Building an Ontology of Product/Service-Systems: Using a Maritime Case Study to Elicit Classifications and Characteristics

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Abstract. In recent years, the innovation strategy and development process entitled Product/Service-Systems (PSS), has attracted considerable attention from the research and industrial communities. The many contributions have come from various academic and professional viewpoints, which despite providing a rich view of PSS as a strategy, also leaves some confusion as to what actually constitutes a PSS. The definition of a PSS ontology could provide the basis for a more systematic knowledge gathering within the field and facilitate the application of integrated solutions within the industry. Ontologies provide an effective tool for a knowledge management process, due to their semantic capabilities, interoperability and extendibility. A PSS ontology for domain conceptualisation is proposed that captures the underlying end-user value and relates to existing PSS offerings. The PSS ontology is subsequently integrated into an ontology for the maritime sector, in order to allow for the identification of the PSS implementation opportunities within the industry. A maritime ontology can help the industry to document and reuse tacit knowledge while facilitating the implementation and value assessment of PSS solutions.

Keywords: Product/Service-Systems (PSS), ontology, knowledge base, maritime industry.

1 Introduction

In an ever competitive and globalised market, companies strive to enhance their competitive advantage, in order to survive and eventually expand. A viable strategy is to enhance the traditional product offering with service elements that foster customer loyalty and allow for increased product diversification. Product/Service-Systems (PSS) provide an integrated view on tangible and intangible elements of products, where products are considered equal to services, since both are means to satisfy customer needs [1].

Product/Service-Systems are regarded as a business opportunity for the shipping industry, where it is discussed that there is a growing demand from shipowners with respect to after-sales service [2]. One reason for this growing demand is that, due to

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current over capacity of the fleet [3], freight rates are low and it is currently economically unattractive to invest in new-builds. Since new vessels cannot be financed, focus is set on improving the performance of the current vessel portfolio and extending its economic life. A number of strategies can be followed that can reduce fuel consumption, increase availability and mitigate operational risks[3].

In light of the industry-wide challenge of fleet overcapacity, PSS can provide a novel alternative for shipowners to prolong the life-time of the fleet, reduce costs, enhance relationships with the supplier base and improve vessel tradability [2] [3]. In order to allow the transition to a service-centred economy, a wider understanding of the available PSS solutions and their associated value propositions must be communicated both to suppliers and the end-users – in our case the shipowners. These solutions must be able to adapt to existing business models and allow the involved stakeholders to communicate and share their views without ambiguity [4]. In this direction, ontologies can prove an effective tool to map domain knowledge, promote information sharing and increase information systems' interoperability [5].

The particular contribution of this paper is twofold. Firstly, a PSS ontology is proposed. The ontology provides a basis for the analysis of existing integrated service solutions within the maritime industry and connects PSS to key product/service solutions and their associated value. Secondly, a local ontology is built in order to explore the connectivity of the PSS ontology to actual business practices. It is shown that the exploration of PSS solutions is simplified, as the combined ontology can infer the total package of PSS offerings, as well as their impact on end-user value.

2 Literature Review

The potential benefits of PSS are well documented in the literature [6]. As companies evaluate PSS alternatives during the total life cycle of a product, a broader perspective is gained. Tukker & Tischner argue that this holistic approach is in itself a first step towards achieving better results [1]. In addition, PSS can create new profit centres and new partnerships with other businesses [7] whilst also providing incentive for the continuous improvement of the business, innovation in quality, and the satisfaction of consumer demand [8].

According to Lindberg & Nordin, a major challenge that companies face when transiting from a product-centred to a service-centred strategy is the difficulty in comprehending complex service offerings [9]. A knowledge-based decision making framework which describes PSS alternatives and their value propositions could promote such a transition. It would allow knowledge integration from the whole product life cycle phases and their associated services [10], systematic identification of customer needs and PSS concepts [11] and quick retrieval of knowledge to the strategic, tactical and operational levels of a company [5]. Furthermore, the PSS research community could also benefit from a systematic knowledge gathering exercise, encompassing the whole life cycle of services and products.

For the establishment of a common terminology and a reusable Knowledge Base (KB) on a subject or phenomenon, ontologies have proven to be an effective tool.

