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Service and manufacturing knowledge in product-service systems: a case study

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Abstract
In the developing Product-Service Systems (PSS) field, an emerging research challenge is supporting the PSS design activity. This paper presents a case study in which manufacturing and service knowledge is captured and classified in order to support the design activity. A knowledge capture exercise took place to identify manufacturing and service knowledge applied in the design process. A design knowledge capture exercise led to the creation of a design process model. The case study reports on the proposed structure for the application of manufacturing and service knowledge to a conceptual and a detailed design task. The knowledge framework is implemented using the Protégé knowledge base editor. PSS design requires an integrated system level approach to design, and therefore a system level knowledge structure is required. The detailed case study indicates where manufacturing and service knowledge is applied in the design activity, which is divided into 'conceptual' and 'detailed' stages.

Keywords:
Product-service systems, service knowledge, manufacturing knowledge, design

1 INTRODUCTION

The emerging paradigm of Product-Service Systems (PSS) focuses on the integration of products and services to deliver customer value. The design of PSS is not simply product design followed by service design. An integrated approach taking service into account at the earliest stages of design is necessary. PSS should reflect an optimised product and service system: as such, that system becomes the focus for the design effort. This paper presents the results of an industrial case study, which took place during a 3-year industrial project and where manufacturing, design and service knowledge were captured and represented in a common knowledge base using Protégé software.

The overall project aim is to develop a methodology to capture, represent and reuse knowledge to support product development in a collaborative enterprise context. The three core elements are: design knowledge, manufacturing capability knowledge, and service knowledge. The project aims to develop a means to ensure authorised access to the right knowledge for the different work functions in the product development process. Recognising crossover and synergy between design, manufacturing and service is a key aspect. The original aim of the project did not explicitly reflect the PSS design challenge, however it has been identified that this research can contribute to the developing area of technical Product-Service Systems through recognising the need for system level design and developing a knowledge framework to support it.

The particular contribution of this paper in relation to the project is a description of the knowledge reuse framework, and applying a model of the design process as a central mechanism for knowledge reuse. In particular, this paper will describe how service and manufacturing knowledge is applied within the framework, in terms of *when* it is applied according to the design process and *how it is structured* according to the ontology. Recognising the co-development of products, services, and their corresponding processes is contributing to the understanding of life cycle design knowledge support requirements.

The process of developing the knowledge base as well as how it can be used and help designers at the conceptual and detailed product design is described in this paper. The future research agenda will then be outlined, which includes the final validation of the knowledge structure and a description of its possible applications and limitations.

2 LITERATURE FINDINGS

2.1 Service and PSS

As far as technical services are concerned, several types of service activity can be identified, including: planned maintenance, unplanned maintenance, service exchange, product repair and overhaul, retrofitting and upgrading, product installation, commissioning and monitoring [1]. Product-Service systems extend the traditional functionality of a product by integrating additional services [2]. There are three different types of PSS that can be found in the literature [2]:

1. Product-oriented PSS: traditional sale of a product with the addition of services, like warranty, repair, maintenance, upgrades, re-use and recycling. The ownership is transferred from the supplier/ manufacturer to the customer.
2. Use-oriented PSS: sale of the use or availability of a product (e.g. leasing). The ownership is not transferred to the customer.
3. Result-oriented PSS: sale of the result or capability of a product. The ownership of the product is retained by the company and the customer pays only for the delivery of the agreed results.

2.2 PSS design methodologies

PSS represents an integrated product and service offering. This needs an integrated development approach for products and services [1]. Therefore, a methodology to support PSS design is required.

Aurich and Fuchs present three approaches to product and service design [4]. These approaches are presented in Figure 1. The first approach stems from the traditional view of manufacturing companies, whose core competencies are the development and production of innovative and highly reliable products. In this case, the product design process is systematically structured, whereas the service design process is carried out in an intuitive fashion. This approach is called 'liability driven', since the objective is to minimise in-service problems.

The second approach supports service enhanced products. Systematic product design leads to the development of product variants, each of them supported by a service package. These service packages are also developed using a systematic service design process. Products and services are not regarded as separate artefacts; they can be combined based on the customer requirements. This approach can be called 'function driven', where still the focal point is the physical product, but its function is accomplished through services. The focus on service increases as it becomes a more integral component of the business strategy.

