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A representation scheme for digital product service system definitions

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ABSTRACT

The growing trend for delivering physical products to customers as parts of product service systems (PSS) is creating a need for a new generation of Computer Aided Design (CAD) system to support the design of PSS: so-called "PSS-CAD". Key research issues in the development of such systems include building understanding of the kinds of applications that designers of PSS might need and the establishment of well-founded representation schemes to underpin and support communication between PSS-CAD systems. Recent literature includes numerous descriptions of integrated PSS development processes, PSS-CAD tools to support these processes and early meta-models to provide information support. This paper complements this work by proposing a representation scheme that is a key prerequisite to achieving the interoperability between PSS-CAD systems which would be necessary to support the deployment of integrated PSS development processes in industry.

The representation scheme, a form of meta-model, draws on learning from the product definition community that emerged in the 1970s in response to a need for interoperability between the different shape-based CAD systems that were being developed at the time. The initial focus on shape representation has developed to digital product definitions that define the design of a product coupled with meta-data recording details of processes by which the design was created and, more recently, supported through-life. Similarly, PSS-related information includes both PSS definitions, to support the lifecycles of physical products and associated services, and meta-data needed to support the management of PSS development processes.

This paper focuses on information requirements for the definition of service elements of PSS and relationships with product elements and service actors. These requirements are derived from earlier work on the use of service blueprinting for the visualisation and mapping of service activities to deliver different types of service contract. Key information requirements addressed include the need to represent service process flow and breakdown structures, relationships between service and product elements, substitution relationships, and service variants. A representation scheme is proposed and demonstrated through application to a PSS case study. The representation scheme is built on a generic information architecture that has already been applied to problems of product definition; as such there is an underlying compatibility that offers real promise in the future realisation of integrated PSS development processes.

1. Introduction

The transition from the delivery of products to product service systems (PSS) is driving companies to focus on the performance of not only the products they develop and deliver to customers but also the services used to provide through-life support for these products. A consequence of this transition is that the role of the physical product is changing. Where once the development of products was a goal in its own right, increasingly products are parts of PSSs where the goal is to support and operate products through their lifecycles. This has led to an increasing interest in both the integration of products and services [64] and innovation in service offerings [37,53]. In response, the description of integrated service development processes is growing [20,30,47,59] and the need to consider both product and service lifecycles, and interactions between them, early in PSS development processes when the cost of change is at its lowest, is increasingly recognised [31,72]. In their broadest sense, PSS-CAD systems will support PSS developers in understanding these issues and many authors describe service design and development tools [23,51].

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Like product development processes, integrated PSS development processes will require underlying information architectures through which the integration of these tools can be achieved. A key to the realisation of such architectures lies in the establishment of well-founded representation schemes to support the definition of PSS through their lifecycles. This paper introduces such a representation scheme for service elements of PSS. It has been validated through application to case studies on the definition of contracted services in high value manufacturing systems [34]. The resulting digital service definitions have been used to support risk management of an industrial service [35] and the articulation of information requirements in the defence sector [14]. In the future such definitions could increase the use of computer-based evaluations of service concepts, for example by integrating them with simulation models [15], and more human-centred service design activities such as those discussed by Meiren et al. [47].

The representation scheme draws on learning from product definition both on the kinds of functionalities that might be required in PSS development processes and how such information might be represented. Parallels between the definition of product and service elements of PSS are introduced in Section 2.1 and used to inform requirements for digital service definition. The model has been implemented to support the definition of a range of industrial services that are subject to confidentiality restrictions. For this reason, a fragment of a fictitious case study that exhibits key characteristics of these real-world PSS, a coffee making machine repair service with two types of contract (spares only and availability [71]), is introduced in Section 3. The representation scheme, in the form of an information model, is introduced in Section 4 and its efficacy demonstrated through application to the coffee maker case study through population (in Section 4) and through implementation in a prototypical PSS definition system (in Section 5). An analysis of its efficacy in comparison to PSS meta-models available in the literature is provided in Section 6 and areas for further research are outlined in Section 7.

