KNOWLEDGE SHARING ACROSS BOUNDARIES: WEB 2.0 AND PRODUCT-SERVICE SYSTEM DEVELOPMENT

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In recent years there has been a growing interest among product development organizations to capitalize on engineering knowledge as their core competitive advantage for innovation. Capturing, storing, retrieval, sharing and reusing of engineering knowledge from a wide range of enterprise memory systems have become crucial activities of knowledge management practice in competitive organizations. In light of a changing and dynamic enterprise definition, including a move towards Product-Service System (PSS) development, this paper discusses some of the limitations of current enterprise systems in reusing engineering knowledge across functional and corporate boundaries. Further, the paper illustrates how Web 2.0-based collaborative technologies can leverage cross-functional knowledge for new PSS development projects through an open, bottom-up, and collective sense-making approach to knowledge management.

Keywords: Cross-functional teams, Product-Service System development, Knowledge sharing, Knowledge life cycle, Engineering 2.0, Web 2.0.

1. INTRODUCTION

Engineering companies have traditionally focused their design and development activities on realizing physical artifacts (i.e. products). However, in today's competitive and global business environment, engineering companies are under pressure to bring product-service combinations into the market, which satisfies customer needs with minimum environmental impact. This new emerging trend is called Product-Service Systems (PSS) [1]. PSS development is a new business innovation strategy that combines design of both tangible products and intangible services in an integral way to fulfill increasingly sophisticated customer needs. The basic principle of the PSS paradigm is to offer the customer the function of a product while retaining ownership and responsibility throughout the entire product life cycle. Other related business trends that are commonly related to the PSS concept include 'Functional Sales' [2], 'Functional (Total Care) Products' [3], and 'Integrated Product and Service Engineering' [4]. For example, aircraft engine manufacturer Rolls-Royce has, at least partially, shifted its business model from the provision of physical engines to the provision of 'Power by the Hour' [5].

Shifting towards a PSS paradigm places new demands and requirements on competences, capabilities and resources related to product and service design processes. Hence, PSS development leads to a complex organizational structure with involvement of cross-functional teams from different stakeholders throughout the whole life cycle, from understanding of customer needs to the

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development, use, maintenance and disposal phase of the product. These dispersed, multi-disciplinary, cross-functional and cross-organizational teams operate in a dynamic, multi-cultural, and highly unpredictable environment, creating and managing massive amounts of information and knowledge everyday in different form or different contexts by using a diverse set of enterprise software and system solutions [6]. In PSS development, a major part of the value creation process is about developing a deep understanding of what customers need and value, an understanding which can be shaped from accessing a wide range of information, knowledge and communication related to customer activities in all life cycle phases. The collaborative PSS development process requires enterprise-wide teams to consider the full range of product life cycle needs in the earliest phases of the development project, especially when making trade-off decisions among many requirements and alternatives that impact the complete system. In most cases such decisions' rationale, if captured at all, is stored in corporate memory systems that are usually not widely available and accessible across corporate or even team boundaries, making it more difficult to retrieve the right information at the right time in the later stages of the product life cycle.

Earlier research studies in PSS [7–9] have acknowledged the challenges that organizations would need to deal with to successfully offer PSS. In this paper, the authors are mainly focused on challenges related to managing knowledge in cross-functional teams, dealing with how to leverage the existing knowledge in an organization's product life cycle management activities by complimenting the existing enterprise systems with enhanced capabilities for social co-creation and networking.

