9 REQUIREMENTS FOR A KEE SYSTEM SUPPORTING PSS DEVELOPMENT

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In Product Service System (PSS) development, understanding the customer use of goods is vital, since the product per se is not sold but rather the performance it brings to the purchaser in terms of added value. Moving away from offering just a product or service to become a provider of "integrated solutions" implies inevitable changes in the way knowledge is managed and shared in a cross company environment. The main aim of this paper is, on one hand, to provide examples of how PSS raise the demand of such cross-functional knowledge sharing; on the other hand it points out a set of requirements for the successful development of Knowledge Enabled Engineering systems supporting a PSS paradigm in a Virtual Enterprise context.

Keywords: Product-Service Systems, Knowledge Enabled Engineering, Virtual Enterprise.

1. INTRODUCTION

Traditionally engineering companies have sold products. Customers bought these products, owned them until they were decommissioned and were responsible for maintaining the artefacts they had purchased. However, as competition and market pressure have put downward pressure on profit margins, some companies have been moving towards offering capabilities rather than products to increase profit opportunities.[1] Such a new paradigm, sometimes called Product-Service System (PSS),[2,3] is a result of an innovation strategy embarking from customer needs and based on the merging of hardware and service capable to fulfil the customer specific needs of functions. The new view where the function, more than the product, is the solution, implies inevitable changes in the company product development process too. The true integration of product and services is more than the simple "bolting-on" of services into the product[4] and raises new and crucial questions concerning how to recognize what can add value to the customer and how to continuously accomplish innovation.

Although the concept of PSS has been openly discussed in the literature for over a decade, yet the uptake of such ideas by industry appears limited.[5] On the author advice, this is partly related to the lack of methods and tools supporting companies in managing PSS knowledge in a lifecycle perspective and in a cross-company environment. PSS claims, in fact, for enhanced knowledge management capabilities to help designers in better understanding the market demands, to adopt the offer to the changing environment and to continuously innovate the products.[6]

The main aim of this paper is, on one hand, to provide examples of how Product-Service Systems raise the demand on such cross-company knowledge sharing; on the other hand it aims to point out a set of requirements for the successful development of Knowledge Enabled Engineering (KEE) methods and tools able to support a PSS paradigm in a Virtual Enterprise[7] context.

2. RESEARCH APPROACH

The research approach can be described as inductive, qualitative and participatory, that means the starting position is found in real industrial cases rather than in theory in order to ground the theoretical

state-of-the-art inventory on what is found important in industry (i.e. from state-of-practice). These empirical studies have the purpose of rendering a map of knowledge aspects (i.e. domains, sources, categories, knowledge workers and tools) thus the key themes for the research. The knowledge problem has been defined through numerous workshops, physical meetings, informal interviews and company site visits during the course of the projects. Such findings have been then analyzed in view of theory; improvements and implications have been proposed using as a reference the scenario created together with industrial partners.

2.1. Research Steps

The KEE system requirements express the functionalities a KEE application should be able to provide to support PSS design, without taking physical constraints into consideration. Their definition has followed several steps (see also Ref. 8).

First, a case study analysis have been performed, together with partner companies, with the purpose of outlining needs, objectives and constraints related to the development of product-service combinations in industry. Such analysis has brought to the definition of a set of *Business-related Requirements* (BRs). BRs describe those elementary actions on the business process enabling the achievements of the initial high-level objectives from a PSS point of view. Targets are expressed in a measurable form for the organization, such as "Reduce the time/cost for [process/activity]" or "Improve the quality of [output of an activity/process]".

The focus has been then oriented towards the definition of the *specific Knowledge-related Issues* to be solved in order to satisfy the BRs. *K-issues* detail the knowledge management needs from a product development team perspective, in form of *"We need to know [knowledge element]"*. The list of K-Issues has been then translated in form of *Knowledge-related Challenges*. *Challenges* cascade down the generic and process-oriented *Issues* into self-explanatory descriptions of a knowledge management matter, in form of "*How to [knowledge management action] a [knowledge element]?"*.

