TCO evaluation in physical asset management: benefits and limitations for industrial adoption

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Abstract The aim of this paper is to recall the concept of total cost of ownership (TCO) of industrial asset to highlight its relevance in asset management. Nowadays, being able to evaluate the TCO of assets is more and more recognized by companies and researchers as a basis for taking informed decision making both for investments and managerial issues, nevertheless its importance within asset management strategy still remains generally undervalued. Based on a literature review, the paper defines a framework that categorizes the benefits and potential applications that a TCO model can have for different stakeholders. Together with that, industry related issues that influence its adoption are also considered. Based on that, empirical evidences are analyzed through a multiple case study to understand if those benefits are recognized in practice and which are the limitations, if any, for the practical adoption of a TCO model that should allow exploiting such benefits.

Keywords. Total Cost of Ownership, asset management

1 Introduction

In the capital-intensive industry, the operating time of the production asset after the green-field investment is typically long and during such time numerous rebuilds, replacements and expansion investments take place. All of these decisions, together with the chosen operations and maintenance strategies, affect the productivity of the physical capital (Komonen et al., 2006; Tam and Price, 2008). In order to meet the challenge of low returns on investment, enterprises need to create an asset management strategy and the core issue of physical assets management should be how to sustain or improve the life cycle profits of the original investment (Komonen, 2006). With this regard, one of the challenges in the physical asset management field is to improve the quantification process of costs, in order to be able to evaluate the total cost of operating a production system throughout its life cycle (i.e the so called Total Cost of Ownership) (IAM, 2012; Parra et al., 2009) since it represents a synthetic and complete information that should be considered as a basis for informed decision-

making in order to achieve improvement in cost, productivity and profits through good asset management.

More in detail, this work refers to the concept of TCO intended as the actual value of the sum of all significant costs involved for acquiring, owning and operating physical assets over their useful lives (Woodward, 1997). TCO is strictly related to the concept of Life Cycle Cost (LCC) and they are often used without distinction in literature. The widely shared idea is that TCO provides a selected perspective on LCC. In contrast to LCC, it focuses on the ownership perspective of the considered object and all the costs that occur during the course of ownership (Lad and Kulkarni, 2008; Thiede et al., 2012). Moreover (Clarke, 1990) and other authors later on, gave it a more strategic connotation than the general concept of LCC, giving it the meaning of a supporting information for strategic choices regarding both investment decisions and operational strategies.

2 Methodology

This paper aims at defining a framework that categorizes the benefits and potential applications that a TCO model can have for different stakeholders. In order to do so, an extensive literature review has been developed in order to identify the different perspectives given by different authors. The search for related publications was mainly conducted as a keyword search using "TCO" and similar terminologies such as LCC, etc. Both search through library services such as Scopus or Google Scholar and a more wide surfing in the web were addressed so to consider journals and conferences publications but also white papers and industrial reports. The analytic categories which allowed the classification of the reviewed literature and the definition of the framework have been derived both deductively considering the body of theory in the physical asset management field and inductively from the material analyzed by means of generalization (Mayring, 2003). After the framework has been defined, empirical evidences have been analyzed so to confirm the framework from a practical point of view. This also allowed to identify the main limits for the practical adoption of TCO models. With this regard a multiple case study has been developed and more details on the related methodology are given in Section 4.

3 TCO applications and benefits: definition of a framework

It is widely accepted in the academic literature (Schuman and Brent, 2005) that TCO should be an integral part of an asset management strategy and the same is assessed by the body of standards ISO 55000 on asset management (ISO 55000:2014(E), 2014). The latter puts into evidence the relevance of being able to quantify the TCO of an asset, being it an industrial system or a single equipment, and it is indicated that: "[…] Life cycle cost, which may include capital expenditure, financing and operational costs, should be considered in the decision-making process. […] When making asset management decisions, the organization should use a methodology that evaluates options of investing in new or existing assets, or operational

alternatives [(ISO 55001:2014(E), 2014), 6.2.2.4]. Moreover, companies are acknowledging how a TCO model can represent a reliable economic-sound support for taking decisions and to convey the information it represents not only to people within the manufacturing unit in question, but also to people in other parts of the organization, such as company management or outside the company, such us costumers / suppliers (Al-Hajj & Aouad, 1999; Fleischer, Weismann, & Niggeschmidt, 2006). The ability to effectively identify cost drivers and manage cost reductions is a competitive advantage for companies (Heilala et al., 2006).

