedy et al. (2002) in their review of the literature review and Bevilacqua et al. (2008), the Poisson distribution is the most widely-used mathematical-statistical model in the literature for optimizing inventories of spare parts, and is premised on modelling the behaviour of demand for the item by a probability distribution, which is widely used to describe rare random events, such as, for example, the unforeseen failure of certain types of equipment, and hence is adhered to when representing demand for some cases of spare parts replacement. Among the main properties of the Poisson distribution, it can be stressed that it is discrete and assumes independence between events, and is represented by Expression 1.

$$P_x(t) = \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad (1)$$

where:

x = consumption of replacement parts by time interval for which the wish is to estimate the probability;

t = time interval considered;

λ = historical consumption rate of the replacement parts by unit of time;

$P_x(t)$ = probability of there being “x” requests for replacement parts during time interval t.

3. The Mathematical Model

The detail in section 2 can be summarized and mathematically represented as follows:

SP_i = each bus spare part (critical or non-critical);

x_i = amount in stock of each bus spare part;

λ_i = monthly rate of consumption of the i-th spare part;

LS_i = level of service of the i-th spare part associated with the quantity xi;

C_i = unit cost of the i-th spare part;

K = budget for spare parts for maintenance (pre-defined);

J = level of service desired (target pre-defined);

ΔLS_i = gain in the level of service of the i-th spare part with the addition of 1 more unit in the stock;

CB_i = cost-benefit of the i-th spare part.

Such that:

$$LS_i = P(x \leq x_i) = \sum_{i=0}^{xi} \frac{(\lambda t)^{xi} e^{-\lambda t}}{x_i!} \quad (2)$$

$$\Delta LS_i = LS(x_i + 1) - LS(x_i) = P(x \leq x_i + 1) - P(x \leq x_i) \quad (3)$$

$$CB_i = \frac{C_i}{\Delta LS_i} \quad (4)$$

Thus the problem consists of:

$$Max \sum_{i=1}^{n} LS_i \quad (5)$$

Subject to

$$\sum_{i=1}^{n} C_i x_i \leq K \quad (6)$$

$$\sum_{i=1}^{n} \frac{LS_i}{n} \geq J \quad (7)$$

4. Case Study

For the case study, first of all, the procedure followed was: (1) to define the replacement spare parts components of the buses to be studied, such that 33 items used were defined in corrective maintenance actions alone, and (2) to define the parameters to be quantified, which in this case were the consumption rate λ, the unit price, the criticality, and so forth.

The data were collected from an urban collective public transport company that has been operating buses in Natal for more than 25 years and it has been regarded as anonymous in this study. This company has a fleet of 83 buses the average age of which is 5.69 years, which run 600,000 km per month. The initial data collected are in Table 1.

Spare Part	Monthly Consumption	Unit Price	Quantity per bus	Criticality	Lead-time (days)
P1	0.636	168.00	1	Y	1
P2	0.364	660.00	1	Y	3
P3	0.727	2,700.00	1	Y	3
P4	1.0	1,843.00	1	Y	3
P5	1.0	229.00	4	N	1
P6	0.364	23.00	1	Y	1
P7	2.273	882.00	1	Y	3
P8	2.727	1,176.00	1	Y	3
P9	1.364	136.00	4	Y	1
P10	0.273	168.00	4	N	1
P11	1.273	197.00	4	N	1
P12	1.818	129.00	4	N	1
P13	1.273	70.00	4	N	1
P14	0.909	200.00	2	Y	1
P15	27.636	12.97	8	N	1
P16	18.0	1,180.00	6	Y	1
P17	6.364	1.25	8	N	1
P18	7.727	8.90	4	N	1
P19	5.364	1.25	2	N	1
P20	6.273	0.77	4	N	1
P21	3.091	134.00	2	N	3

P22	7.636	380.00	2	Y	1
P23	85.455	14.49	16	Y	3
P24	68.545	14.10	16	N	3
P25	63.364	16.65	16	N	3
P26	97.455	18.21	16	N	3
P27	1.273	268.00	4	Y	3
P28	1.636	279.00	4	N	3
P29	0.909	265.00	4	N	3
P30	1.636	76.31	4	N	3
P31	2,642.36	0.45	256	N	3
P32	1,279.36	0.54	256	N	3
P33	3.0	30.00	1	Y	3

Table 1 – Initial data on the 33 replacement spare parts of a bus

With these initial parameters, the critical items (which cause the bus to stop running when they fail) and non-critical ones (which do not immobilize the vehicle) were determined. By using the Poisson function and establishing a rate of 10% as the initial minimum for the level of service (LS), we obtained Table 2 for the critical items.

Part	**λ**	**Unit Cost (C)**	**Initial Stock**	**LS**	**ΔLS**	**Cost benefit (CB)**
P1	0.636	168.00	0	52.9%	33.7%	499
P2	0.364	660.00	0	69.5%	25.3%	2.611
P3	0.727	2,700.00	0	48.3%	35.1%	7.683
P4	1.0	1,843.00	0	36.8%	36.8%	5.010
P6	0.364	23.00	0	69.5%	25.3%	91
P7	2.273	882.00	0	10.3%	23.4%	3.767
P8	2.727	1,176.00	1	24.4%	24.3%	4.835
P9	1,364	136.00	0	25.6%	34.9%	390
P14	0.909	200.00	0	40.3%	36.6%	546
P16	18.0	1,180.00	13	14.3%	6.5%	18.021
P22	7.636	380.00	4	12.2%	10.4%	3.639
P23	85.455	14.49	74	11.6%	2.4%	614
P27	1.273	268.00	0	28.0%	35.6%	752
P33	3.0	30.00	1	19.9%	22.4%	134

Table 2 – Initial data from the critical items.