Ontology is a formal explicit description of concepts, in a certain domain, followed by the properties of each concept that describes various features and attributes and restrictions on these attributes[12]. A knowledge base is essentially constituted by an ontology, together with a set of individual instances of classes. Classes are concrete representation of concepts and are interpreted as sets that contain individuals[13].

Ontologies provide the basis for domain knowledge analysis, knowledge reuse, and allow domain knowledge to be separated from operational knowledge, thus also making domain assumptions explicit [12]. In this work, the need to include heterogeneous databases and describe dissimilar concepts using the same vocabulary was early recognized. In that direction, unlike traditional data models like UML class diagrams or entity relationship diagrams, ontologies provide methods for integrating fragmented data models into a unique model without losing the notation and style of the individual ones[14]. Compared to a database, an ontology can be better when the model consists of rich data, with many relationships that are often traversed [15].

In the literature, various ontologies have been proposed for product & service development. Shen & Wang [16] present a framework for understanding and conceptualising product centred services. A generic knowledge model for service conceptualisation is proposed, which enables knowledge sharing and reuse among the different stakeholders during service planning. Zhang et al. develop an integrated knowledge management framework for Product/Service-Systems [17]. It is argued that knowledge in product-related services allows manufacturers to improve products and an ontology is created, which links to meta-knowledge, such as documents, databases, and 2D CAD models. Annamalai et al. propose an ontology for top-level concepts of PSS. The aim of the ontology is "*to aid clarity to the top-level concepts of PSS which would help to communicate these concepts better between researchers and practitioners*". The top-level concepts in PSS are identified in collaboration with industry and validation is carried out in collaboration with PSS researchers [18]. Doultsinou et al. propose an ontology-based structure for manufacturing and service knowledge classification in their so-called knowledge reuse framework [10] . The proposed KB aims at understanding and documenting knowledge support requirements throughout the product life cycle. A number of recognised service issues that occur at different phases within the product life cycle are identified and integrated during the conceptual design phase.

Although past literature approaches provide a basis for systematic analysis of Product/Service-Systems, a number of issues remain unanswered. Existing knowledge bases do not focus on the actual service contents of existing PSS solutions, but rather aim at facilitating communication within existing value delivery networks. Furthermore, knowledge management of Product/Service-Systems is viewed purely from a supplier point of view and the end-user perspective on procurement of PSS is ignored. As PSS is widely acknowledged as being a co-development of value creation through concurrent production and consumption of a function [19], these unanswered issues are important to address in PSS ontology work, which we include in this paper.

3 Proposed Ontology Structure

In order to integrate the end-user perspective and evaluate the service contents of actual PSS offerings, an explicit formal specification of the underlying concepts in PSS must be initially established. Noy & McGuinness' ontology development methodology [12] was followed, in order to create an ontology for domain conceptualisation. The following steps were followed; in the order they are presented.

Determine the Domain and Scope of the KB. The scope of the KB is to explicitly describe the domain of PSS and explore the applicability of PSS solutions, by testing it in the maritime sector. In particular, the ontology illustrates the relationship between products, services and the network of the involved stakeholders during the product life cycle. The proposed KB further aims at describing the value in combined Product/Service solutions and depict the value proposition of existing PSS offerings.

Reuse Existing Ontologies. The developed KB has drawn elements from a number of proposed ontologies and information sources. Root concepts of PSS were extracted from [18]. The main classes that were included in the ontology were: Business Model, Product Service, PSS Life Cycle, PSS Need (and its equivalent class PSS Requirement), Stakeholder and Support Systems. Attributes of Value-in-Use were identified in [20], and the following classes were added: Ability To Source, Access, Administration, Contract, Convenience, Cost, Delivery, Detailed Analysis, Environment, Inventory Management, Knowledge, Offhire, Price, Proactive, Quality Of Equipment, Range Of Offering, Relational Dynamic, Responsiveness, Risk, Service Orientation, Support Systems, Traceability, Understanding Customer Business and Urgency. Furthermore, the developed KB made use of integrated offerings that were developed by the PROTEUS Innovation Consortium [3], in which the following classes were identified: Channels To The Customer, Spare Parts, Customisation, Packages, Education and Installation.

