Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 11 (2017) 1940 – 1949

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

A TCO model for supporting the configuration of industrial plants

Marco Mandolini[a]*, Eugenia Marilungo[a], Michele Germani[a]

[a] *Università Politecnica delle Marche, via Brecce Bianche - Monte Dago, Ancona (AN) 60131, Italy*

Abstract

In the current industrial context, where processes are extremely flexible to meet the changes of the market demand, the traditional strategies for managing the design and investment of industrial assets are too restrictive. Indeed, such strategies just consider the procurement price of an asset rather than its lifecycle cost. In this framework, the paper proposes a Total Cost of Ownership (TCO) model that can be adopted in B2B context for establishing the best asset configuration and procurement strategy by considering its CAPEX and OPEX. Such a TCO model has been implemented into an Enterprise Application Software for supporting the TCO evaluation. The presented model and software tool have been applied within an Italian food company for supporting the assets investment management.

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing

Keywords: Total Cost of Ownership (TCO); Suppliers selection; Industrial plant configuration; Asset management; Lifecycle approach

1. Introduction

In the current industrial world, where the production is changing from mass production to customised production, the main driver to reach the success is the flexibility of industrial processes [1]. In this way, industrial companies can achieve the market demand that changes very rapidly in a global competition. In this context, the asset management for those companies becomes a strategic mean to configure the production process and then the entire production plant in order to minimise the assets costs along their lifecycle.

* Corresponding author. Tel.: +39-(0)71-2204799; fax: +39-(0)71-4801.
E-mail address: m.mandolini@staff.univpm.it

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing
doi:10.1016/j.promfg.2017.07.339

In order to address such a scope, a novel model able to recognise and optimise all the asset's costs along the lifetime is required, because the traditional cost assessment, based only on the manufacturing costs, is too restrictive. Indeed, manufacturing costs are a pillar for industrial companies in order to establish the purchasing cost of an asset, but usually it is only the tip of an iceberg. In fact, the Capital Expenditure (CAPEX) involves only the research, design and purchasing costs, without covering the Operational Expenditure (OPEX) such as maintenance, hidden costs, energy exploited, etc., which arise during the use phase of any asset [2]. Moreover, in the asset management, the role of each supplier (the manufacturer of the asset) involved in the supply chain consists in offering production systems characterized by high quality and performances while minimizing the operating cost during the lifecycle [3][4].

For these reasons, the paper presents a TCO model for the preventive analysis of industrial assets, which can be used during the design phase, for supporting the asset configuration, and during the procurement phase, for supporting the supplier selection and negotiation. At the design phase, the model foresees a configuration framework, which allows the designer to configure the asset by selecting its features in accordance to the product to realize. The model informs the designer about the preventive TCO of each possible solution (a solution consists of a combination of supplier and asset technology). At the procurement phase, the model allows the investment manager to select the best supplying strategy by simulating and optimizing different scenarios. A scenario consists of an asset technology, supplier, production plant and useful asset life.

The paper begins with a discussion about the TCO models adoption in literature, highlighting what are the main models adopted, in which sectors and the main lacks and challenges to face (Chapter 2). Then, the Chapter 3 presents the TCO model proposed in this paper and its exploitation into a dedicated tool (Chapter 4). Chapter 5 presents a case study and the results gathered by implementing the TCO model into an industrial scenario. At last, Chapter 6 drafts the main conclusions and future works.

2. TCO models in literature

A deep analysis conducted over more than 50 papers of the last seventeen years demonstrated a main research trend in TCO literature. Indeed, the papers closer to 2000s were more interested in investigating the TCO models as a mean to select the best suppliers to involve into the supply chain [5][6][7]. Instead, after ten years, these authors have started to approach the TCO models as a mean to analyse and optimise the product, process or service costs along the lifecycle [8][9].