A KEE system requirement list has been then defined together with the industrial partners and mapped on the *K-Challenges* list to identify the ones of interest for the solution. The mapping has been performed by using QFD[9] matrixes to evaluate the impact of each requirement on each *K-Challenge*. At the end, the list of requirements for the KEE solution has been identified. Such list is presented in the following sections.

3. PSS ISSUES FROM A KNOWLEDGE PERSPECTIVE

PSSs represent a big depart from consolidated business patterns since they decouple economic success from material consumption.[3,5,10] This shift implies a deep change in the way products are designed and, therefore, in the way knowledge has to be managed within the design team as well as inside and outside the organization. This section aims to outline how PSS features raise the demand for knowledge and for cross-functional knowledge sharing.

- **Value Creation**. In a PSS view the product per se is not sold but rather the performance it brings to the purchaser in terms of added value.[6] PSSs need to be designed at a systemic level, understanding the value creation through the eyes of the user. In such a situation, companies need to become more customer-centric[1] and PSSs to be designed, made, and delivered on a case-by-case basis.[5] Therefore, knowledge dimensions not explicitly considered in the past, such as usage patterns, take-back, recycling, and refurbishment issues have to be considered during design in order to better understand the customer perception about the product.
- **Heterogeneous domains**. Developing competitive and sustainable PSS solutions means being capable to "think outside the box" by combining heterogeneous elements (people, cultural frames and technological artefacts) in design.[11] From a knowledge perspective, heterogeneous knowledge domains have to be brought together in a cohesive way, despite the fact that such knowledge is typically stored in different parts of the organization and it is usually not readily available

for decision making. Increased capabilities to communicate such knowledge to people, teams and departments are needed, in spite of their different backgrounds, competencies and sectorial languages.

- **Customers as innovators**. In PSS design most of the knowledge about the requested product/service is tacit and embedded in the user's context.[12,13] In such a context, customers have to be treated as innovators, although they cannot always express their needs adequately, especially in the case of innovations where there are no solutions in early phases. From a knowledge perspective, static as well as dynamic data[14] about the PSS in use might suggest important improvements as well as inspire radical changes in current service/product design.
- **Simulation capabilities**. Manufacturers aiming to shift to a PSS paradigm may find difficult to understand the business potentiality of their product/service combinations. The capability to evaluate PSS economic success in the early phases of design becomes a crucial topic for companies.[15] Downstream lifecycle knowledge may help in realistically forecast the future and in evaluating different scenario alternatives, to better orient the decision making activity in the early design steps.
- **Consumers' inertia**. Consumers may not be enthusiastic about ownerless consumption. In a sense, customers have to be "trained" and guided in the use of PSSs, which means they have to be taught about features and characteristics of the new paradigm. Increased capabilities to establish, maintain and enhance relationships with customers are needed to overcome their inertia towards the PSSs and to ensure that the objectives of both the parties are met.[15]

KEE methods and infrastructures for PSS design are requested, therefore, to facilitate the collection, formalization, storage and sharing of the company know-how, in the light of a closer interaction between all the product development stakeholders.

4. REQUIREMENTS FOR A KEE SYSTEM SUPPORTING PSS DEVELOPMENT

Reasoning on the PSS issues outlined in the previous section, the authors have tried to point out a set of requirements for the successful development of KEE methods and tools supporting the development of product/service combinations in a Virtual Enterprise situation. A high-level functional requirement structure, the Knowledge Lifecycle Framework (KLC) developed by Nuzzo and Lockwood,[16] has been used to group such heterogeneous material (Figure 1).

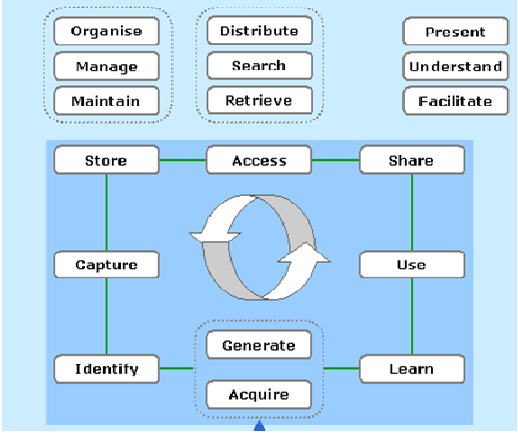

Figure 1. Knowledge LifeCycle Framework.

Table 1. Generating knowledge in PSS — requirements.

GR1	Browsing simultaneously several knowledge elements.
GR2	Identifying links between heterogeneous knowledge elements.
GR3	Maximizing the number of relevant objects that are retrieved
GR4	Networking designers with heterogeneous experiences and skills
GR5	Developing social ties
GR6	Gaining access to user/customers K-elements and know-how.
GR7	Networking of users and providers through remote collaboration

4.1. Generating Knowledge

Developing PSSs means moving away from the hardware-centric view of product development and adopting a new level of thinking, where a lot of time is spent to clarify ill-defined issues instead of well-defined problems. In such a situation, complexity might be considered a driver for innovation rather than as a source of unpleasant trade-offs[17] and the system should be able to assist users in performing exploratory and investigative activities, moving beyond known-item searches, fact retrieval and question answering. In such a context, serendipity becomes more important than precision. The system should support users in browsing a wide variety of topics that makes sense to others and in highlighting the links between known and unknown objects, that is to maximize the number of possibly relevant objects retrieved more then to minimize the number of possibly irrelevant ones.[18]

Moreover, as far as the complexity of the problem space increase, it becomes more important to involve people with different expertise in design. Within a traditional company, however, it is rare to find all the competences needed to develop real PSS combinations. The KEE solution should support designers in increasing the density of their "social ties", networking with experts working in different enterprise contexts.

Moreover, since customers are partaking in PSS development,[15] it becomes crucial to elicit their knowledge about the product and to use them in future designs. The mutual networking between users and customers may help in making explicit the real meaning of the word "value" and in outlining what customers really want from the PSS.

4.2. Identifying and Capturing knowledge

Identifying and capturing lesson learned, design rationale and best practices is a basic requirement for every KEE system supporting collaborative design. However, the development of product/service combinations requires a deep investigation of topics that are typically outside the technical horizon of the engineer.[11] Therefore, it becomes increasingly important to *know who knows*[19] and the KEE system should support newcomers in exploiting the network of connections that typically distinguish more experienced engineers, finding expertise inside and outside the company.

Dealing with not-well-defined design problems, people tend to base their decision on tacit knowledge or on "gut-feelings" and the rationale behind a certain design decision is often communicated in an informal way (by means notes, sketches, e-mails, spontaneous meetings). Capturing the content and the context of such informal flows is increasingly important to understand how PSS have been (and should be) designed. Contributions from Hu *et al.*[20] and from Hooey and Foyle[21] are interesting to be analyzed in order to capture such informal knowledge exchange.

Moreover, there are situations where the customers may create the innovation by using a hardware in a different way from what the company had thought during its development. Identifying and capturing such experiences is crucial to help companies in identifying opportunities for innovation. This topic is clearly understood in the car industry, where remote diagnostics services are used to communicate real-time problems to the manufacturer, which can address them more quickly, leading to fewer recalls, better problem forecasting, and therefore providing added value to the customers.[15]

Table 2. Identifying and capturing knowledge in PSS — requirements.

IC1	Identifying and capturing internal lesson learned, design rationale and best practices.
IC2	Identifying and capturing partners' experiences and skills.
IC3	Identifying people in the company that possess experiences in a particular domain.
IC4	Identifying experts and knowledge owners outside the organization.
IC5	Capturing informal communications among the different PSS stakeholders.
IC6	Capturing the content of informal communication.
IC7	Capturing the context of informal communication.
IC8	Capturing the performances of the PSS in use.
IC9	Identifying groups of customers that possess specific knowledge about the PSS in use.
IC10	Identifying and capturing users/customers experiences with the product.
IC11	Capturing the user/customer behaviour along the product lifecycle.
IC12	Capturing user/customer opinions and suggestions.
IC13	Capturing updates of the knowledge elements.

Table 3. Storing knowledge — requirements.

SR1	Storing heterogeneous knowledge elements (different media).
SR2	Linking knowledge elements stored on different media.
SR3	Linking the knowledge elements to the right application domain.
SR4	Linking heterogeneous knowledge sources.
SR5	Indexing and categorizing knowledge elements.
SR6	Storing informal notes and informal communications.
SR7	Easily-configurable and customizable solution.

4.3. Storing knowledge

The need for a more holistic insight in the PSS design process deeply influences how knowledge has to be stored in the system. On one side, disparate knowledge domains have to be merged together in a cohesive way to support creativity and also innovations. The possibility to automatically establish links between these elements and sources may facilitate the serendipitous discovery of new knowledge within the system. Such automatic indexing may avoid people to waste their time in categorizing the knowledge objects, lowering at the same time the threshold related with the use of IT technologies.

The huge amount of data to be moved inside an outside the enterprise suggests, moreover, to focus on flexible architectures able to be populated and expanded quickly and able to manage both formal and informal knowledge elements, stored in different media (sketches, pictures, movies, chats).

Customizability is another important requirement for the KEE tool. The different actors involved in design may have different backgrounds, skills and competences and the solutions should be adaptable on the basis of their preferences. This means The KEE solution should be conceived as a sort of bridge connecting and interfacing several knowledge sources, from PLM, PDM systems to sectorial knowledge repositories.

4.4. Accessing Knowledge

The PSS paradigm requires a mutual collaboration and exchange of knowledge across and between the organizations. On one side, a KEE solution should allow searching for heterogeneous knowledge elements and within different sources at one time. On the other hand it should support users in searching for the *knowledge owners*, to figure out where tacit knowledge assets are more likely to be found. Flipping such *knowing who knows* concept upside-down, it is also very important to *know who should know*, since knowledge is often generated in small niches of the organization and people may find difficult to make it visible for the people who could be potentially interested in it.[22]

The KEE solution should also be capable to rank the knowledge elements on the basis of their applicability to a specific user context, in order not to overwhelm people with unnecessary information.

Table 4. Accessing knowledge — requirements.

AC1	Searching into different knowledge sources.
AC2	Showing connections with knowledge elements that relate to the one accessed.
AC3	Searching for knowledge elements as well as knowledge owners.
AC4	Searching for the knowledge stakeholders/contributors.
AC5	Searching for people who *should know*.
AC6	Filtering knowledge on the basis of the customer/user preferences.
AC7	Filtering knowledge elements on the basis of their reliability and quality.
AC8	Filtering knowledge elements on the basis of their applicability to the user context.
AC9	Blocking unauthorized access.
AC10	Filtering knowledge on the basis of the user profile.
AC11	Hiding the context of the information exchanged.

Filtering features are important in order to discern between knowledge elements with different levels of maturity, applicability and updating.

The need to cooperate in a Virtual Enterprise scenario raises inevitably problems related to what should/should not be accessible to the partner companies. Blocking or limiting the access to important information to specific groups (i.e. context-based filtering) may reduce the risk of losing core know-how. In such sense companies may let users to access information (the *how*), but not its full context (the *why*), making difficult for them to learn from row data.

4.5. Sharing Knowledge

Shifting towards a PSS paradigm, it becomes increasingly important to make sure that knowledge and expertise created in one discipline, domain or company is correctly understood and quickly utilized by other actors throughout the value chain.