The third approach supports the development of individualised product-service solutions for each customer. It is referred to as 'use driven'. In this case products and services are indivisible artefacts. Consequently, the design of each solution requires the integration of service elements into the product design process.

Aurich et al. [5] suggest that in companies, product design is typically performed by technical staff. Service design, however, is typically carried out by marketing and distribution personnel. PSS design requires both aspects: an understanding of the product, along with the delivery supply chain and service environment.

Similarly, Morelli states that the design of a PSS is a challenge from the designer's perspective because an extension of their traditional know-how into new areas domains is necessary [3]. The designer needs to take into account various customer needs, and to develop a solution as a result of their synthesis. The customer perspective of the product-service experience is a central theme in PSS design.

Another example of a PSS design methodology is the MEPPS handbook [6], which was created under the Fifth Framework Programme supported by the European Commission. The MEPPS handbook describes the PSS design in terms of selection, design and development of PSS business model. MEPSS aims to impart active support during actual phase-by-phase execution of PSS innovation projects of organisations by suggesting a comprehensible modular structure and giving management and design support. Product-service systems are related with systems that consist of several actors (producers, service providers and users) which altogether offer and consume products and services. For this, system analysis is essential because it constitutes a vital basis for the understanding of the system variables, the relations between the stakeholders involved, and potential development alternatives using the current market situation as a starting point. Therefore, the main difference between MEPPS methodology and the other literature approaches is that it takes into account the system as a whole and its variables, the market requirements, sustainability and it recognises the value of the early involvement of stakeholders. The MEPPS handbook is largely focused on the communication that takes place, rather than the knowledge used, during the design of a new PSS.

Tukker and Mont suggest that the emerging variety of PSS design methodologies conflicts with the potential for a generic methodology. They advise that selected generic principles will always be applicable and then they recommend that each company needs to find and apply its individual practical approach. They highlight the necessity to focus on the system perspective in PSS design [7].

In summary, the current limited number of approaches to PSS design available in the literature all emphasise the requirement for an integrated system level design of products and services. Few approaches are supported by industrial cases, with the exception of Aurich et al. None of the existing PSS design approaches provide a framework for integrating the various sources and types of knowledge required; in fact, since the area is relatively new there are no papers describing in detail the types and sources of knowledge required in technical PSS design.

2.3 Knowledge integration frameworks

Since the integrated knowledge framework is the main outcome presented in the paper, literature related to

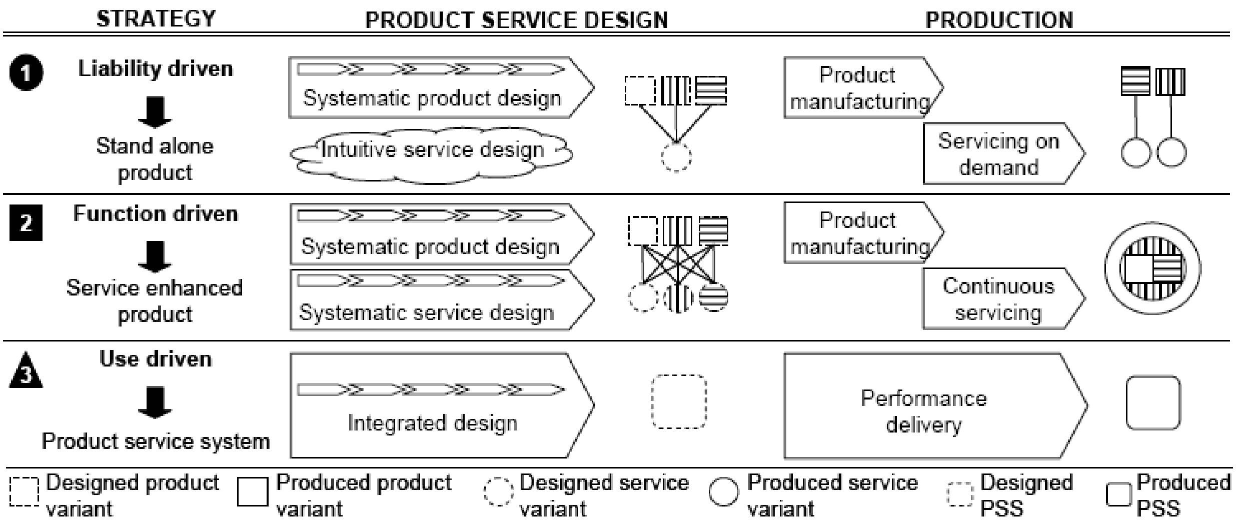

Figure 1: Product-service design strategies (Aurich and Fuchs, 2004)