According to this approach, which is also the current vision in TCO adoption, the literature works have faced the topic of lifecycle costs by different perspectives (see Fig.1). For examples, some papers have discussed the integration between TCO model with other tools, such as Bayesian networks in order to investigate the costs and benefits of specific solutions for optimising them [10][11][12]. Others have proposed theoretical models to recognise all the product costs along the lifecycle [13][14][15], but without the exploitation of these models in industrial contexts; thus, they remain too theoretical for industrial applications. Some authors have also discussed the application of TCO models along the time, proposing interesting literature reviews that allow identifying the main pillars and issues in such topic [16][17]. Other authors [18][19]have focused their attention on the definition of TCO models for the product and process sustainability. For example, the main scope of these researches was the optimization of part of a product or production process through the implementation of a TCO model. In this case, the costs analysis along the lifetime becomes a mean to investigate what are the main product or process components more impactful by an economic point of view to be optimized.

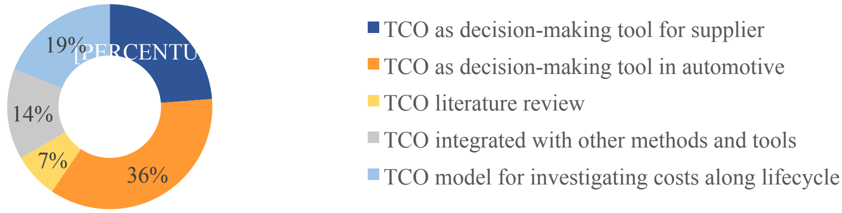


Fig. 1. Literature review analysis from 2000 to 2017.

By this literature analysis, most of the TCO models have been applied within the automotive sector [20][21][22][23][24]. The high competitiveness of such a sector and the operating cost of such products (compared to the manufacturing cost) have fostered the application of TCO models. Some authors have also approached the asset management through the cost assessment of each asset throughout its lifetime, for each supplier involved in the network [10][25]. However, these examples are not so common in literature, and a clear and structured TCO model to support the asset management is missing.

According to this overview, the main aspects that outline the TCO topic are highlighted in the following. Moreover, they are discussed in a critical way in order to identify the main lacks and challenges that should be covered and addressed.

- TCO can be used as a decision-making tool for the suppliers' selection. The models involved in this specific field assess the suppliers' costs at different levels but they do not address the lifecycle perspective. Indeed, such a models are mostly focused on the supplier, order, batch and unit [16], with the aim of configuring an optimised supply chain, but without considering the actual usage of the product, which is an aim of a preventive TCO.
- TCO models widely disseminated in literature are customised solutions that remain valid only for specific applications or in specific research contexts [16]. This is the main limit in the application of such methodologies to different products, services, or assets in general, because missing a high-level approach that can be broadly adopted.
- TCO models can be applied both in B2B (Business2Business) and B2C (Business2Customer) scenarios, but their main scope is the analysis of a specific item by economic point of view (e.g. an industrial solution, a supplier, a technology to adopt, etc.) in order to understand which solution can be adopted. Anyway, in this framework, a model for supporting the purchasing decisions, before deploy a specific asset, is not provided.
- TCO models imply that, for being applied within an industrial scenario, the costs items requested by the model itself must be previously defined and available. This means that all these costs are consumptive costs and thus they can be adopted only as a mean for selecting or analysing more solutions in order to identify the best one, according to the previous observations. The consumptive TCO models should evolve toward preventive TCO models for supporting the selection of assets that minimize the TCO throughout its lifecycle.

According to the main lacks and challenges identified, the present paper would propose a preventive TCO model for assessing the lifecycle costs of an industrial asset during the asset configuration and relative investment analysis. Such a TCO model supports the designers mainly in configuring/designing production machines (production lines/areas or even buildings). Indeed, by a preventive TCO evaluation, the designer can update his design before beginning the supplier's selection and proceed with the investment. The proposed TCO model also supports the investment managers in finding the best supplying strategy by an optimization process through preventive TCO simulations. This is step beyond the literature, mainly oriented to consumptive TCO evaluations.

3. Methodological approach for the asset's TCO assessment

3.1. Asset configuration model

The approach proposed to assess the asset's costs throughout its lifecycle in order to configure a production plant involves both the asset's owner and the related supplier. Indeed, it implies that the asset's owner establishes a collaborative relationship with its main suppliers, in order to share the information necessary to build the asset configuration and recognise all the required costs.