Enumerate Important Terms. A number of terms which are central to the field must be described. These terms are concerned with both the definition of Product/Service-Systems as well as their application in case studies. The main terms were identified in a highly cited review paper from the field of PSS [4] and included the following categories: Services, PSS, Requirements, Life Cycle Stage and Process. Furthermore, the PSS design framework was based on Transformation Models [21] from which the following terms were included: Material, Information, Energy, Effect, Input, Output, State, Transformation Process and Transformation System

Define the Properties and the Classes' Structure. There are several approaches for developing a class hierarchy [12]. In this work a combination of bottom-up and top-down approaches were followed, including the important concepts and distinguishing the most general classifications. The KB attempts to incorporate both the academic and the industrial perspective on the nature and application of PSS. To facilitate its structure and subsequent use, it consists of three mapping layers shown in Fig. 1.

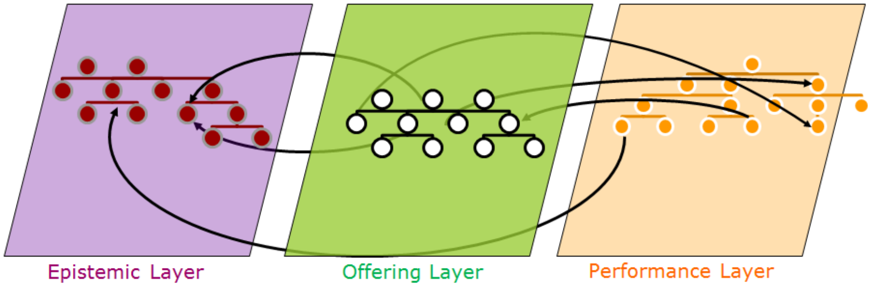

Fig. 1. PSS ontology layers and their connections

The epistemic layer is an abstract description of the PSS. The scope of this layer is to conceptualise the nature and the affinities between products, product life cycle, services, stakeholders, business models, requirements and the transformation process. Transformation is defined as the translation of inputs into desirable outputs in the form of material, energy and/or information [22]. The offerings layer is an explicit description of existing product/service solutions [3]. The scope of this layer is to enumerate existing integrating offerings and describe the synergies between them. The performance layer is a conceptualisation of the value that products and services entail for all relevant stakeholders. The scope of this layer is to explicitly define different types of customer and supplier value and bridge abstract value propositions to performance metrics. The individual layers were imported into the final knowledge model and relationships between the layers were established to connect the various heterogeneous taxonomies. For example, Product/Service Offerings were linked to their individual value offerings using the object property “increasesValue”, while instances of products were linked to their associated PSS Offering using the property “hasPSS” and its inverse relation “isPSSOf”.

Ontology Design Decisions. In developing the ontology a number of design decisions were made, regarding the structure of the KB. The ontology was developed in Protégé 4.3 [13] while elements of the ontology are named based on the CamelBack naming convention [13]. In order to cope with synonyms, the equivalent class concept was employed in order to link closely related terms [23]. Furthermore, in some cases, classes belonged to more than one superclasses (multiple inheritance) in order to cope with the ambiguity of terms and the difficulty of classifying some of them into a unique category. In the offering layer, offerings are modelled as classes and specific offerings as individuals that belong to these classes. These individuals in turn are linked in terms of their dependency on each other via the transitive [23] property ‘isRequiredBy’ and its inverse property ‘requires’.

4 Case Study

Evaluation and update of the KB can be performed by applying it in a real problem and by discussing its structure with experts in the field [12]. In this work the particular case study stems from the maritime sector and focuses on Company A, a shipowner which is interested in procuring PSS solutions from external suppliers. The fleet of Company A consists mainly of tankers that transport clean petroleum products such as naphtha, gasoline, fuel oil and jet fuel around the globe. The company operates in the so-called “spot market”, meaning that its vessels do not have fixed schedule and are mainly chartered on a voyage-by-voyage basis.