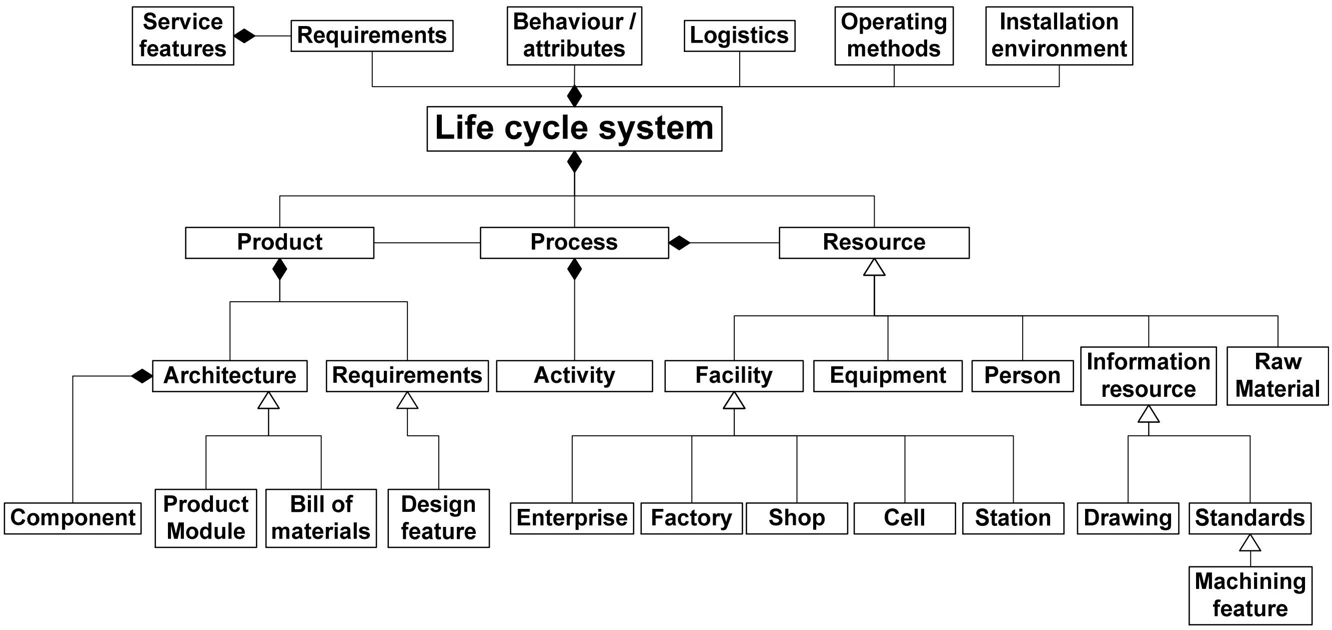

Figure 2: System knowledge structure

knowledge integration frameworks has been investigated, and is presented here. Badil and Sharif [8] present a framework for optimising knowledge integration. Their approach relates to an internal, social process that facilitates dialogue and reflection. Huang and Newell [9] also propose a knowledge integration process, again focusing on social processes. It is the intention of this paper to develop a technocratic solution, which is intended to support an integrated design effort in the context of a mature domain. This information systems approach (in contrast to an approach focusing on interpersonal communication) requires a framework to provide structure for knowledge storage and reuse.

Young et al [10] propose an information and knowledge framework that can be applied to various life cycle contexts (design, manufacturing, operations) with the product as the central element. Using the product as the central element limits its use for PSS design, since the development of the PSS concept requires a system level view. Various elements of the framework can be adopted, such as the manufacturing resource descriptions; however a broader 'upper level' focus is required.