The preventive TCO evaluation of an asset and the comparative analysis among suppliers imply, first of all, the definition of a configuration method. This is a challenging aim since the asset owner does not design the asset itself, so that it is not possible develop a detailed configuration model. For this reason, the configuration model adopted in this work follows a simplified approach, where a specific machine configuration or standard type (e.g. flowpack for primary packaging, flowpack for secondary packaging) consists of a list of features/requirements, each one with a specific value. The way of configuring an asset depends by the asset family (e.g. flowpack, refiner, etc.). The features are classified in:

- *Characterizing features*: define a standard type (base configuration) of a machine;

- *Base features*: contribute in the definition of the standard type;
- *Optional features*: all the other features that are not base features.

Each feature generally represents a functional group of a machine. In addition to the machine configuration, for computing the TCO it is necessary to know the OPEX and CAPEX costs information with the following splitting:

- Cost of the base configuration (C_{base}). See Appendix A for abbreviations;
- Cost of each optional, depending by the base configuration the optional belongs ($C_{optional}$);
- Country factor, an index for weighting the costs according to the plant where the asset will be installed (C_{factor});
- TCO data in accordance to the TCO model presented below.

Fig. 2 depicts the Object Oriented schema for configuring an asset and related procurement costs.

During the machine configuration process, the designer firstly defines the general information such as the plant, the product realized by the asset, production rate and the technical requirements (e.g. power, dimensions, weights, etc.). According to such a data, a set of rules, connecting the charactering feature of a machine configuration and the general information, allow the definition of the machine configuration. While the base features are a constraint for that configuration, the optional ones are a free choice of the designers and they can strongly influence the TCO.

Once the designer defined the characteristics of the machine, he checks the suppliers able to provide what required. While the base features have to be respected, the optional ones are welcome. A similarity index measures the number of feature the supplier provides out of the number of features requested by the designer. The country factor multiplies the TCO for considering extra expenditure of the supplier for installing an asset on specific countries. It considers cost related to the logistics and particular adjustment of the machine to respect the regulations required by a country (e.g. environmental certifications).

