Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 47 (2016) 78 – 83

www.elsevier.com/locate/procedia

Product-Service Systems across Life Cycle

A System Quality Attributes Ontology for Product-Service Systems Functional Measurement based on a Holistic Approach

Arturo Estrada[1] and David Romero[1-2*]

[1]*Tecnológico de Monterrey, Del Puente 222, Col. Ejidos de Huipulco, Tlalpan, Mexico, 14380*
[2]*Griffith University, 170 Kessels Rd, Nathan QLD 4111, Australia*
*Corresponding author. Tel.: +52 (55) 5483-1605; Fax: +52 (55) 5483-1606. *E-mail address:* arturoestrod@hotmail.com, david.romero.diaz@gmail.com

Abstract

The importance of cost engineering within Product-Service Systems (PSS) discipline has increased in recent years. Literature reveals that there is a need for holistic PSS cost determination approaches dealing both with PSS cost engineering and PSS functional uncertainty - as a System of Systems (SoS), as PSS cost determination uncertainty arises from the limited understanding of PSS behavior as a SoS. This work proposes a System Quality Attributes (SQA) Ontology developed to measure the function of a PSS: How well it performs in light of its intended purpose? The PSS-SQA Ontology was constructed on the foundations of SoS Engineering and Reliability Engineering disciplines. It propose a holistic approach to PSS functional measurement, covering the most accepted PSS typology, including product-, use- and result-oriented PSSs. The work contributes to PSS engineering by offering an SQA Ontology that quantifies PSS functionality and reduces PSS functional uncertainty for further cost determination.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle

Keywords: Product-Service Systems; Holistic Modelling; System Quality Attributes; Ontology; System of Systems Engineering; Reliability Engineering.

1. Introduction

The importance of cost engineering within Product-Service Systems (PSS) discipline has increased in recent years [1-3]. Literature [1-4] reveals that there is a need for holistic PSS cost determination approaches dealing both with PSS cost engineering and PSS functional uncertainty - as a System of Systems (SoS). *PSS Cost Engineering* can be defined as: *"the set of activities in order to determine/predict the cost of a PSS functionality level as well as the awareness of the certainty degree of such determination/prediction"*. Hence, PSS cost determination *uncertainty* arises from the limited understanding of PSS's behavior as a SoS. Moreover, *uncertainty* is classified as *epistemic* and *aleatory* [4]. The first type arises from the lack of understanding of the analyzed entity's behavior (i.e. due to lack of relevant information), while the second type arises from an entity's random nature.

This work proposes a *System Quality Attributes (SQA) Ontology* developed to measure the function of a PSS: How well the PSS performs regarding its intended purpose? It uses *functionality* as the representation of PSS's behavior.

An *Ontology* describes the form and nature of the studied reality, while *Epistemology* is the way we acquire knowledge of reality. A lack of knowledge of a system and its emerging properties may mean that the ontology itself is *uncertain* [4].

Based on the above, we believe that PSS cost engineering requires a *holistic approach* to make the emergent properties of a PSS as a SoS visible through a *systemic ontology* thereby reducing the *epistemic uncertainty* in PSS cost determination.

The proposed *PSS-SQA Ontology* has been constructed on the foundations of *SoS Engineering (SoSE)* and *Reliability Engineering (RE)* disciplines.

A search in Elsevier, Springer and Taylor & Francis databases found no work connecting PSS, SQA, SoSE and RE.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle
doi:10.1016/j.procir.2016.03.215

This finding gave us the idea to develop a multi-disciplinary approach for PSS functional measurement, covering the most accepted PSS typology: product-, use- and result-oriented PSSs.

This paper presents the first part of an on-going research towards a *"Holistic Method for PSS Cost Engineering based on the combination of a SQA Ontology and a System Cost Uncertainty Analysis"* [see also 5]. Both *ontology* and *analysis*, are intended to mitigate the whole spectrum of PSS *uncertainty* (epistemic and aleatory respectively).

