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Product-Service Systems across Life Cycle

Towards a Cost Engineering Method for Product-Service Systems based on a System Cost Uncertainty Analysis

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Abstract

The following research work introduces a Cost Engineering Method for Product-Service Systems (PSS) based on a System Cost Uncertainty Analysis (SCUA). The proposed SCUA is a probabilistic method focused on determining the total operational cost of a PSS. The main purpose of this paper is to introduce a PSS cost engineering approach that reduces the aleatory uncertainty that exists in every PSS cost determination, and therefore provides certainty in the cost-capacity relationship that exists in every PSS offering.

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Keywords: Product-Service Systems; Cost-Engineering; Holistic Costing; System Cost Uncertainty Analysis.

1. Introduction

Original Equipment Manufacturers (OEMs) have become increasingly interested in understanding and managing the cost of their commitments (e.g. performance- and availability-based contracts) to deliver specific Product-Service System (PSS) results to their customers through-life [1]. However, current PSS costing approaches in literature hardly offer a real holistic approach for PSS cost engineering, considering the system of systems nature of a PSS. A PSS can be then defined as: *"a system of systems consisting of a system product and a set of system services, which are jointly capable of fulfilling a specific customer demand"*.

Based on previous research [1] [2], this paper proposes a probabilistic method to determine the total operational cost of a PSS, based on a System Cost Uncertainty Analysis (SCUA), which aims to capture the *aleatory uncertainty* that exists in every cost determination. The main difference from other cost engineering approaches is that the present work proposes to treat *functional performance* as a random variable. This enables us to consider that the cost behavior of a PSS is influenced by the interconnections/interactions among its subsystems (resulting in a holistic approach).

A comprehensive a literature [3], identified the need for holistic PSS cost engineering approaches. Current trends for PSS cost estimation are based on four main approaches [3]: (a) cost estimation by analogy, (b) activity-based costing, (c) parametric method, and (d) extrapolation. The selection of a PSS cost estimation method largely depends on the available data, and more than one method is normally applied in order to reduce *uncertainty* in the cost prediction, but the most popular method is *estimation*. It is proposed then that a change from *cost estimation* to real *cost engineering* must be made in order to reduce *uncertainty* in PSS costing.

It is important to mention that the proposed cost engineering method for PSS, includes a PSS Ontology, based on System Quality Attributes (SQA) [see 2], in order to initially measure the functionality of the PSS, from which total operational cost will be calculated. The main purpose of the *PSS-SQA Ontology* is to reduce the *epistemic uncertainty* involved in the behavior description of a PSS. Since the main objective of this research is to provide *certainty* in the *cost-capacity relationship* that exists in every PSS offering, both the research *method* and *ontology* [2] are intended to mitigate the entire spectrum of *uncertainty* (aleatory and epistemic).

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2. Product-Service System (PSS) Functionality

According to literature [4], the focus of a PSS is on the delivery of functions. It is widely accepted that PSS constitute a paradigm shift from selling pure products or pure services to an integrated value offering, where the customer looks for functionality instead of ownership [5], where a *function* is defined as: *"the intended purpose of the system"* [6].

In order to understand how well a PSS's function has to be performed, the concepts of *functional result* and *functional performance* are introduced. The *PSS functional result* is defined as a standardized unit of function delivery (system output), while the *PSS functional performance* expresses the quality and quantity of functional results [4]. The relationship between *functional result* and *functional performance* is shown in Fig. 1 and Fig. 2.