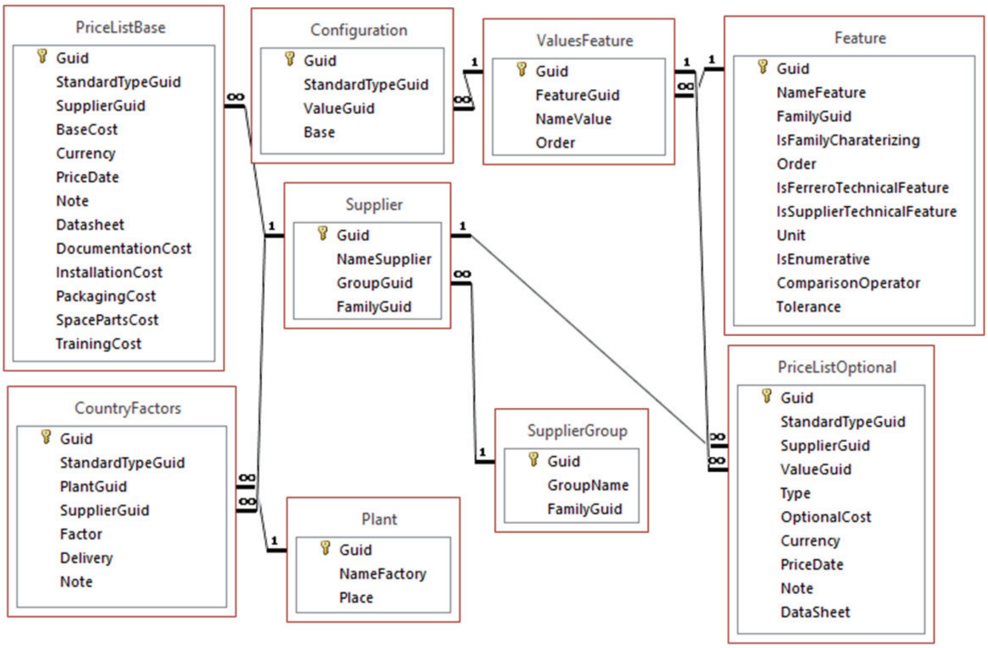


Fig. 2. OO schema for the asset configuration and procurement cost

3.2. TCO model

The TCO model conceived in this paper aims to assess all the asset's costs throughout its lifecycle. $C_{investment}$ is the cost occurred during the asset manufacturing phase and it is the investment cost (supplier perspective), C_{use} is the cost of the asset usage due to the owner exploitation (owner perspective), C_{EoL} is the cost generated by the management of asset End-of-Life (owner perspective).

$$TCO = C_{investment} + C_{use} + C_{EoL} \quad (1)$$

The TCO model here described (Equation 1) considers both the CAPEX, which are the investment costs coming from the asset manufacturing delivered by a supplier, and the OPEX, which are the operative costs due to the asset usage by the owner. The end of life phase is beyond this work.

3.2.1 CAPEX

The investment cost (CAPEX) calculation schema reflects the asset configuration approach presented above (§3.1). It consists of a cost for the base/standard configuration, a cost each optional feature and a list of cost items for deploying the asset within the workshop. The country factor identifies how much the transportation costs affect the overall investment cost. The cost values are the result of a negotiation process with the suppliers.

Equation 2 presents the way for calculating the investment cost.

$$C_{investment} = \left(C_{base} + \sum_{o=1}^{O} C_{optional} + C_{packaging} + C_{installation} + C_{documentation} + C_{training}\right) \cdot C_{factor} \quad (2)$$

3.2.2 OPEX

The running cost (OPEX) is in charge of the asset owner and it is calculated as the sum of the energy, consumable and maintenances costs (Equation 3).

$$C_{use} = C_{energy} + C_{consumable} + C_{maintenance} \quad (3)$$

The energy cost considers the energy curriers of the whole asset (i.e. electricity, steam, hot water, cold water, gas and compressed air), by summing the contribution of the base/standard asset configuration plus each optional feature (Equation 4).

$$C_{energy} = \sum_{y=1}^{Y}\left(\sum_{e=1}^{E}\left(EC_{e,y} \cdot AP_y + \sum_{o=1}^{O}\left(EC_{e,o,y} \cdot AP_y\right)\right)\right) \quad (4)$$

The consumable cost calculation follows a schema similar to energy. For consumables, the consumption depends by the production rate since the consumables are strictly related to the product (Equation 5).

$$C_{consumable} = \sum_{y=1}^{Y}\left(\sum_{c=1}^{C}\left(CC_{c,y} \cdot CP_{c,y} \cdot PR_y + \sum_{o=1}^{O}\left(CC_{c,o,y} \cdot CP_{c,o,y} \cdot PR_y\right)\right)\right) \quad (5)$$

The maintenance cost follows a simpler schema, calculated summing the cost for maintaining the base configuration plus the cost for each cost item (Equation 6).

$$C_{maintenance} = \sum_{y=1}^{Y} M_y + \sum_{o=1}^{O} M_{o,y} \quad (6)$$

Each cost item depends by the asset configuration (defined as a combination of base/standard configuration and list of optional features), supplier, product realized by the asset, installation plant and age (wear level).

4. TCO software platform

The TCO platform is an Enterprise Application Software (EAS) conceived for supporting the asset management (design and investment). Such a platform allows firms in evaluating preventive and consumptive TCO analyses, by using data available within corporate software systems. By implementing the asset configuration schema described in §3.1 and the TCO equations presented in §3.2, such a platform represents a mean for easy and fast TCO evaluation. Available through a web interface, the platform (Fig. 3) is accessible to designers, investment managers, production plant managers and an administrator.