Lee et al [11] developed an object-based knowledge integration system for product development. They apply an object-oriented architecture, using XML as a data interchange protocol. Their integration system is primarily for message exchange during product development, rather than for knowledge support for designers. Chen and Liang [12] developed a collaborative engineering information system intended to support the integration, management and sharing of engineering information, including product and manufacturing process information as well as a description of the engineering process. The framework is not strongly focused on a central product model, so could be applied to a system level design problem; however it is lacking a service component. As such, it does not provide a complete platform for PSS design support. Sudarsan et al [13] describe a product information modelling framework to support "the full range of PLM information needs". The framework is based on various standards, including the NIST core product model, open assembly model, design analysis integration model and the product family evolution model. Whilst 'product in use' is recognised as part of the life cycle view, the approach to managing in-use data is not presented. With no clear references to system level design, it is not clear how this framework could be applied to a PSS design problem.

3 INTEGRATED FRAMEWORK DEVELOPMENT

An attempt has been made by the researchers to create a framework that integrates the various knowledge types from a lifecycle system perspective both for manufacturing and service. In order to achieve this, a detailed case study has been carried out. In combination with the literature findings, this has supported the proposal for a knowledge integration framework.

The case study research consisted of approximately 30 semi-structured interviews with the collaborating company. Interviewees with various job roles took part, including service engineers, designers, manufacturing engineers, quality engineers, project managers and service managers. Notes were the primary mechanism for recording the interviews. 8 of the early interviews in the service and manufacturing contexts were recorded and transcribed; following this, a thematic analysis was carried out. Two knowledge structures were developed and validated: one for manufacturing and one for service Baxter et al., 2008).

In order to extract the service knowledge types from the interview data, the following procedure was followed Doultsinou et al., 2008):

- 10 semi-structured interviews (using the critical incident technique); the main service knowledge types were identified
- 5 semi-structured phone interviews: the initial service knowledge types were modified and enriched
- 6 interviews: the final service knowledge structure was developed

The service structure is described in detail in this section. Two main classes were considered: the 'product' and the 'service organisation'. Then, these two classes were divided into subclasses, so that the detailed service knowledge types can be illustrated in the structure.

Product	**Service organisation**
Service feature	Training
Product attribute	Personnel

Subsystem	Facility
Component	Spares
Service process	Logistics
Maintenance strategy	
Operation	

Table 1: Classes and subclasses

Protégé software was the tool used for the development of the knowledge structure. Therefore, according to the requirements of this software the subclasses needed to have ‘slots’, which describe the properties of the classes and subclasses. For example, ‘can be recycled’, ‘part of product’, ‘part of spares kit’ are the slots of the ‘component’ subclass. Then, ‘availability’, ‘cost’, ‘definition’, ‘spares ID’ are the slots of the ‘spares’ subclass.

Considering the structure of the service knowledge base, two issues that were faced during the service of the case study product can be described:

1. Long time to disassemble due to the big number of water pipes: This is implemented in the KB using the original structure: this is a serviceability issue of a specific product than can be recorded. It also relates to the subsystem issues (i.e. water system), where the issue and the actions taken to tackle it can be recorded.

2. Small pump is harder to move. This issue is described as part of the manoeuvrability class, where the service engineers can report any issues regarding this specific product attribute.

The two knowledge structures were then integrated, taking into account the requirements for a system level design perspective. The final (generic upper level) structure is presented in Figure 2. Lower level classes are implemented for the specific case example, including component types, module types, requirements categories and design features.

Figure 2 illustrates the generic knowledge structure, providing a mechanism to structure and store various knowledge instances that need to be considered from a manufacturing and service perspective when the whole lifecycle of the product needs to be designed. The top level class ‘life cycle system’ is comprised of three key classes: product, process and resource. The other classes, e.g. requirements, behaviour, logistics, operating methods and installation environment, are used to describe the system.

After having created the class-subclass-slot structure, some instances were created using one of the collaborator’s products as the main focus (Figure 3).