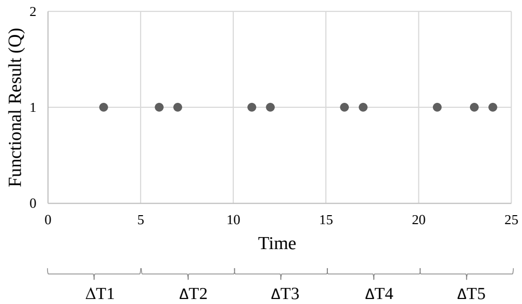

Fig. 1. Functional Results Delivery (Q)

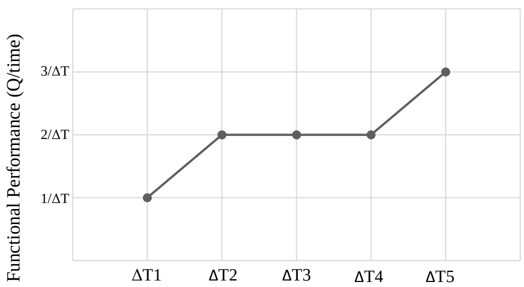

Fig. 2. Functional Performance (Q/Time)

Both *functional result* and *functional performance* must be defined in the design stage of a PSS lifecycle by the PSS engineering team, which will be the responsible for the cost and functionality aspects of a PSS development.

3. System Cost Engineering

Cost Engineering is defined as: *"the area of engineering practice where engineering judgment and experience are used in the application of scientific principles and techniques to problems of cost estimating, cost control, business planning and management science, profitability analysis, project management, and planning and scheduling"* [7].

The proposed PSS cost engineering method focuses on the *cost estimation* problem of the above definition. *Cost Engineering* can be then simply defined as: *"a methodology used for predicting/forecasting/estimating the cost of a work activity or output"* [8]. Every cost prediction entails a certain amount of *uncertainty*.

3.1. Uncertainty Theory

Uncertainty is defined as: *"any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system"* [9], and can be classified as *Epistemic* or *Aleatory*. *Epistemic uncertainty* arises from the limits of the human knowledge (e.g. events regarding the future: obsolescence, changes in legislations, etc.), its influence can be reduced through increased understanding and/or increased availability of relevant data. *Aleatory uncertainty* arises from the random nature of the analyzed entity, where independently of the available data events remain unpredictable [10].

The current trend in the PSS cost estimation field regarding *uncertainty* is divided into two types: (a) probability theory, and (b) evidence theory, interval analysis, and possibility theory [10]. The second classification is focused on issues that arise from data: vagueness, lack of data, and lack of structure. It can be seen that *probability theory* works with *aleatory uncertainty*, while the *compounding theories* of the second classification work with *epistemic uncertainty*.

3.2. Ontology and Epistemology Relationship

Ontology describes the form and nature of reality to be studied, while *Epistemology* is the way to understand the world and communicate this knowledge [11]. The two are related since *ontology* defines the cognitive boundaries of the piece of reality described, which represents the constraint of what can be known from this piece of reality. An ontology is used in order to organize information and reduce complexity. Therefore, it is stated that *epistemic uncertainty* is a matter of perspective because…*"The way we look at phenomena not only influences but determines what we are able to see and in the end determines what we are able to find"* [12].

Among several ontologies that describe the same piece of reality, some may entail a higher complexity for the determination of relevant data. In [2] a *PSS-SQA Ontology* was introduced to describe the complex nature of a PSS as a system of systems, and to reduce *epistemic uncertainty,* in particular knowledge about *functional performance*.

The scope of the proposed cost engineering method is focused on the total operational cost of a PSS calculated using complex probabilistic models and Monte Carlo simulation.

The probabilistic approach is not only supported by the *PSS-SQA Ontology* [2], but we believe that it will be able to reduce the *epistemic uncertainty* of analyzed events, and cost estimation will be based on these methods.

3.3. Systems Cost Uncertainty Analysis

Systems Engineering as a discipline compounds the required scientific and engineering efforts in order to develop, produce and sustain systems [13]. The cost estimation of any future system is one of the key aspects to attain a successful design. The PSS engineering team should carry out a *Cost Uncertainty Analysis* in which the costs impacts of uncertainties associated with a system's technical definition and cost estimation methods are quantified [13] [14].