- *Designers*: they design machines, production lines, production areas, auxiliary systems or even buildings. They use the platform for preventive evaluating the purchasing cost or TCO with the aim to check the target cost;
- *Investment managers*: they manage the supplying strategy by certifying the suppliers, defining pricelists for specific products and selecting the best suppliers (based on the whole enterprise needs). An investment manager is generally responsible for one or more type of asset. They use the platform for defining the best supplying strategy by considering the TCO variable;
- *Production plant managers*: they manage the asset of their own production plants. They cooperate with the designers and investment managers for discussing about machines/production lines/areas revamping activities. They use the platform for consumptive TCO analysis of their assets;
- *Administrator*: he supports the investment managers (e.g. supplier's certification, definition of the pricelists, energy cost, discount rates, etc.) and the production plant managers (management of the assets and related information such as operating costs, OEE, technical features, etc.) in managing the platform database.

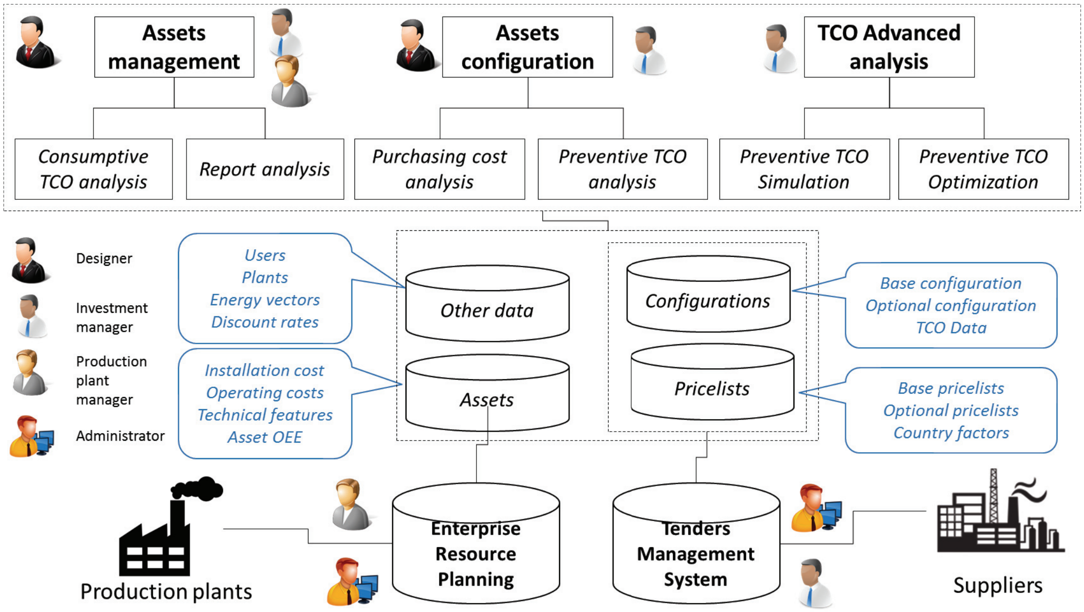


Fig. 3. TCO platform architecture

The platform consists of three modules, each one conceived to be mainly used by the three operative users. The administration module contains the common administration functionalities used for managing the database. The main modules are:

- *Assets management*: module mainly used by the production plant managers for analysing the assets of their plants. They carry out consumptive TCO analysis and comparative evaluations for identifying economic criticalities of single machines or whole production lines. The module is also useful for designers and investment managers. The first ones because, for designing/revamping a machine, it is important to know the characteristics of the assets. The second ones use this module for analysing the overall efficiency of the plants, from the technical and economic viewpoints, defining the needs for new investments and selecting the best supplying solution by preventive simulating the TCO on a specific plant. Moreover, by analysing the asset related data (e.g. comparative analysis), it is also possible to roughly foresee the TCO of a new investment.
- *Assets configuration*: module mainly used by designers for configuring/revamping machines. It is a configurator that accepts a list of requirements, allows the selection of optional features and calculates the TCO by comparing the available suppliers. For a flowpack, machine used for packaging products (e.g. brioches) by using a plastic material, the requirements are the packaging type (primary, secondary of both), linear speed of the product

