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On the relationship of spare parts inventory policies with Total Cost of Ownership of industrial assets

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Abstract: This work presents the results of a simulation study aimed at characterizing the relationship of spare parts inventory policies with Total Cost of Ownership of industrial plants. The study is motivated by the expectation that several spare parts management decisions cause important effects in the long-term profitability of industrial assets. Such decisions may regard, amongst the others, the initial provisioning, the inventory policy and the end-of-life acquisition. This work adopts simulation to test a specific spare parts inventory policy, i.e. a continuous review system, with the final purpose to assess its effects on the operational performance of an industrial comminution plant and, consequently, on its Total Cost of Ownership.

Keywords: Spare parts management, Inventory policy, Asset life cycle, Total Cost of Ownership.

1. INTRODUCTION

Total Cost of Ownership (TCO) is the sum of expenditures made by the owner of a physical asset along its entire life cycle. Those expenditures are required to acquire, install, put into service, operate, maintain and, eventually, dispose the physical asset. Those costs play an important role within the decision making process, especially regarding decisions on purchasing, maintenance planning, operations strategies, spare parts / logistics support design, as well as replacements and renovations.

Publications on TCO evaluation of industrial assets can be found in the scientific literature since 1970 (Kaufman, 1970; Ntuen, 1985; Taylor, 1981). From those years on, proposals of TCO models are present at a great extent. Nevertheless, despite it may seem an overcome problem. Nowadays TCO is gaining momentum both in industry and scientific research (Thiede et al., 2012), and several gaps can still be identified when analyzing the state of the art. In fact, i) most of the currently existing life cycle cost models assume a piecemeal approach and no systemic view (Xu et al., 2013) and, ii) there is a lack of adequate cost models describing the links between system performance parameters and the costs involved and that take into account the configuration complexity of asset systems (Chen et al., 2013).

More in detail, as it is stated by Roda and Garetti (2014), many existing TCO models lack in considering the performance characteristics of the industrial installations, i.e. physical assets, as a whole. Indeed, the operational performances achieved as a system (e.g. a production line, composition of machines) are rarely evaluated by means of a TCO model. In other words, besides availability, reliability, maintainability, other characteristics as the production capacity achievable by the system should be considered for a decision under a systemic perspective.

Maintainability is a key dimension for a physical asset, which leads to Key Performance Indicators (KPIs), such as MDT (Mean Down Time). Through maintainability, a decision maker can be aware of the probability that failed equipment can be restored to its normal operable state within a given timeframe. One of the main aspects to guarantee or maintain a certain level of maintainability is spare parts availability. Therefore, a main concern when defining maintainability is the configuration of inventory policies (also stocking policies as synonym used by literature) for each spare part, in order to sustain the availability of the physical asset and, as a final consequence, to guarantee the capacity of the production system where the asset is operating.

Despite the importance of maintainability for physical assets, main effects of spare parts inventory policies are still poorly covered in economic evaluations along the asset life cycle, as demonstrated by the lack of models proposed that incorporate those aspects into TCO evaluation. Our interest is to reflect on this gap and, to this end, we decided to make a simulation study with the purpose to unveil the relationship between the spare parts inventory policies and TCO.

The paper is organized as follows. Section 2 provides a quick literature review focusing on the relationships between TCO models and spare parts management decisions. Section 3 provides a conceptualization of the relationship of spare parts inventory policies with TCO of industrial assets. Then, section 4 and 5 are dedicated to the simulation study: they are respectively presenting the simulation and cost models used for the study, and the analysis of the experimental results. Section 6 provides the concluding remarks of this work.

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2. LITERATURE REVIEW ON TCO MODELS AND SPARE PARTS MANAGEMENT DECISIONS

Roda and Garetti (2015) proposed a Cost Breakdown Structure (CBS) for performing TCO analysis and trade-offs in order to suit the objectives of the company under concern.

Amongst the categories in the CBS there are the spare parts costs. In that category, many are the aspects that have to be considered. In fact many are the decisions on spare parts management that a company can make along the lifecycle of the asset system and that affect its TCO. Briefly speaking, a series of spare parts management decisions can cause economic effects into TCO, as for example, supplier selection, initial provisioning, stocking policy (i.e. inventory control and location), repair or replace policy, end of life acquisition using/acquiring salvage spare parts.

