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Measuring the functional dynamics of product-service system: A system dynamics approach

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ABSTRACT

In the light of the prevailing trend towards product-service systems (PSSs), this paper focuses on the measurement of PSS functional performance. As a 'dynamic' system wherein various stakeholders achieve functional performance through long-term relationships in a complex value network, PSS functional performance requires a dynamic approach for measuring its effectiveness, an approach that is missing in the literature. This study aims to fill that void. Firstly, we address the concept of *functional dynamics* as a distinctive measure of PSS functionality with regard to functional performance and propose a five-phase analytic scheme of functional dynamics. Then, to measure the functional dynamics of PSS using the analytic scheme, a four-step procedure based on the system dynamics is suggested. As a representative method for measuring the long-term dynamics of a complex system, system dynamics is effectively employed to measure PSS's functional dynamics comprehensively. To illustrate the proposed approach, a case study of a u-healthcare system is presented.

1. Introduction

In a fiercely competitive market, the product-service system (PSS) has emerged as an essential survival strategy for firms (Alfian, Rhee, & Yoon, 2014; Baines et al., 2007; Beuren, Ferreira, & Miguel, 2013; Manzini & Vezzoli, 2003; Morelli, 2006). As an integrated offering of various elements including intangibles and actors as well as tangibles, PSS is considered capable of sharpening a firm's competitive edge to meet the various and demanding requirements of customers (Goedkoop, van Halen, te Riele, & Rommens, 1999; Manzini & Vezzoli, 2003; Mont, 2002a). However, firms that have joined the prevailing trend towards PSS have faced challenges in their new PSS business (Baines, Lightfoot, Benedettini, & Kay, 2009; Brax, 2005; Geng, Chu, Xue, & Zhang, 2010; Mont, 2002b; Oliva & Kallenberg, 2003; Tukker & Tischner, 2004; Yang, Moore, Pu, & Wong, 2009). Because of PSS's distinguishing characteristics, the conventional approaches to dealing with a traditional business with a single product or service do not fully support it. Therefore, new approaches are vital for dealing with PSS characteristics in firms' businesses (Mont, 2002a). A successful PSS business faces various issues including the developing and operating of an offering. However, this paper focuses on the issue of measuring the functional performance of PSS, which is one of the most important tasks of a firm since it influences competitiveness in the market, cost-effectiveness, and finally, business performance (Qian, 2011).

Although various approaches to deal with the issues of PSS have been suggested, literature concerning how to measure the functional performance of PSS is surprisingly sparse. Owing to the scarcity of literature, the functional performance of PSS has been measured using the conventional approaches that were developed for and applied to measure the functional performance of traditional offerings, that is, single products or services. However, the conventional approaches cannot fully incorporate the characteristics of PSS—a 'dynamic' system including various stakeholders (Goedkoop et al., 1999; Maxwell & van der Vorst, 2003) that achieve functional performance through their long-term relationships in a complex value network (Baines et al., 2007; Bertoni, Bertoni, & Isaksson, 2013; Lim, Kim, Hong, & Park, 2012; Mont, 2004). In other words, because of the characteristics of PSS, a dynamic view is required when measuring the functional performance of PSS.

In keeping with that requirement, this paper suggests employing a system dynamics approach for measuring the functional performance of PSS. Firstly, to highlight the distinctive features of PSS functional performance, the concept of *functional dynamics* is

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proposed as a distinguishing measure of PSS functionality with regard to functional performance. Defined as the functional performance of PSS over time, the functional dynamics of PSS depict how the PSS functions and changes over time. However, these do not remain as a fragmentary value to be measured, but rather are a comprehensive analysis of a complicated value network. The related strategic decision makings do not result in the strengthening or weakening of a certain feature, but rather enable operating business under various uncertainties. Reflecting these aspects, the analytic scheme of PSS functional dynamics is suggested for its measurement and utilization.

To operationalize the analytic scheme of PSS functional dynamics, a measurement methodology that uses the system dynamics approach is suggested. The system dynamics approach can comprehensively analyse the functional dynamics of PSS by measuring the long-term dynamics of a complex system on the basis of its causal structure (Sterman, 2000). Moreover, as a simulation technique, system dynamics provides a convenient means for testing scenarios involving various factors and uncertainties, which influence the functional dynamics of PSS and thus can aid strategic decision making. Taking the benefit of system dynamics into account, the proposed approach supports the analytic scheme of PSS functional dynamics with four-step procedure. Coping with the characteristics of PSS functional dynamics by providing comprehensive view with convenience in scenario approach, the proposed approach is expected to be usefully employed for measuring functional dynamics of PSS; specifically, the application of this research includes a wide range of latest ICT-embedded services from digital contents service with device (e.g. Amazon Kindle, Apple iPod, etc.), sharing system (e.g. car sharing, bicycle sharing, etc.) and mobile/wearable-based system (e.g. u-healthcare, Nike+, etc.) to various IoT-based services (e.g. connected car, smart home, location-based services, etc.).