Distortions and misunderstanding are main problems in sharing, since the real meaning of the knowledge exchanged may be lost during the transmission. Such distortions may be mitigated by reducing the number of intermediaries, but this asks for an active involvement of all the stakeholders in formalizing what they know about the PSS. To overcome their inertia, low threshold methods and tools for knowledge formalization may be adopted to help people in directly contributing in building the PSS knowledge base. Using different media depending on the preferences of each single group may also be helpful to lower the barriers for the users.

Giving understanding on what to share and on *whom to share with* is another crucial topic for the organization. Making people aware of potential knowledge stakeholders outside the organization (both users and partners) may help in better directing the knowledge flows. Syndication may also be used to improve the visibility of the knowledge exchanged and to push knowledge to the people who are looking for it.

Table 5. Sharing knowledge — requirements.

SH1	Reducing the number of intermediaries.
SH2	Including low-threshold knowledge sharing functionalities.
SH3	Sharing knowledge using personalized media.
SH4	Sharing information about how to manage knowledge correctly.
SH5	Sharing information regarding potential knowledge owners and stakeholders.
SH6	Sharing user preferences and behaviours and partner experiences and backgrounds.
SH7	Making knowledge more visible for users/customers using syndication.
SH8	Making customer feedbacks more visible for the PSS design team using syndication.

Table 6. Using knowledge and learning — requirements.

UL1	Collecting feedbacks on the relevancy/applicability of a knowledge element.
UL2	Flagging unreliable or inapplicable knowledge elements.
UL3	Ranking knowledge elements on the basis of users feedbacks.
UL4	Involving users/customers in building the knowledge base.
UL5	Emphasizing authorship (highlight knowledge owner expertise).
UL6	Including low-threshold editing functionalities.
UL7	Blocking unauthorized access.
UL8	Defining different editing/publication rights for different users.
UL9	Rewarding users providing useful knowledge.

4.6. Using Knowledge and Learning

Protecting the system against obsolescence as well as vandal actions is a crucial issue when managing cross company knowledge, which raises further questions regarding the quality and reliability of the information used. In a PSS scenario, the knowledge elements to be managed are too complex, heterogeneous or simply to many to be controlled by a central entity. The only way to ensure the quality of the information exchanged is to directly involve the users in verifying accuracy, reliability and updating of the knowledge used for decision making. Quick editing mechanisms, possibly different for different users, may assist knowledge workers in discovering and repairing possible damages in the system as well as in keeping up-to-date the knowledge base.

Of course, incentives should be set up in order to motivate users in contributing in such activity. One way may be emphasizing the authorship, and weighing rewards on the basis of the contribution explicitly given by each single user.

5. CONCLUSIONS AND OPEN ISSUES

The main purpose of this paper is to stimulate the discussion regarding the development of KEE methods and tools capable to manage PSS knowledge in a cross-company scenario. The list of requirements proposed in this paper is still high-level and generic, and it is intended to be a basis for developing more in-depth KEE system specifications depending on the particular company environment.

The analysis has outlined how the PSS perspective shift the focus from guiding designer in solving well-defined problems towards supporting them in more explorative activities. Therefore, also the requirements for the knowledge infrastructure become different, asking for methods and approaches better equipped to enable an open, bottom-up, collective sense-making approach to knowledge management.

From such a perspective, the integration between traditional PDM/PLM systems and more "lightweight" technologies seems a promising solution for this problem. Lightweight technologies borrow the Web 2.0 concept and translate it in more engineering terms.[23] Web 2.0 emphasizes the need to aggregate and make personal data available to other people and groups, since. The "Engineering 2.0" paradigm[23] is built on such a concept and focus on the social aspect of design, where the users (and not the IT applications) add value to product and services. Lightweight technologies for knowledge management may facilitate the capturing of knowledge which, following a more rigorous approach would be very difficult to identify, store and share in a cross company environment. Further research will focus on the development of lightweight methods and tools to identify, identify, capture and formalize cross-company knowledge to support PSS development team in early phases of design.

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