2. PSS Holistic Modelling and Ontology Development

2.1. Systems Science and Engineering

Systems Science and *Engineering* play an important role in understanding PSS complexity. A PSS is defined as: *"… products and services combined in a system to deliver required user functionality…"* [6], whereupon *"a system is an assemblage or combination of elements or parts forming a complex or unitary whole, with a functional relationship, and a useful purpose"* [6]. A system is composed of components with attributes and relationships. On a first level of abstraction components of a typical PSS are heterogeneous, and may be tangible (products) or intangible (services). On a second level of abstraction a product may be broken down into subassemblies (still products), and a service can be divided into processes, i.e. a PSS is a compound of products and processes. Some of PSS complexity arises from *interconnections* of heterogeneous components each with its own properties and behavior, while the system presents some characteristics or behaviors that cannot be attributed to any of its components [7]. This is expressed by the term *holism*, i.e. a system is more than the sum of its components. Properties only exhibited on the system level are *system attributes*, e.g. a PSS has attributes that cannot be found in any of its product or service subsystems. Not only are the components of a system interconnected, system attributes also have relationships [7]; this is called: *system attributes configuration*.

A system is *engineered* with a purpose in mind (what the system must generate as its output, how well it must perform to guarantee the output, and under what conditions it has to operate). PSS engineering, and in particular PSS cost engineering, must not only focus on the main system output, but also on the quality of the output, and on the circumstances in which such output quality must be achieved, as all parameters will impact on the overall PSS operational cost. The system attributes configuration depends on the nature of components, and their interconnections. Hence, system purpose depends on the system attributes configuration, which further depends on system components configuration. A PSS engineering team may try many system components configurations to attain the desired purpose. The problem is how to visualize the attributes configuration, and how to link it with the system's purpose?

Fig. 1 shows relationship between system components configuration, system attributes configuration, system purpose, and its relationships.

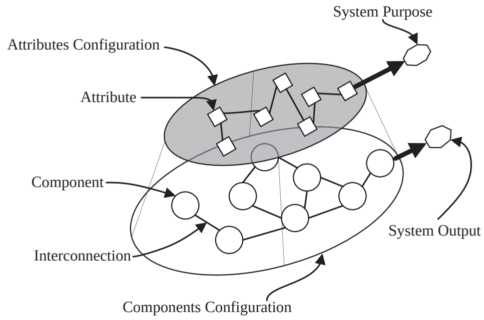

Fig. 1. System Components, Attributes and Purpose, and its Relationships

2.1.1. System of Systems (SoS) Engineering (SoSE)

A PSS as a system has components, and some components (often heterogeneous in nature) of this system may themselves be systems [6]. Hence, a PSS is a *System of Systems (SoS)*, and its component systems are called: *subsystems*.

"The main thrust behind the desire to view the systems as a SoS is to obtain higher capabilities and performance than would be possible with a traditional system view" [8].

The SoS view is a high-level perspective and explains the interconnections among independent systems. *"A SoS is a super system comprised of other elements, which themselves are independent complex operational systems and interact among themselves to achieve a common goal. Each element of a SoS achieves well-substantiated goals even if they are detached from the rest of the SoS"* [8]. A system is more than the sum of its components parts, however, the components of a system may themselves be systems [6]. Since a PSS is a compound of heterogeneous elements (products and processes) it is considered as a complex system. Moreover, some of its components can be described as a system itself; therefore a PSS is considered as a *System of Systems (SoS)*. In order to differentiate the compounding systems of the PSS from the PSS itself (since both are systems), the compounding systems are named: *subsystems*.

From the traditional systems view, the interconnections among components are commonly described by means of process-based thinking, in which a chain of inputs-outputs link the components in a certain configuration. This approach is useful when the components of the system are homogeneous; but for the case of a PSS this approach entails great complexity. Therefore, it is proposed to use a SoS point of view, in which every component of the PSS is a system itself. Hence, the PSS engineering team must define the boundaries of each system in order to architect a SoS comprised of (possibly heterogeneous) systems, each with its homogeneous components, while every subsystem must be independent. It is proposed that every product is defined as a system, and a service is divided into several independent sets of processes (if possible), each one representing a system; the level of granularity will depend on the PSS engineering team. For this case, interconnections among systems are proposed to be established by means of its intended purposes; in which a chain of functions link the systems in a certain configuration. This chain is defined as a *teleological* interconnection.