If we also consider the environment where the physical asset is operated, a series of challenges and opportunities are influencing the spare parts management decisions and, thus, their economic effects measured by the TCO. Amongst them, it is worth considering the operational behaviour and characteristics of the asset (i.e. failures' dependencies, deterioration, changes in the process severity, etc. …), the management practices (i.e. standardization / commonalities of spare parts, outsourcing of inventory control to suppliers, decentralized stocks, co-operative stock pools, etc. ….), and the changes in the outer context (technology innovation, new commercial offers from spare parts vendors, etc. …).

Last but not least, spare parts classification is also worth of a remark, as a relevant step of the whole management process for driving decisions on spare parts (Roda et al., 2014). Many advantages can be achieved as a consequence of a proper classification, e.g. a company may align stocking policies with criticalities of the spare parts (Macchi et al., 2011). In fact, it has to be considered that in order to define the stock sizes for the spare items, a company needs to select the inventory model amongst different options and proper classification can help for this scope (Macchi et al. 2011), (Miranda et al. 2014). In this regard, it is worth remarking that literature is providing a wide set of models for stock management control; the following list collects the majorly used or cited models (Cavalieri et al., 2008).

- The continuous review, with fixed reorder point (r) and fixed order quantity (Q), referred to as (Q, r).
- The continuous review, with fixed re-order point (s) and order-up-to level (S), referred to as (s,S).
- The periodic review, with fixed ordering interval (R) and order-up-to level (S), referred to as (R,S).
- The continuous review and order-up-to level (S) in a one-for-one replenishment mode, referred to as (S-1, S).
- The continuous review, with re-order point (s) one or zero policy that resolves the main spare parts problem: stock or no stock.

Notwithstanding the importance of spare parts management decisions in practice, in an extensive literature review, few works have been found that address the integration of such decisions within TCO models. In Carpentieri et al. (2007) a simplified life cycle cost (LCC) model which integrates spare parts issues is proposed. In that work, the authors suggested the application of a simulation study to estimate the average monthly consumption rate of the mechanical and electronic components used by a production line. That work does not consider inventory policies or other aspects present in a spare parts management system. Carpentieri and Papariello (2006) incorporate operational aspects and spare parts management issues into a LCC model, taking into account the maintenance costs for two different maintenance policies (preventive and corrective) to calculate the costs of the spare parts that are annually required. Thus, a number of indicators is considered in their LCC model such as the total annual spare parts cost and the total maintenance hours required by a station, with logistics considerations about assembly and disassembly operations. Jun and Kim (2007) incorporated with more detail the spare parts aspect into a LCC model for a railway vehicle. They highlighted that an optimized strategy in spare parts management can decrease the operational costs. In their work they classified total LCC into two categories: recurring and non-recurring costs. Recurring cost (cost annually calculated) includes labour, consumable, power, on-going training, documenting and upgrading cost. On the other hand, the non-recurring cost includes initial spares, amongst others: they are calculated once when the asset is purchased, and they are usually added to the investment costs.

3. CONCEPTUAL MODEL ON THE RELATIONSHIP OF SPARE PARTS INVENTORY POLICIES WITH TCO

A conceptual model is now proposed to set the relationship of spare parts inventory policies with TCO (figure 1).

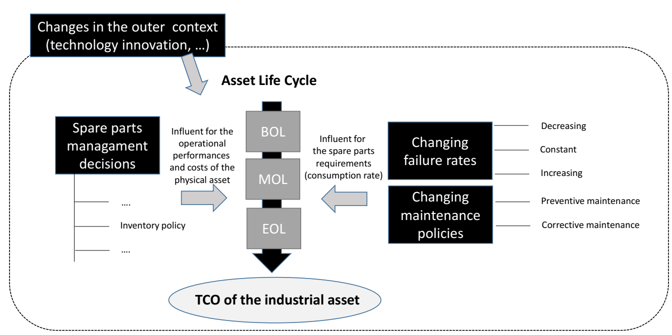

Figure 1. Conceptual model

Three inner dimensions (internal to the management system) are defined: i) spare parts management decisions, ii) changing failure rates and iii) changing maintenance policies along the life cycle. Besides, changes in the outer context are influent on such inner dimensions.

For what concern the first dimension, a lot of decisions can be identified in regard to the spare parts of physical assets. Spare parts inventory policy is one decision, amongst others. In particular, initial provisioning of spare parts is required at the Beginning of Life (BOL) of the physical assets. Besides, other decisions are needed, dealing with the inventory policy, repair or replace policy, locations (comparing centralized or decentralized stocking).These may be changing along the asset life cycle as the environmental conditions change: