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A through-life costing methodology for use in product–service-systems

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ABSTRACT

Availability-based contracts which provide customers with the use of assets such as machines, ships, aircraft platforms or subsystems like engines and avionics are increasingly offered as an alternative to the purchase of an asset and separate support contracts. The cost of servicing a durable product can be addressed by Through-life Costing (TLC). Providers of advanced services are now concerned with the cost of delivering outcomes that meet customer requirements using combinations of assets and activities via a Product Service System (PSS). This paper addresses the question: To what extent are the current approaches to TLC methodologically appropriate for costing the provision of advanced services, particularly availability, through a PSS? A novel methodology for TLC is outlined addressing the challenges of PSS cost assessment with regard to 'what?' (cost object), 'why/to what extent?' (scope and boundaries), and 'how?' (computations). The research provides clarity for those seeking to cost availability in a performance-orientated contractual setting and provides insight to the measures that may be associated with it. In particular, a reductionist approach that focuses on one cost object at a time is not appropriate for a PSS. Costing an advanced service delivered through a PSS is a problem of attributing the value of means to the economic activities carried out for specific ends to be achieved. Cost results from the interplay between monetary and non-monetary metrics, and uncertainties thereof. Whilst seeking to ensure generality of the findings, the application of TLC examined here is limited to a military aircraft platform and subsystems.

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1. Introduction

Through-Life Costing (TLC) has its roots in defence procurement practices and has been extensively applied across several fields (Korpi and Ala-Risku, 2008). Typically, TLC begins with the identification of a long-life asset such as a building, an aircraft, a piece of equipment, or one of their constituent parts. With the asset acting as the centre point, a one-off appraisal of the disbursements associated with its acquisition and existence over a time span is carried out (Dhillon, 2010). TLC often involves the designer forecasting how much alternative product concepts should cost as a direct consequence of their features, focussing upon those related to inherent reliability (Newnes et al., 2008). A common assumption in TLC is that the distinction between the Original Equipment Manufacturer (OEM) and its customer's responsibilities for product acquisition and ownership is clear-cut and therefore so are the cost items of concern (Chen and Keys, 2009). Such a logic reflects a business context in which the OEM's responsibility is to design and manufacture a product, whilst equipment failure in the use phase provides an additional revenue stream for the OEM after sales and support service. The 'product and support' business model incentivises a 'throw it over the wall' approach with respect to the customer, and is detrimental to product reliability (Caldwell and Settle, 2011).

There have been attempts to challenge the established business model described. With reference to military equipment, it has long been noted that allowing the purchaser's viewpoint to be represented only when contractual reliability requirements are specified does not ensure a satisfactory final deliverable per se (Perrigo and Easterday, 1974). Integrated Logistic Support (ILS) emphasizes the ability of a weapon system to deliver the output for which it is designed (Galloway, 1996). Long-term service agreements incentivise the usability of an asset while covering all or most of the costs associated with support activities (BS EN IEC, 2009). In particular, availability-based contracts aim to guarantee that an asset performs its function when called upon to do so, and typically uses the ratio between

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satisfactory operations to downtime as a metric (Jazouli and Sandborn, 2011). Availability-based contracts are increasingly used by engineering OEMs. For example, Rolls-Royce Plc.'s move from selling aircraft engines to selling the availability of its engines has been has been acknowledged as a success story that "…could offer lessons for Britain's other industries" (The Economist, 2011). Similar agreements are also re-shaping the approach to procuring industrial machinery (Hypko et al., 2010), and the development of infrastructure projects through Public–Private Partnerships (Sharma and Cui, 2012).

An advanced service sustains the customers' core business processes and the service delivery system enabling the customer to attain specific beneficial outcomes becomes just as important as the offering itself (Ng et al., 2011; Baines and Lightfoot, 2013). This construct is a knowledge-intensive socio-technical system referred to as Product–Service-System – PSS (Meier et al., 2010).

An OEM transforming to a service provider is concerned with the cost of delivering a result through a PSS (Tukker and Tischner, 2006), for example agreed availability or other performance levels over time. TLC often includes complementary non-monetary performance metrics such as the availability of an item. Ntuen and Moore (1986) provide an early overview of this approach to TLC. However, attention is placed on a stand-alone product unit and its reliability features which it is assumed, once designed-in, will hold indefinitely. How a product instance operates, fails and is restored to operation is typically described by means of time distributions. Essentially, for modelling purposes the product unit is stripped of its broader delivery, use and support context. Neely et al. (2005) illustrate that performance is attained through a business's actions, their effectiveness (the extent to which customer requirements are met) and efficiency (how economically the resources are utilised). From this perspective the cost of performance is not designed into a product, rather, it is the cost of doing something 'right' from the customer's point of view (e.g. delivering value 'in use' through an outcome – see Ng et al., 2011), or dealing with the consequences of failing to do so. As such, cost is contained in the flow of work through the organisational system (Seddon et al., 2011).

The academic literature dealing with advanced services, in particular availability, provided via a PSS focuses exclusively on the cost of the in-service stage of an individual durable product, without questioning and enriching substantially the overall methodology of TLC. For example, Lindahl et al. (2014) compare integrated product–service offerings and more traditional product offerings without specifying what is meant by TLC, or disclosing how it is performed. Datta and Roy (2010) provide extensive discussion and a framework, but suggest combinations of existing cost estimation techniques for use at a particular product-accompanying service lifecycle stage. Huang et al. (2012) analyse these techniques and identify the challenges of adapting them for the purpose of service cost estimation. In both cases TLC is not presented as an autonomous methodology but is the result of the application of different cost estimating techniques. The distinction between methodology and technique is relevant. Methodology is concerned with 'thinking about how to think', guiding the intellectual process of choosing concepts and deciding how they might be structured, whilst techniques are well-defined ways of 'going about' a problem: like cookbooks, if followed will produce a defined outcome (Wilson, 2001).

The purpose of the research presented in this paper is twofold: first to ascertain whether and to what extent the TLC literature provides sufficient methodological foundation in the case of costing an advanced service delivered by a PSS, particularly availability; and second to outline a methodology for TLC, addressing the challenges of PSS cost assessment related to the '*what?*' (cost object), '*why/to what extent?*' (scope and boundaries), and '*how?*' (computations and metrics).

The remainder of this paper is structured as follows. Section 2 presents the research questions and strategy. Section 3 summarises the state-of-the-art in TLC. Section 4 identifies the challenges of costing advanced services provided through a PSS, and analyses the TLC literature accordingly. In Section 5 the findings are discussed and a methodology of TLC outlined. Section 6 summarises the contribution and limitations of this research and links to future work.

2. Research questions and strategy

This paper answers the following research questions:

- *RQ1*: To what extent are the concepts and structures embedded in the prevailing approaches to through-life costing appropriate for costing advanced services provided via a product–service-system?
- *RQ2*: What methodological aspects of through-life costing should be reconsidered for use in product–service-systems?

The research strategy followed to address the research questions is shown in Fig. 1, and can be summarised in two main steps:

(1) Provide analysis and synthesis of an extended body of literature on TLC at the interface between key fields – management, design and engineering. Both narrative (tables) and meta-synthesis are used to enable comparison between strands of literature which are heterogeneous in terms of methodologies and concepts (Tranfield et al., 2003).
(2) Build on the identified aspects of providing advanced service through a PSS which are a challenge for TLC to set guidelines which stimulate the intellectual process of analysis (Wilson, 2001), and provide directions for future research (Webster and Watson, 2002).

Fig. 2 gives an overview of the composition of the 128 works on TLC reviewed in the first step. The contributions were retained based on the insight they provide into TLC methodology in terms of concepts (theory and frameworks), models (computational structures and metrics) and state-of-the-art (survey and review). Works on TLC within environmental management have been largely excluded due to their specific methodological issues (Settanni, 2008). Finally, applications in which TLC is merely mentioned e.g., to make generic claims on savings associated with particular product designs, were not included.

References have been accessed via keyword searches of librarian services (IEEE Xplore, EBSCO), management and engineering publishers' databases and web-based resources (NATO Research and Technology Organisation, RAND Corporation, and the Management and Accounting Web). The literature features a heterogeneous terminology – the approach being labelled alternatively as e.g., Life Cycle Costing (LCC), Whole-life Costing (WLC), Total Cost of Ownership (TCO). Hence, the search was initiated with the keywords "life" and "cost", and then refined using "availability" or "performance". Whilst no date restrictions have been applied it was noted that the literature on TLC up to the early 1980s was comprehensively covered by Gupta and Chow (1985) who examined over 600 works. Each reference is considered as a potential source, which facilitates the identification of the earliest works.

In order to provide focus in terms of case studies reviewed, preference has been accorded to applications of TLC in defence and aerospace – be it whole military aircraft platforms or their subsystems, aero-engines and avionics. This choice takes into account that a range of other applications have been reviewed

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