3.1 The framework

Based on the literature review, the proposed framework, that highlights the potentialities for a company of having a TCO evaluation model / tool, is organized on three main dimensions: i) type of stakeholder, ii) type of supported decision, iii) phase of life cycle.

- **Type of stakeholder**. Different stakeholders with different perspectives can be interested in TCO analysis. Given the meaning itself of TCO, it is evident that asset users (industrial equipment or plant owners / managers) are the primary interested subjects. Nevertheless TCO is also a relevant issue for asset providers (industrial equipment or plant builders / manufacturers). This is evident by the raising number of white papers and publications by companies themselves, both users and providers, communicating the potentiality of having a tool able to calculate the TCO of industrial assets (Barringer and Weber, 1996; Barringer, 2003). Clearly it has to be considered that each of the two types of stakeholders have some common and some distinguishing reasons for interest on TCO. Besides, from an application point of view, it has to be considered that the ability of a provider to perform TCO evaluation is affected by the quality of information available in a higher way than for users (Korpi and Ala-Risku, 2008).
- **Type of supported decision**. A TCO model has potentiality to support different kinds of decisions. In particular, in the following framework two main categories have been identified: (i) configuration decisions and (ii) management decisions. The first category includes all those decisions that have direct influence on the asset configuration, while the second one refers to those decisions that deal with the management and operation of the asset (marketing, purchasing, usage, etc.).
- **Phase of life cycle.** TCO analysis is preferably carried out in any and all phases of an asset's life cycle to provide input to decision makers (Kawauchi and Rausand, 1999; Schuman and Brent, 2005). According to the conventional perspective, the lifecycle of an asset is composed by three main phases: beginning of life (BoL) including the activities involved in bringing an asset into operation (the conceptualization, design, construction, installation and acquisition), middle of life (MoL) including the activities involved in asset operation and maintenance and finally the end of life (EoL) involving the final retirement of the asset (Amadi-Echendu, 2004). In the following framework (Table 1) the involvement of the two different types of stakeholders is considered at each phase of the life cycle, and it is evident

that the perspective differs depending on it. As an example, the BoL phase represents the commissioning and acquisition step for asset users and the design and selling phase for providers.

The framework shows which benefits a TCO model can bring to each of the two types of stakeholder at each lifecycle phase by supporting different kinds of decisions (configuration or management decisions).

Table 1. Framework

	ASSET PROVIDER		ASSET USER	
	Configuration	Management	Configuration	Management
BOL	- Evaluation of project alternatives - Comparison and optimization of design alternatives - Components / equipment procurement and construction alternatives evaluation - spare parts requirements estimation. [1], [2], [3], [4]	- Communicating value to the customer and selling - Propose the clients specific design solutions - Pricing - Contracting maintenance service provision [1], [2], [4] , [5]	- Evaluation of design alternatives offered by provider [6]	- Suppliers and tenders evaluation & selection - Maintenance service contract evaluation - Investment, budget planning, cost control [2], [7], [8], [4], [9]–[11]
MOL	- Proposal of re-configuration solutions	- Maintenance service provision offering - Spare parts provision offering	- Reconfiguration decisions - WIP sizing [12], [13]	- Maintenance scheduling and management - Repair level analysis - Asset utilization and production strategies [15], [2], [14]
EOL	- Proposal of reconfiguration for EoL optimization	- Evaluation and proposal of rehabilitation strategies	- Reuse strategies for components / machines	- Evaluation of rehabilitation strategies [3], [16], [11]