(defined in ranges). The machine standard type, a general machine available from the suppliers that respect a basic configuration for the required production, is defined as a combination of these features. This configuration can be enriched by designers that want to select optional features (according to the machine standard type) required for respecting specific packaging conditions (e.g. modified atmosphere packaging, tearing strip), or production conditions (e.g. automatic roll change) or other constraints or general info (e.g. production plant, production rate, etc.). Elaborating such information, the platform inspects the database by calculating the TCO for each machine available from the suppliers. The module elaborates line graphs containing *TCO* vs *asset useful life* (years), required for identifying the Break Even Point among asset technologies or suppliers. The module presents also a cost breakdown (*CAPEX* vs *OPEX* and *energy* vs *maintenance* vs *consumable*) for identifying lifecycle criticalities.

- *TCO Advanced analysis*: this is a module used by the investment managers for managing the procurement strategies. A manager use this module by firstly collecting the investment requests (e.g. installation of new production machines, revamping of a production line, etc.), from the plants and the designs/configurations, from the designers. For establishing the best suppling strategy, the manager starts simulating the overall TCO for these requests by changing supplying variables (i.e. supplier and optional features). The objective is finding the best configurations and suppliers that minimise the TCO at the enterprise level. For instance, if a supplier is convenient for a specific plant, it cannot be the best one for other plants/countries because transportation/installation costs, machine efficiency vs energy cost, etc. This kind of simulation is automated by the optimization sub-module, which finds the best solution by analysing the database.

The database consists of four main groups of information:

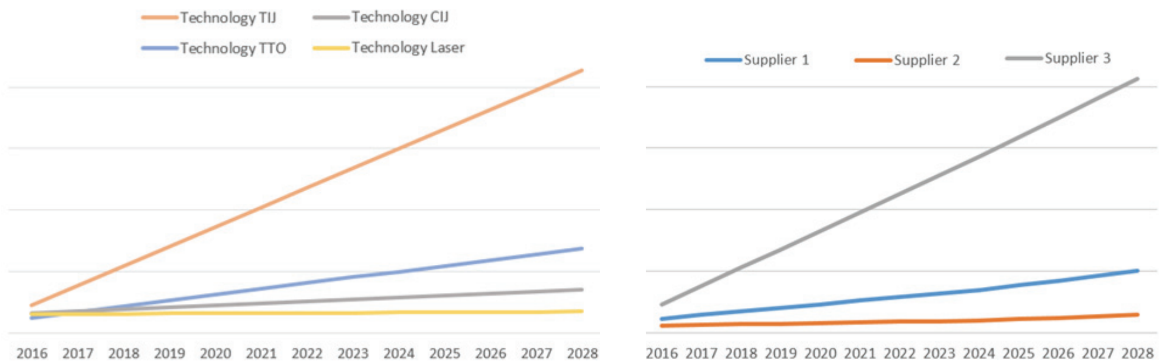
- *Configurations*: it comprises the list of the standard machine/production lines/areas configurations, machine families, features. This database area does not contain any information related to the suppliers;
- *Pricelists*: it contains the suppliers' pricelists for machines (standard configurations and optional features). Each price list contain the economic values required for calculating the TCO. This area is integrated with a Tender Management System (TMS) used by the enterprise for managing the tenders through that they define the pricelists;
- *Assets*: it contains the assets and related technical/economic features. The asset information can be synchronized with the Enterprise Resource Planning (ERP) system of the enterprise;
- *Other data*: it contains the data for the general functioning of the platform.

5. Case study and main results

This section presents a preliminary evaluation of the proposed approach and software platform within an Italian large food company (design and investment departments). This enterprise was looking to an improvement of the method used for managing the assets investment, by introducing the Total Cost of Ownership analysis at this stage. The asset managers and the designers focused the test case on a specific family of assets (printers). Designers firstly defined the technical standards of a printer, by listing the most important technical features (packaging area: primary, secondary, pelletizing and printing technology: continuous inkjet-CIJ, thermal transfer overprint-TTO, thermal inkjet-TIJ and laser) and grouping such a features in order to define a list of seven standard configurations. These ones have been loaded into the tender management system. The company evaluated three suppliers to involve in this project and after a preliminary discussion about the standard configurations, suppliers were invited to provide a quotation to each of them. Once completed this tender, the suppliers were aware of the quotations given by their competitors. At this stage, a second tender started with the aim to gather quotations for the optional features (even including the data for calculating the TCO) and country factors (factor for adjusting the supplier quotation according to the installation plant). At last, the definitive pricelists have been shared with the suppliers for their approval.