Figure 3: Case study product

An instance, which has been created and is related to the product selected, has the following structure:

1. Product name
2. Has Bill of Materials
3. Product process
4. Description
5. Product ergonomics
6. Recorded failures
7. Has architecture
8. Operating system
9. Similar products
10. Has maintenance strategy
11. Product requirements

4 INDUSTRIAL CASE STUDY

The case study company is a leading manufacturer of vacuum pumps. A description of their design process is illustrated in Figure 4. It is divided according to the conceptual and detailed stages. The black boxes (square corners) represent activities. The blue boxes (rounded corners) represent the datasets which are used as inputs to the activities. These datasets are also activity outputs.

As a result of the case study, the researchers have suggested that the manufacturability analysis activity should be formally applied at the early stages, providing an input to the performance modelling activity. The output from the manufacturability analysis activity – the feature list – is comprised of module clearances, derived from component tolerances. A critical element of these activities is the association between machining tolerances and product cost, which is calculated using the normal component cost plus the expected scrap rate. This supports the commercial decision relating product performance to product value, and supports the comparison of expected value with expected cost to determine expected profit. This activity is currently applied in the company; however there is not currently a systematic approach with a supporting knowledge structure.

Having conducted interviews with service personnel, designers, manufacturing engineers and people involved in the new product development process, the service elements identified as contributing to the design process have been positioned according to specific design process activities. This refers to aspects of service such as service package design and service location decision. Service location is an input to the machining process design, and later contributes to test system design. Service package design, in the process model shown, is incorporated into the requirements specification. A detailed level service package design process is required as an extension to this model.

Currently, manufacturing location is decided in the early stages, however service location is not formally considered. As such, the constraints of those service facilities are not known at the conceptual stage. The detail of the requirements specification activity has been extended to include a range of service requirements. More specifically, the researchers have adapted the Hooks and Farry requirements classification from the literature [14], and combined it with the existing requirements specification format for the case study product at the collaborating company. This represents a combined requirements specification, detailing both product and service. All the requirements were matched with the service knowledge types identified through the interviews with the collaborating company. Table 2 shows these relationships and the location of each requirement in the ontology that was developed.

An additional service related input at the conceptual stage is service failure reports. An investigation into the availability and format of failure report data is required in order to specify the content of the failure reports. It is envisaged that the designers could be presented with failure reports to understand the main causes of failures, issues faced with the product and how these were tacked in the past, so that they do not repeat the same mistakes and more importantly, not to 're-invent the wheel' in cases where a solution has been found in the past. An example application is identify whether a relationship exists between pump, previous bearing types, and product failure. Such analyses are complicated by several factors, including the ability to identify single factors or components in a pump failure, and the ability to identify root cause. For example, a thermal seizure may be caused by contact between the rotor and stator. That contact may be due to bearing wear, shaft bending, different rates of thermal expansion, rotor deformation, or a variety of other factors. The service engineer may not be able to correctly identify the root cause. As such, further work is being carried out relating to the capture and presentation of failure data. So far, it is apparent that reports on components that were replaced, descriptions of the applications in which they were used, and any known differences between actual and expected life could support design improvements.

An investigation is carried out by service personnel (strip and rebuild) at the prototype build and test stage. This informs the design team on physical issues relating to pump disassembly and rebuild.

Alongside the manufacturing process design, service process design needs to take place. The detailed description of service process design will be carried out as a future research activity. Service activities include clean, disassemble, inspect, rebuild and test. An example service process was captured, and is shown in Figure 4. The process is implemented in the Protégé knowledge editor tool. It shows the sequence of the activities as well as the resources used by the process. In addition to the service processes, detailed knowledge captured and represented in the Protégé system includes requirements, design features, manufacturing features, machining processes, machining best practices, inspection processes, manufacturing resources (tools, machines), product descriptions, module descriptions, and component descriptions.

When the control system and interfaces are designed, the application environment needs to be described and taken into account, as it plays an important role and can affect the performance of the pump. The design process is also incorporated in the Protégé knowledge base. In the detailed implementation there is a class called 'installation environment', which describes the environment that the pumps will be installed in terms of heat, humidity and space requirements.