References in the framework	
[1] Carpentieri and Papariello, 2006	[9]Denkena, et al., 2006
[2]Korpi and Ala-Risku, 2008	[10]Thiede, et al., 2012
[3]Asiedu and Gu, 1998	[11]Waghmode and Sahasrabudhe, 2012
[4]Schuman and Brent, 2005	[12]Tomasella and Parlikad, 2012
[5]Snelgrove, 2012	[13]Arata and Arata, 2013
[6]Fabrycky and Blanchard, 1991	[14]Lad and Kulkarni, 2008
[7]Rühl and Fleischer, 2007	[15]Barringer, 2003
[8]Ellram and Siferd, 1998	[16]K. Shahata and T. Zayed, 2008

It is evident that the TCO method is useful in asset provider-user communication, and helps in trade-off analyses of system concepts (Heilala et al., 2006). The core aim of a TCO evaluation is to avoid problem shifting decisions by keeping an integrating perspective (Thiede et al., 2012). In the following sub-sections the content of the framework is more deeply articulated considering each lifecycle phase and presenting which are the main applications of a TCO model at that step for different stakeholders and different kind of decisions.

- **BoL -**.Several authors highlight the role of TCO in supporting decision making at the design phase; according to them cost must be an active rather than a resultant factor throughout the system design process (Fabrycky and Blanchard., 1991; Waghmode and Sahasrabudhe, 2012; Woodward, 1997). Though, generally speaking only 15% of the total TCO is consumed during the design and the development

phase, research has shown that as much as 85% of the remaining TCO is determined by decisions made during this stage (Lad and Kulkarni, 2008). The early identification of acquisition and ownership costs provides the decision makers with more opportunity of balancing performance, reliability, maintenance support and other goals against life cycle costs by taking documented decisions such as using different levels of automation, redundancies, etc. (Kawauchi and Rausand, 1999). TCO evaluation at this step allows the providers and the users to economically evaluate different scenarios at a pre-design step (Carpentieri and Papariello, 2006); determining the most cost efficient design amongst a set of alternatives; identifying cost drivers for design changes and optimization and, determining the cost of a design for budgetary purposes (Korpi and Ala-Risku, 2008).
TCO can be seen also as a procurement (from the user perspective) and sales and marketing (from the provider perspective) tool. (Snelgrove, 2012) asserts that at the heart of pricing and selling in the twenty-first century is the ability to price based on created value and in this context, TCO plays an important role. Moreover, TCO allows abandoning traditional feature-based marketing to showing how the asset that is offered create specific benefits considering its lifecycle and how it affects customer profitability. In this way companies are able to reposition their price. On the other side, through a TCO model, users are able to support their supplier selection and evaluation steps (Ellram and Siferd, 1998; Ellram, 1995; Korpi and Ala-Risku, 2008; Rühl and Fleischer, 2007). Ellram (1995) defines TCO as "a purchasing tool and philosophy which is aimed at understanding the true cost of buying a particular good or service from a particular supplier". In this phase the supplier is also interested in TCO evaluation in case there is the possibility to enter into a service contract where it is held responsible to maintain the equipment. With such an agreement it is in the best interest of the provider to supply equipment with the lowest TCO. Moreover a TCO model is able to support investment decisions supporting budget planning and costs control helping preventing decision makers from incurring investments which might be cheaper in acquisition, but significantly more expensive in O&M and consequently in total costs over their life cycle (Denkena et al., 2006; Thiede et al., 2012). Finally TCO plays a supporting role also during the construction and installation life cycle phase for asset providers. In fact, although it is a late stage in the project for major changes, recommendations should still be considered in terms of TCO and the most favorable solution implemented. Parallel with equipment procurement and construction, spare part requirements and provision are evaluated at this phase (Schuman and Brent, 2005).