By using the TCO advanced analysis module, the investment manager was able to compare the preventive TCO for the four technologies and three suppliers. Twelve simulations allowed the company to establish the best combination of supplier and printing technology. Fig. 4, which represents the preventive TCO (the y-axis has been removed for confidentiality reasons) vs the asset life, highlights that the purchasing cost is much smaller than the TCO (up to -90%) for a useful life of twelve years. This means that the purchasing cost is not a robust parameter for selecting the best procurement scenario. The laser printing technology is a solution with the lowest OPEX (around 15% of the CAPEX). The OPEX of a thermal inkjet printer, instead, is around 1300% of its CAPEX.

The test case allowed the enterprise to reduce the investment costs by standardizing the machine configurations (reduction of the asset customizations), stimulating the competition between suppliers (each supplier is aware of the pricelists of its competitors) and evaluating the preventive TCO of an asset during the investment analysis phase.



a b

Fig. 4. a) TCO preventive analysis, for the supplier #2, by changing the printing technology; b) TCO preventive analysis, for the laser printing technology, by changing the suppliers

6. Conclusion and future work

The paper presented a preventive TCO model used by engineers and investment managers for assessing the lifecycle costs of an industrial asset during its lifecycle. Such a TCO model supports the designers in configuring/designing production machines and investment managers in selecting the best procurement strategy. To foster the TCO model application, the authors developed a preliminary software application integrated with other corporate solutions (a Tender Management System and an Enterprise Resource Manager). The model and relative software tool have been tested by an Italian food company, with the aim of optimizing the design and procurement phases of a printing system. However, the firm has implemented such a platform for other families of asset (i.e. chillers, air compressors, flowpack machines, X-ray testing machines, ovens and presses). Despite the tailored exploitation into a specific sector, the application of the proposed TCO model and platform for common assets (e.g. air compressors, ovens and chillers) make the approach applicable for the asset management in other industrial sectors.

In the context of preventive TCO models for supporting the design and procurement phases, a future work consists in studying and developing preventive TCO models for production lines and buildings. Such models should be integrated with those ones of single machines, while considering the features of the products realized by the machine itself and by the production line.

References

[1] FLEXINET European project. Intelligent system configuration services for flexible dynamic global production network. FP7, 2013-2016. http://www.flexinet-fof.eu/
[2] S.P. Javier, A.C. Márquez, A.S. Rosique. Criticality Analysis for optimising OPEX cost lifecycle. IFAC-PapersOnLine, Volume 49, Issue 28, 2016, Pages 7-12
[3] I. Wenzler. Development of an asset management strategy for a network utility company: lessons from a dynamic business simulation approach. Simulat Gaming 36:1 (2005) 75–90.
[4] J. Schneider, A.J. Gaul, C. Neumann., J. Hografer, W. Wellßow, M. Schwan, A. Schnettler. Asset management techniques. Electrical Power and Energy Systems 28 (2006) 643–654.
[5] Z. Degraeve, E. Labro, F. Roodhooft. Total cost of ownership purchasing of a service: The case of airline selection at Alcatel Bell. European Journal of Operational Research 156 (2004) 23–40.