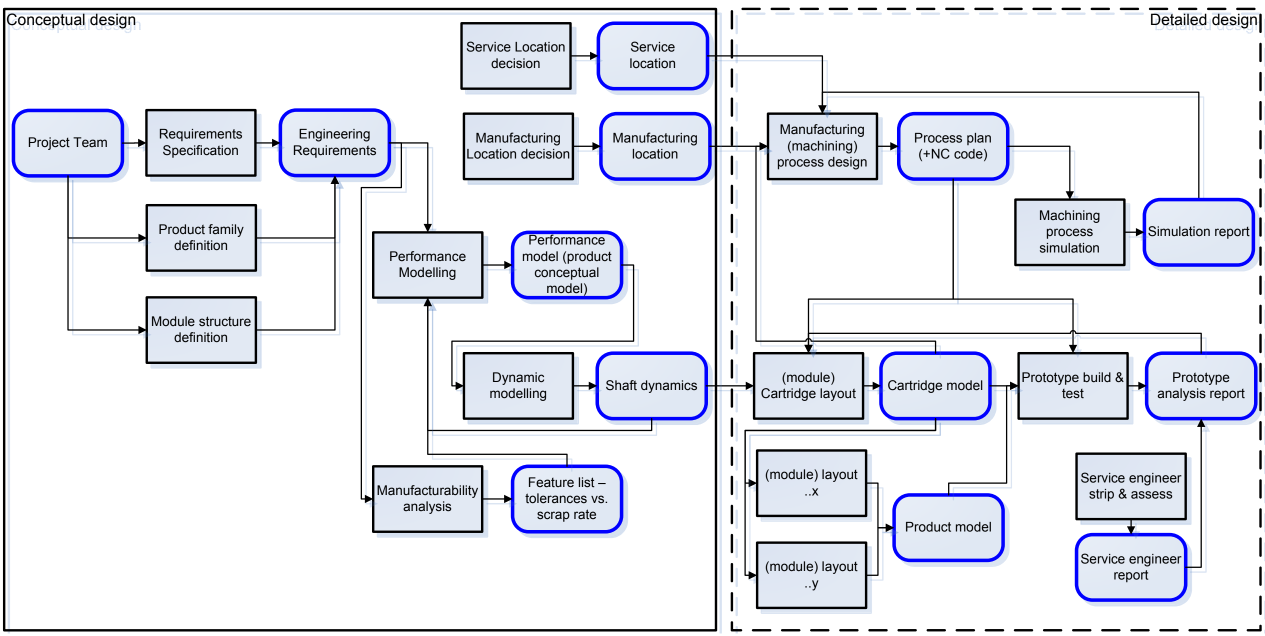

Figure 4: Design process with manufacturing and service inputs

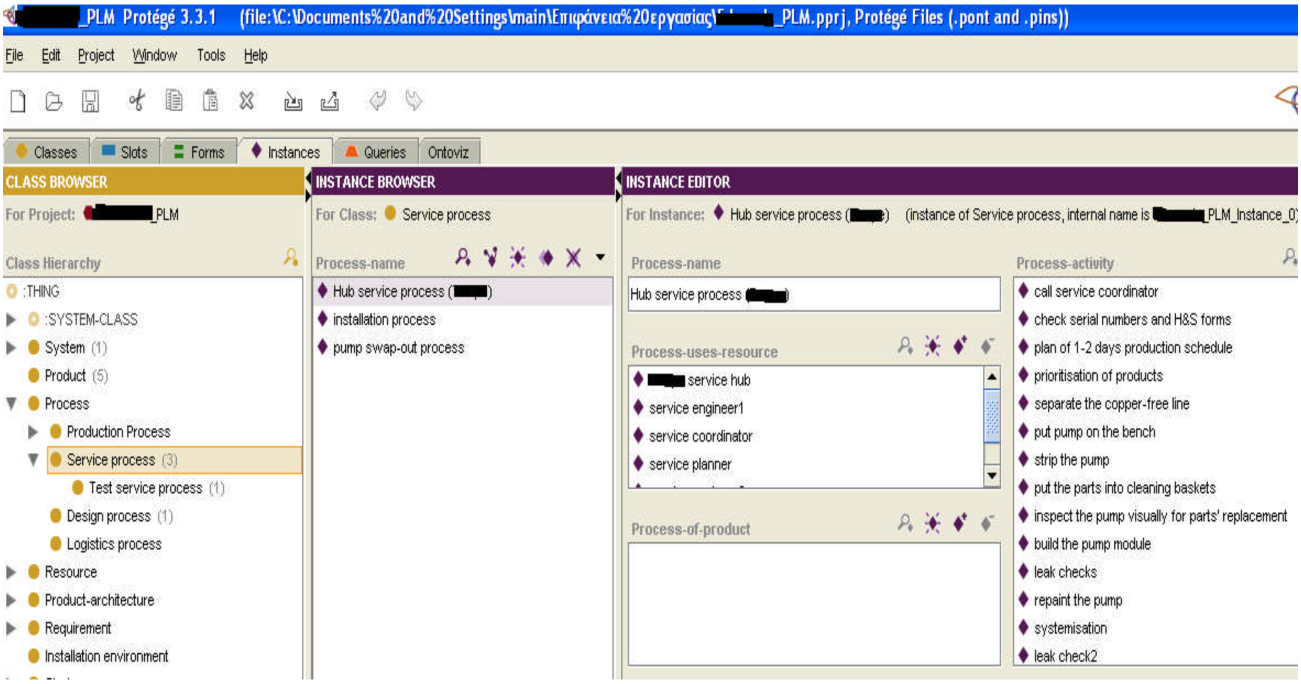

Figure 5 : Integrated ontology screenshot

5 CONCLUSIONS

This research set out to develop a knowledge framework to support PSS design. Existing PSS design methodologies in the literature are available to promote communication, from both technocratic and behavioural knowledge management perspectives. There are currently no knowledge frameworks which support the requirement for system level design – a fundamental element of PSS design.

The proposed framework enables designers to take into account manufacturing and service knowledge when developing a new product or PSS, both at the conceptual and the detailed design stage. This is enabled by the integration of manufacturing and service knowledge, and the relationships identified between those knowledge elements and design process activities.

Our detailed case study shows that manufacturing and service knowledge can be integrated in the design of a technical product and demonstrates how to. It also reveals the difficulties met in the attempt of combining two different areas, i.e. manufacturing and service, due to the difference in the level of abstraction. Manufacturing is mostly product/ component focused and it takes the system slightly into account, whereas in the service area system is taken predominantly into account and a little focus is given on the product/ component. Since the existing design process does not include the systematic development of an integrated technical PSS, our examples are product plus service design rather than true PSS design. The framework developed takes into account the requirement for a system level approach, in order to support true PSS design.

6 FURTHER WORK

In order for this research to be completed, two main tasks need to take place. Firstly, the combined ontology (manufacturing, design and service) needs to be validated by the collaborating company and it should be proved that the framework can provide benefits to the company by the integration of service elements in the new product development process. Secondly, the proposed framework requires validation by another manufacturing company so that it can be generalisable and not just applicable to the collaborating company.