- **MoL -** The evaluation of TCO and its usage for decision making support does represent a relevant aspect also during the O&M phase of an asset (Arata and Arata, 2013; Kawauchi and Rausand, 1999), both for configuration and management decisions, mostly for the asset users. At this stage of the life cycle, the asset is operative and, compared to the design stage, the level of uncertainty for the TCO evaluation is lower (Kawauchi and Rausand, 1999). Opportunities for reduced support costs and more effective support are based on the systematic capture and reuse of all information throughout the equipment life cycle (Bouachera et al., 2007), hence the best scenario is the case where data for technical performance evaluation

are regularly collected. If this is not possible, the uncertainty in cost evaluation is anyways lower given that even if the analysis are based on estimations by people working on the field, these are related to an existing and operative asset. The use of TCO in this step can support asset users for configuration decisions such as the evaluation of the reconfiguration of the asset by applying some changes in the current layout for achieving a better availability level and hence lower costs, involving also considerations on the WIP level (Arata and Arata, 2013; Tomasella and Parlikad, 2012; Woodward, 1997). Moreover TCO evaluation can support management decisions such as the evaluation of changes in the actual maintenance strategy. The key factor is to find an optimal level of maintenance service in order to be consistent with the organization's objective of attaining minimum total cost (Woodward, 1997). In fact, maintenance offers the opportunity to strongly influence the TCO through different strategies by balancing failure and preventive maintenance costs (Thiede et al., 2012), hence, asset users have great opportunities to evaluate different policies through a cost evaluation (Lad and Kulkarni, 2008). Likewise, decisions on the operative conditions of the asset; its utilization and the production strategies can be supported by the TCO evaluation.

- **EoL -** TCO has got relevance also at the End of life of an asset. In fact, in this stage the asset is taken out of service for disposal or redeployment. In the latter case a potential new TCO may begin (Woodward, 1997), therefore the asset manager may use the TCO evaluation of the existing asset in order to support decisions for rehabilitation or reuse of the asset itself (Asiedu and Gu, 1998; Shahata and Zayed, 2008).

3.2 The industry-influence

An additional aspect that emerged from the literature analysis is about the influence of the industry a company belongs to on the value given to TCO analysis. The TCO concepts was firstly introduced for procurement purposes by the US Department of Defense (DoD) in 1960 and its importance in defense was stimulated by findings that operation and support costs for typical weapon systems accounted for as much as 75% of the total cost (Asiedu and Gu, 1998). Since then the need for more extensive application of engineering economy methodologies in the planning and control of systems for the production of goods and services has been more and more recognized. The applications of LCC analysis have spread to other industries such as aircraft, electrical power plants, oil and chemical industries, and railway systems (Kawauchi and Rausand, 1999). In fact, capital intensive, mostly process industries, have a tradition of viewing their physical asset management as a strategic resource given the high vulnerability to disturbances and the need for production regularity. This is why they traditionally practice TCO evaluation and its integration with RAM analysis. Nevertheless, presently these concepts are increasingly being considered by industrial goods manufacturers too. In fact, the emergent global competition is now forcing the manufacturing industry to estimate and optimize the overall system life cycle cost with reference to performance, safety, reliability and maintainability (Waghmode and

Sahasrabudhe, 2012) in order to be able to compete not only on price, but on cost effectiveness and technological leadership also (Lad and Kulkarni, 2008). More and more contracts are based on TCO evaluation in several sectors such as the automotive, the packaging and the food sectors. These concepts have been summarized in Table 2 which highlights the critical factors connected to the TCO relevance for a process and a discrete manufacturing industry.

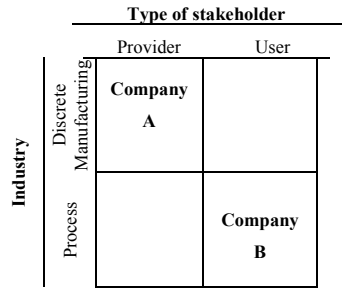
Table 2. Relevance and critical factors of TCO in process and manufacturing industries

Type of industry	*Critical factors*	*TCO relevance*
Process industry (i.e. power plants, mining and oil, chemical sectors)	• capital-intensive assets • high vulnerability to disturbances (failures, emergency shutdowns, etc.) • need for production regularity	• High strategic relevance of physical asset management, RAM analysis and TCO evaluation.
Discrete manufacturing industry (i.e. machine tools manufacturers)	• high competition and need to compete on cost effectiveness and technological leadership than just on price • need to reduce stock & costs	• Total Costs of Ownerships is getting more and more relevance. Need to go beyond capital cost in contracts, by demonstrating value for money of investments.