[6] M. Weber, M. Hiete, L. Lauer, O. Rentz. Low cost country sourcing and its effects on the total cost of ownership structure for a medical devices manufacturer. Journal of Purchasing & Supply Management 16 (2010) 4–16 Contents.
[7] M. Wouters, J.C. Anderson, F. Wynstra. The adoption of total cost of ownership for sourcing decisions - a structural equations analysis. Accounting, Organizations and Society 30 (2005) 167–191.
[8] L. Nurhadi, S. Borén, H. Ny. A Sensitivity Analysis of Total Cost of Ownership for Electric Public Bus Transport Systems in Swedish Medium Sized Cities. Transportation Research Procedia 3 (2014) 818–827.
[9] S. Bonetti, M. Perona, N. Saccani. Total Cost of Ownership for Product-Service System: Application of a Prototypal Model to Aluminum Melting Furnaces. Procedia CIRP 47 (2016) 60-65.
[10] I. Dogan, N. Aydin. Combining Bayesian Networks and Total Cost of Ownership method for supplier selection analysis. Computers & Industrial Engineering 61 (2011) 1072–1085.
[11] I. Dogan. Analysis of facility location model using Bayesian Networks. Expert Systems with Applications 39 (2012) 1092–1104.
[12] S. Morssinkhof, M. Wouters, L. Warlop. Effects of providing total cost of ownership information on attribute weights in purchasing decisions. Journal of Purchasing & Supply Management 17 (2011) 132–142.
[13] L. Nurhadi, S. Boren, H. Ny. A sensitivity analysis of total cost of ownership for electric public bus transport system in Swedish medium sized cities. Proceedings of EURO working group on transportation, Sevilla, Spain (2014)
[14] F. Visani, P. Barbieri, F.M.L. Di Lascio, A. Raffoni, D. Vigo. Supplier's total cost of ownership evaluation: a data envelopment analysis approach. Omega 61 (2016) 141-154.
[15] S. Bonetti, M. Perona, N. Saccani. Total cost of ownership for Product Service System: application of a prototypal model to aluminium melting furnaces. Procedia CIRP 47 (2016) 60-65.
[16] N. Saccani, M. Perona, A. Bacchetti. The total cost of ownership of durable consumer goods: a conceptual model and an empirical application. Int. J. Production Economics 183 (2017) 1-13.
[17] Z. Degraeve, E. Labro, F. Roodhooft. An evaluation of vendor selection models from a total cost of ownership perspective. European Journal of Operational Research 125 (2000) 34-58.
[18] S.Y. Sohn, J. Jeon, E.J. Han. A new cost of ownership model for the acquisition of technology complying with environmental regulations. Journal of Cleaner Production 100 (2015) 269-277.
[19] G. Mader, H. Madani. Capacity control in air–water heat pumps: Total cost of ownership analysis. Energy and Buildings 81 (2014) 296–304.
[20] B.M. Al-Alawi and T. H. Bradley. Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. Applied Energy 103 (2013) 488–506.
[21] E. Gilmore and L.B. Lave. Comparing resale prices and total cost of ownership for gasoline, hybrid and diesel passenger cars and trucks. Transport Policy 27 (2013) 200–208.
[22] G. Wu, A. Inderbitzin, C. Bening. Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments. Energy Policy 80 (2015) 196–214.
[23] S. Bubeck, J. Tomaschek, U. Fahl. Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. Transport Policy 50 (2016) 63-77.
[24] J. Hagman, S. Ritzén, J.J. Stier, Y. Susilo. Total cost of ownership and its potential implications for battery electric vehicle diffusion. Research in Transportation Business & Management 18 (2016) 1-7.
[25] O. Duran, M. Macchi, I. Roda. On the relationship of spare parts inventory policies with Total Cost of Ownership of industrial assets. IFAC-PapersOnLine 49:28 (2016) 19-24.

Appendix A. Abbreviations

Symbol	Unit of measure	Description
C_{base}	€	Cost of asset base configuration
$C_{optional}$	€	Cost of each optional features required by designer
$C_{packaging}$	€	Cost of packaging required for the transportation
$C_{installation}$	€	Cost of the asset installation
$C_{documentation}$	€	Cost related for delivery the asset technical documents
$C_{training}$	€	Cost for the training
C_{factor}	€	Country factor
y/Y	-	Asset lifetime
o/O	-	Asset number of optional features
e/E	-	Asset number of energy curriers
AP	Hours/year	Annual working hours
PR	Products/year	Production rate
EC	€/hour	Energy carrier unitary cost
CC	Consumable/Product	Consumable unitary consumption

CP	€/consumable	Consumable price
M	€/year	Maintenance unitary cost