In order to support PSS exploration within Company A, a local ontology – the Shipowner layer- is built in order to conceptualise the explicitly defined embedded knowledge within the company. The Shipowner layer was integrated in the overall PSS ontology to allow for information exchange between the layers. The main objective of the Shipowner layer was to gather tacit knowledge that was distributed among various departments within the company and explore PSS alternatives to existing business models. In this direction, seventeen semi-structured interviews were conducted with key people working on the technical and commercial operation of the fleet. Also, in parallel to the interview process, a number of external sources such as reports, business cases and databases were analysed. Through the interviews, the embedded knowledge was identified, which essentially is focused on the ship and its activities. Furthermore, the benefits and challenges for implementing PSS solutions in specific cases within Company A were discussed. Throughout the interviews, it was stressed that a tool which can illustrate the value proposition and trade-offs for different PSS offerings would facilitate their adoption.

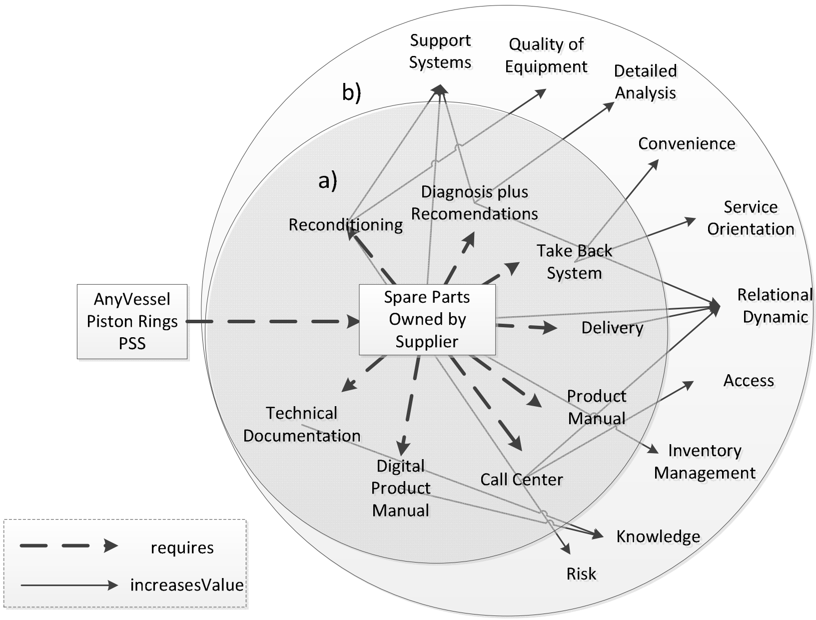

Fig. 2. Example of a PSS design using the developed KB. For a specific project (AnyVessel Piston Rings PSS) the designer picks the associated Service offering (Spare Parts Owned by Supplier), and the KB reasons on (a) the required offerings (shown within the inner circle) and (b) their associated value offerings (shown within the outer circle)”.

The integrated KB, which consists of the combined four layers (Epistemic, Offering, Performance and Shipowner layer), was used for PSS design. An application is shown in Fig.2, where piston rings for the main engine of a particular ship ("AnyVessel") are rented from a certain supplier. Company A can choose a PSS solution for a specific application in the context of its operations, and the KB automatically infers the additional PSS offerings that need to be procured as well as their value propositions.

5 Conclusions and Future Work

In this work a Knowledge Base for PSS conceptualisation has been presented. The KB builds on a growing expertise and interest in knowledge mapping and representation and is largely based on existing classes and concepts. It can provide a basis for PSS design and help evaluate existing integrated offerings in regards to their value propositions. The developed KB was applied in a case study from the maritime sector in order to show, in the context of knowledge representation, the KB's efficacy in helping a shipowner design PSS concepts and understand their benefits. Future work could expand and establish a representative framework for PSS design process using semantic knowledge bases. The overall framework can be compared to current customers' practices during PSS design in order to better describe its usefulness. It should be noted that the proposed KB is not intended to remain stable, as it is subject to scrutiny, refinement, changes in the structure, introduction of new classes and individuals and integration with other knowledge bases. Future research work could also include definition of quantitative instead of qualitative relationships and integration of the ontology with existing open-source knowledge bases that would provide a basis for semantic reconciliation within the field.

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