4 Practical implications: empirical evidences

In order to corroborate the developed framework from an empirical point of view, two different contexts have been selected by involving two companies belonging to different industries and evaluating how they consider TCO for supporting strategic decisions. Company A is a small medium company from the discrete manufacturing industry while company B is a big company belonging to the process industry. Moreover, they have different perspectives on asset management since company A is asset provider while company B is asset user. These differences have been selected referring to the different dimensions of the framework, and to the industry dependency that has been highlighted in section 3. The case has been based on semi-structured interviews and on a defined questionnaire to different roles in the companies both at operative and strategic levels. Triangulation and follow up have been based on archival data (company's public reports and website).

Table 3. The contexts for the multiple case study



A first aspect that emerged from the case study is the different involvement and interest in using the TCO in different life cycle phases depending on the kind of stakeholder the two companies represent. In fact, Company A (provider) declared to be directly involved and being able to take decisions mostly in the BOL phase. In fact, the company is responsible of the design and installation of the asset it produces and its role in the MoL phase is limited to providing the clients with manuals and guidelines for the maintenance activities. No service is provided in this case by company A to its clients. On the other side, Company B is an asset user and it is directly interested in the management of its assets in the MOL phase and in the evaluation of investments for new installations. It has to be specified that Company A recently started to look at TCO as a potential tool and is now pushing its importance at strategic role; for Company B instead the TCO concept is consolidated even if it is still looking for a tool able to integrate technical evaluation into cost estimations. The following table refers to the proposed framework and shows which are the decisions that TCO evaluation can support based on the relevance for the business according to the judgments of the two companies .

Table 4. The TCO benefits: results from the case study

	COMPANY A (ASSET PROVIDER)		COMPANY B (ASSET USER)	
	Configuration	Management	Configuration	Management
BOL	- Comparison and optimization of design alternatives	- Communicating value to the customer and selling - Propose the clients specific design solutions	- Evaluation of design alternatives	- Suppliers and tenders evaluation & selection - Maintenance service contract evaluation - Investment, budget planning, cost control
MOL	- System reconfiguration proposals	- Possibility to develop service offering	Reconfiguration decisions	- Maintenance scheduling and management - Repair level analysis

The results from the two cases endorse what was expected by the theory and confirm the objectives defined into the framework. The case study was also useful to identify the main limitations in the adoption of TCO in practice. In particular, the main findings that emerged are the following:

- both companies assessed the need for a TCO tool able not only to consider all the relevant cost items along the asset lifecycle, but also the technical aspects that have influence on it (the authors developed a literature review about this issue in (Roda and Garetti, 2014);.
- there is the need for a reliable database with both economic and technical parameters to be used for the TCO evaluation; in particular, the main problem for Company A is the necessity for a strict collaboration with its customers in order to get data for the evaluation of the OPEX of the asset under analysis; while Company B needs to focus on a system able to record relevant data regarding the behavior of its asset (failures events, set-up times etc.);

- the use of the TCO at the disposal phase is not considered as a relevant issue for both companies at the moment;
- general desires to minimize the initial expenditures in order to increase return on investment, and general lack inside the organizations of the adequate consideration of the asset life cycle that requires inter-functional cooperation and alignment;
- in general, TCO is seen as a powerful communication tool by both kind of stakeholders, being able to inform different kind of actors, the customers but also the top management by supplying the value of the asset through the language of money, eventually incorporating technical considerations.

5 Conclusions and future research

The paper presents a framework that describes the main applications and benefits that the evaluation of the TCO of industrial asset has got both for asset users and asset providers along the asset life cycle. Moreover, a case study analysis was implemented for an empirical assessment. TCO is seen a useful indication for guiding asset managers in the decision making process for harmonizing the never ending conflicts by focusing on facts, money, and time (Barringer, 2003) and, if properly estimated it does represent a competitive advantage for companies.
Nevertheless, up to day, there are still a number of difficulties that limit a TCO model widespread adoption by industry and there is no single model that has been accepted as a standard; future research should then try to overcome this aspect.

6 References

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