As to the Cost benefit (CB) column, it is the decision parameter. It is calculated by dividing the cost (C) by the variation in the level of service (ΔLS). In the initial situation of the worksheet shown in Table 2, P6 is the part that has the lowest "CB", equal to 91 (with C = 23 and ΔNS = 25.3%, CB = 23 / 25.3 ≈ 91), and thus the choice is to buy another unit for this part, the stock of which goes from 0 to 1 unit at a cost of another R$23.00. For the non-critical items, the program follows the same procedure and suggests that part P20 has the lowest CB (CB = 6) and is elected for the first purchase.

The model proceeds by iterations and at each of them a summary (Table 3) is presented to the manager of the business about which part should be purchased, how much it costs, how many are in stock, and especially, what the total amount spent on the inventory and what the current level of service level are, so that the analyst keeps monitoring step by step the evolution of these parameters and can stop the process whenever he/she wishes.

CB	**Part to be bought**			
390.00	P9			
	Quantity in Stock	**LS**	**Purchase cost**	
	0	25.57%	136.00	
Total Spent	R$ 19,281.26		**LS**	40.05%

Table 3 – Summary of the stock after the 2nd purchase and recommendation

Depending on the goal set by the company, the time to stop the process is linked to the attainment of a stipulated level of service or a budget is arrived at for spending on pre-established stock. For the case study, this situation is presented in Table 4.

CB	**Part to be bought**			
14.360	P2			
	Quantity in Stock	**LS**	**Purchase cost**	
	1	94,79%	660.00	
Total Spent	R$ 41,157.39		**LS**	90.16%

Table 4 – Summary of the stock after the 49th purchase (LS higher than 90%)

On analysing Table 4, it can be concluded, when dealing with the critical items of this study, that to achieve the target service level of 90%, the need is to spend R$ 41,157.39 on the inventory. This was the equivalent of a little more than doubling the stock compared with the initial value of R$ 19,138.26, namely a 115% increase. As the goal of 90% was achieved, with a significant 57.04% increase in the level of service (the LS of the initial stock was 33.12%), the business manager must weigh up this cost-benefit ratio to decide, as per the company's strategy, what to do.

With respect to the non-critical items, the model allows the same procedure already shown for the critical items. As there is therefore a lower criticality, they can be managed with less attention, thus spending less and working with lower service levels. Alternatively, the model offers other options that can give important information about the parts inventory. One of these is the graph that shows the variation curve of the budget spent on inventory items versus the level of service, as shown in Figure 2.

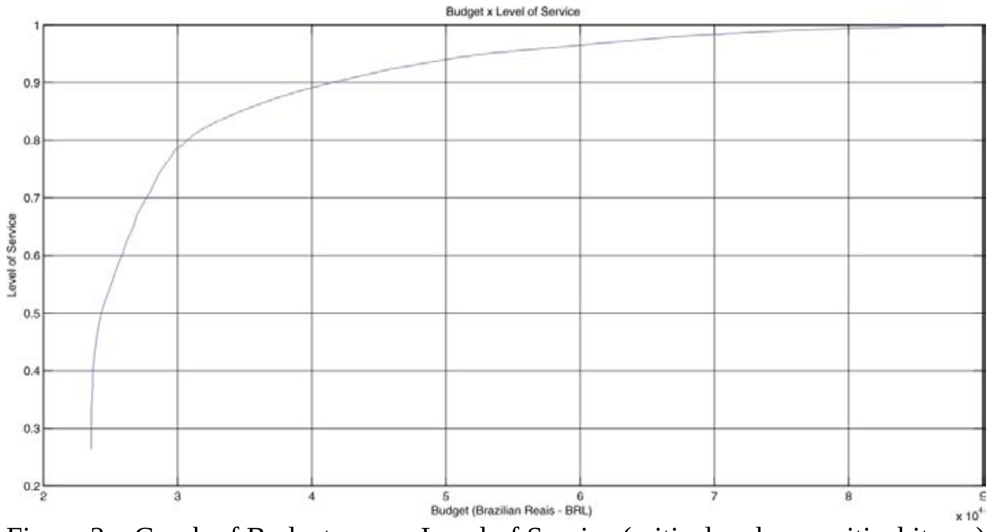

Figure 2 – Graph of Budget versus Level of Service (critical and non-critical items).

On analysing Figure 2, it is easy to see that, starting from the initial condition (LS = 26.43%; budget = R$ 23,563.21), a lot is gained in the level of service with little investment. For example, if more than R$ 7,500.00 is invested, an LS a little more than than 80% is reached (exact figures: LS = 80.82% R$ 31,143.06). With an LS of 90%, there is an investment of a little more than R$ 41,500.00 in the stock of critical and non-critical items. From there, it is soon seen that there is a "saturation" in the curve, thus reversing the prevailing logic, i.e. there are then high investments for little return (low increments in the level of service), which clearly it is not worth the company's spending resources on in this situation.

The option to deal separately with the critical and non-critical items allows the manager to have greater flexibility in managing the contingency element of his/her budget, and certainly yields a better result for inventory management as it allows the logic of the program, based on the typical problem of a portfolio of assets, in which several items (within its group of criticality) to compete for resources simultaneously, thus gaining the one that presents the lowest cost-benefit index, which brings a gain to the operation as a whole.

5. Conclusions

It can be concluded that the model developed and applied in a real situation reached its objective, as it allowed important parameters in controlling the inventory of replacement spare parts to be monitored efficiently, thus contributing to the management of an urban bus company in the city of Natal. It is further understood that this model can be replicated in any other company which has replacement spare parts in its inventory and consumes them when carrying out corrective maintenance.

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