2. MOTIVATION AND OBJECTIVES

The move towards PSS and, consequently, Virtual Enterprise (VE) collaboration [6, 7, 10] are pushing product development organizations to create, share and manage organizational knowledge across functional and corporate boundaries in complex global networks, which includes both formal (i.e. structure) and informal (i.e. unstructured) knowledge. Bell [11] argues that 80% of the organizational knowledge is stored in people's head, 16% is stored as unstructured and while only 4% formalized as structured data. The challenge of leveraging organizational knowledge that exists outside of formal information repositories still persist. Consequently companies need to consider the technologies that allow engineers to work in more integrated ways to support their dynamic processes, which can influence an overall business performance and the way teams can collaborate. The emerging Web 2.0 based conversational collaborative foundation of knowledge management seems to be a more promising approach in this context [12]. Hence, in this paper the authors' hypothesis is that companies increasingly need bottom-up and lightweight technologies to support cross-functional development teams in sharing product/service knowledge when targeting life cycle commitments. The purpose of this study is to verify such a hypothesis by means of observations and interviews with engineers and system users involved in PSS development activities. Since one of the clearest PSS examples is the Total Care package offered by Rolls Royce plc [5], the study has been conducted in collaboration with an aircraft engine component manufacturer that has pioneered the implementation of Web 2.0 like technologies, such as blogs and wikis, to support knowledge sharing in cross-functional teams.

3. METHODOLOGY

This study adopts a qualitative research methodology [13] and the empirical findings are based on an industrial case study performed in collaboration with an aircraft engine components manufacturer, which operates in a business-to-business context. The data have been collected through 17 interviews with several cross-functional team participants at different hierarchical levels, which include engineers, project managers, process owners, and company specialists, all with experience from global projects. During the interviews the concept of PSS and knowledge related issues in a PSS context have been discussed using as a reference a generic knowledge life cycle proposed by the authors. Several forms of interview techniques, formal and informal discussions, and focus group meetings were used for the data collection. The data collected were recorded, transcribed, and further validated by the respondents. The issues were then analyzed with PSS lens to understand the essence of collaborative technologies in terms of how existing enterprise systems leverage cross-functional knowledge while moving towards PSS development. The case study has been complimented by survey questionnaires forwarded to several functional managers within the company in order to quantify the identified patterns in the study. The questionnaires aimed to gather relevant data about the current cross-functional collaboration practices, challenges, and trend of new emerging technologies adoption in cross-company collaborations. External company documents and archival records have been used as secondary sources of data collection to maintain data triangulation [13] to identify the same phenomenon from different points of views.

4. CASE STUDY DESCRIPTION

The case study has been conducted in co-operation with an engine component manufacturer. In the full supply chain towards the airliners, the company has design responsibility for components of aircraft engines. Also, they have one specific product where they are actually OEM (Original Equipment Manufacturers) themselves and thus provide a lot more than a hardware product, i.e. providing all the functionalities around the engine like manual documentation, education, training, engineering support, maintenance, safety issues etc. As a first tier supplier, they have been increasingly involved earlier in design projects with the engine OEMs and aircraft OEMs to enable them to be better prepared from a technology perspective and also to prepare better for a long product life cycle management. This Virtual Enterprise [10] collaboration brings new demands and requirements on information management concerning different access and security levels with many more boundaries between organizations and inherent communication difficulties. Thus, it is important to define how a set of geographical dispersed companies can collaborate and manage their product information, and how their respective workflows could operate together in the ideal VE settings. This involves best practices, methods, systems and collaborative platforms, etc. Internally they mostly communicate through face-to-face meetings, informal meetings, phone and email conversations, and phone/web conferencing, etc. Externally, when it comes to collaboration between the companies, they are using web-based teamspaces with suppliers, and normally there is a lot of phone conferencing and email exchange with customers. It has been more difficult to collaborate with the customers since they normally do not set up shared teamspaces for these partnerships.