7 ACKNOWLEDGMENTS

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Generic requirements	Service knowledge types	Location in the ontology
Functional and performance	machine uptime, failure types	As instance in 'incident', 'product-failure' classes
Physical: size, colour, styling	paint	Product attribute->design feature
Materials, processes and parts use	service process (spare parts use), planned and unplanned maintenance	Strategy->maintenance strategy
Interface requirements	interface issues	As instance in 'product module' (product architecture)
Ergonomics + Usability	accessibility, tooling, personnel skills, training	As instance in 'ergonomics handling' (product attribute->design feature)
Logistics	logistics (shipping)	System->logistics system
Packing, storage and mobility	packaging	Packaging
Serviceability	serviceability	Product attribute->design feature
Maintainability	maintainability	Product attribute->design feature
Availability	machine uptime, product failure record	System behaviour->measured product performance
Reliability	reliability	System behaviour->measured product performance
Safety	safety record / accidents / near misses	'incident' slot
Cost: service	service cost	
Environmental conditions Reuse and refurbishment	temperature, humidity component (reusability, yes or no), subsystem, service cost, spares	Installation environment Product architecture->component, product module
Disposability	packaging, component, subsystem (non-recyclable materials)	Product architecture->component, product module
Test equipment+ testability	service facility + equipment (resources)	Resource->equipment->test equipment
Service features	Service features	System behaviour->measured service features

Table 2: Mapping between generic requirements, service knowledge types and location in the ontology

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