2. Literature review

Information requirements used to inform the development of product data representation schemes result from analyses of (i) the kinds of information that need to be captured to support product-related engineering processes and (ii) the kinds of tools and techniques the representation scheme is required to support. This section provides information requirements for the representation of service elements of PSS (Section 2.3) based on reviews of approaches to the definition of service products when compared with physical products (Section 2.1), and tools and techniques used for the definition of services (Section 2.2).

2.1. Definitions of physical products and service products

For the purpose of this paper, a PSS is a system composed of a physical product and associated services that support the product through-life. Thinking on the dual nature of technical artefacts argues that technical artefacts have both designed physical structures and intended functional structures. On intended functional structures, Vermaas and Houkes, in their ICE (Intentionalist, Causal-role, Evolutionist) theory [74], assert that when engineers ascribe functions to artefacts they have to consider explicitly the goals for which agents use artefacts and the actions that constitute their use; the agents' actions are captured in a "use plan". A number of papers resulting from this work, for example [33], include discussions on the distinction between function, behaviour and capacity of physical artefacts. Mumford [49] provides the following definitions for function and capacity: capacity is a property of an artefact that is understood according to what it can do or what function it can play in relation to other properties; function is a capacity plus the use plan that exploits it for an intended purpose. In this paper we take the view that, in a given PSS, the service elements are forms of use plan for the product elements.

On designed physical structures, Simons [61] uses mereology to provide a theoretical basis for the definition of physical product structures, of which bills of materials are a common manifestation. Key elements for a physical product definition are geometry, material specification and process plan. Design rationale, as captured using tools such as Rationale™ [5,55,73] and DRed [11], is a means by which designed physical structures are related to intended functional structures. Design intent, for example as captured using advanced requirements management techniques [2], enables intended functional structures to be related to stakeholder intents and so aspects of what Vermaas and Houkes refer to as use plans. An initial analysis of requirements for the definition of physical products and services is provided in Table 1.

It can be seen that there are alignments in the lifecycle stages of products and services and potential commonality in the representation schemes that might be used to represent requirements and design rationale. A key difference is that a core aspect of a physical product definition is its shape whereas the core aspect of a service definition is the service delivery process. There are many approaches to the definition of processes in the literature and some include digital process definitions that are used to support process evaluations. For example, Wynn et al. [76] report work related to the definition and simulation of product development processes. However, the underlying representation schemes for these process definitions are typically not published and, for this reason, the extent to which they might be integrated into PSS definitions is uncertain.

2.2. Service definition tools and techniques

A number of tools and techniques are being developed to support the definition of services in the fields of social and behavioural sciences, business, design and information technology; for the range of information to be supported see [69] and for examples of the tools and techniques see [19]. Tassi [65] presents a collection of these tools and techniques according to the following categories:

(i) the design activities they support (e.g. envisioning, designing/co-designing, testing and prototyping);
(ii) the kind of representation they produce (e.g. text, graphs, narratives, models, games);
(iii) the recipients they address (e.g. stakeholders, professionals, service staff, users); and
(iv) the contents of the project they convey (e.g. context, system, offering, interaction).

Service blueprinting approaches have traditionally been used to capture service-only products such as those in the hospitality and financial sectors [21]. Kim et al. [29] and McKay and Kundu [45] report applications of service blueprinting to PSS. In addition to these approaches, which focus on the definition of services, there is a growing body of work on systems that support service development activities and result in service definitions. These systems, which include both PSS-CAD tools such as those described by Tomiyama and Tassi [65,68] and more focussed service development tools, fall into Tassi's first category of tools and techniques. Kim et al. [29] provide an overview of PSS-CAD functionality and the representation tools used in PSS design in the context of a PSS design process framework that includes stakeholder, requirement, product and activity modelling and scenario planning, and which