The paper is organized as follows: Section 2 briefly describes the characteristics of PSS and its functional performance and then addresses the limitations of related works. Section 3 explains the proposed approach in detail by, first, addressing the concept of PSS functional dynamics and the analytic scheme, and then, discussing the utility of system dynamics in dealing with PSS functional dynamics. Following this, the four steps of the system dynamics approach to measuring PSS functional dynamics are explained. Section 4 presents an illustrative example of the proposed approach and considers its various implications. Finally, Section 5 concludes the paper and discusses its contributions and limitations.

2. Background

2.1. PSS and functional performance

The term 'PSS' was first used by Goedkoop et al. (1999), who defined it as 'a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models'. As shown in the definition, PSS was introduced to achieve sustainability in the public sector (Manzini & Vezzoli, 2002). However, more recently, PSS's ability to meet customers' underlying needs has been highlighted, and it has enjoyed tremendous popularity in industry, mainly for its usefulness in delivering greater customer satisfaction (Goedkoop et al., 1999; Mont, 2002a, 2002b; Vandermerwe & Rada, 1988). There is a perception that the shift towards PSS is crucial for firms today.

However, firms have confronted challenges in dealing with their new offering (Baines et al., 2009; Beuren et al., 2013; Brax, 2005; Mont, 2002b; Oliva & Kallenberg, 2003; Tukker & Tischner, 2004). Of the various issues related to firms' PSS business, this study focuses on the functional performance of PSS. Few would argue that the functional performance of a firm's offering is one of the most important issues for strategic business management. In terms of traditional offerings such as a single product or service, functional performance has been of interest to both academic scholars and practising managers, mainly in relation to quality (Forker, 1996; Lehtinen & Lehtinen, 1991; Parasuraman, Zeithaml, & Berry, 1985; Sebastianelli & Tamimi, 2002). However, in terms of PSS as a new type of firm's offering, while the environmental performance or other performances on economic benefit and customer satisfaction has been widely discussed (Goedkoop et al., 1999; Kimita, Shimomura, & Arai, 2009; Komoto, Tomiyama, Nagel, Silvester, & Brezet, 2005), interest in the functional performance is surprisingly sparse in the literature.

2.2. Measuring functional performance of PSS

To manage functional performance strategically in business, the first and foremost issue to be considered is 'how to' measure functional performance. Although the lack of interest in the functional performance of PSS in the literature has resulted in firms depending on the conventional approaches of traditional offerings to measure functional performance, the conventional approaches cannot fully incorporate the characteristics of PSS. The conventional approaches for measuring functional performance do not consider the time dimension, or they consider only the reduction of specific physical features over time, that is, they are static or fragmentary approaches (Hsiao, Kemp, van der Vorst, & Omta, 2010; Mackelprang, Jayaram, & Xu, 2012; Qian, 2011). However, when investigating the characteristics of PSS and its functional performance, it seems obvious that measuring the functional performance of PSS requires a comprehensive dynamic approach.

PSS consists of various elements including products, services, and relevant actors (Baines et al., 2007; Goedkoop et al., 1999). The functional performance of PSS is achieved by the structural interactions of the individual functions of these elements. Unlike the interactions in traditional products or services, the interactions of various elements' functions in PSS depend on the agreement between heterogeneous elements in a relatively loose structure. Table 1 summarizes these interactions. Especially, the complex and interrelated structure of actors needs to be understood in the light of the long-term relationships amongst different stakeholders and how their communication with one another achieves the PSS's functional performance (Baines et al., 2007; Mont, 2004). Therefore, long-term feedback during the product life cycle is expected, revealing the dynamics of PSS and its functional performance (Komoto et al., 2005).

Furthermore, measuring the functional performance of PSS requires a comprehensive and dynamic approach. Since PSS is a large, complex system in which various internal and external stakeholders of a firm participate (Baines et al., 2007; Mont, 2004), measuring the functional performance of PSS serves to

Table 1
Interaction of elements' functions to achieve the functional performance.

Offering	Interaction of elements' functions
Product	Transmission of physical signals
Service	Flow of tasks following the defined regulations through designed procedure
PSS	Agreement between heterogeneous elements in relatively loose structure
	Communication of different stakeholders based on their long-term relationships in complex value network