5. ENGINEERING 2.0 - A BOTTOM-UP/LIGHTWEIGHT COLLABORATIVE ENGINEERING APPROACH- A REVIEW

The advent of Web 2.0 technologies [14] has brought a new culture of sharing information on the Web where users can actively create, store, edit, access, share and distribute the content to larger audiences. These technologies facilitate each individual to maintain their own space for which they have complete control over the information they likes to share. This ‘bottom-up’ sharing and collaboration mode is opposed to the predefined ‘top-down’ structure of most of the existing knowledge management tools. In a way they are ‘lightweight’ because they require little time and effort to setup, learn, use and maintain. Many organizations are starting to deploy Web 2.0 capabilities in their working environment to take advantage of corporate social networks and collective intelligence [15], and further to bridge the gap between social and technical aspects. A 2009 McKinsey survey outlined that more than 2/3 of 1700 companies worldwide have investigated or deployed Web 2.0 tools to support their product development activities [16]. Several initiatives are currently ongoing to integrate social capabilities within traditional engineering tools to improve the work practices of engineering and product development organizations. PTC [17], for instance, is exploring how to leverage social interaction and collaborative features, among global design and engineering teams, complementing CAD/PDM/PLM tools with the development of platforms like Vuuch, Pro/ENGINEER Wildfire, Windchill ProductPoint and SocialLink. Some other examples are Dogear social bookmarking from IBM, Tagger and 3D ContentCentral from

SolidWorks, 3DLive and bluekiwi from Dassault Systems, IdeaStorm from Dell, and the Quest internal communications system from Microsoft.

To capture the advent of Web 2.0 adoption in the fields of engineering and product development, Larsson et al [6] coined the term 'Engineering 2.0', which specifically targets geographically dispersed cross-functional project teams working in business-to-business situations, where the available technology support for knowledge sharing still centers heavily on comparably 'heavyweight' and 'top-down' technologies like CAD, PDM, and PLM systems. Engineering 2.0 is intended as a set of methods and tools to support bottom-up and lightweight modes of sharing knowledge and stimulate the knowledge flow in social networks throughout PSS development. A set of these technologies, including blogs, wikis, social networking, RSS feeds, tagging, micro-blogs, instant messaging, social bookmarking, mashups, prediction markets, social search, media sharing, collaborative editors, dashboards, idea banks etc, and few of their application scenarios in PSS development have been explained in [18]. A categorization framework [19] for Engineering 2.0 tools has also been proposed to show to what extent the PSS development activity may benefit from the integration of different applications.

6. RESULTS

6.1. Issues in the current knowledge practices

Knowledge Life Cycle (KLC) frameworks are getting increasing attention, and several such frameworks have been proposed in the literature [20–23] with varying stages as shown in Table 1. Most of these frameworks are proposed with a view of developing a technology platform and enterprise system that incorporates life cycle knowledge limited to a functional or organizational boundary. However, the requirements for the knowledge infrastructure become different in a PSS context, asking for methods and approaches better equipped to enable an open, bottom-up, collective sense-making approach to knowledge management [18, 24], which could support social creation, knowledge sharing for engineering and product development activities. Hence authors propose a generic KLC (Table 1) to classify the findings in the case study to better structure their argumentation, that can support cross-functional teams social creation across functional and geographical boundaries, and which is particularly focused on reusing knowledge from distributed cross-functional teams using a diverse set of information repositories. The motivation for the new framework is also for capturing and using existing knowledge in people in tacit form.

The empirical findings from the industrial case study are described below in each stage of the proposed knowledge life cycle (see Table 1).

Knowledge Capture, In the aerospace domain, the early phase of the development process is a complex exercise where often the market needs from the airliners put forward to engine manufacturers. Currently, this is performed mostly through business relations, group meetings to agree upon formal business deal that usually captured in the business agreement reports. In the design process, geographically distributed engineers did several iterations before they get to a design to develop hardware from. The first few iterations are not likely to make it into the final design, but it is still useful to extract lessons learned that might arise in these early iterations. They usually capture the design rationale in design reports, excel sheets, internal shared spaces, etc. Most importantly, it is often very difficult to find "why" explanations for the decisions in databases. One of the design informants

Table 1. Knowledge Life Cycle frameworks.

Authors	Knowledge Life Cycle stages
Blessing *et al*. (2000)	Capture, Learn, Store, Retrieve, Use, Generate
Chan *et al*. (2001)	Identify, Create, Transfer, Store, Reuse, Unlearn
Fruchter *et al*. (2002)	Create, Capture, Index, Store, Retrieve, Reuse
Nuzzo *et al*. (2006)	Identify, Capture, Store, Access, Share, Use, Learn, Generate/Acquire
New framework	Capture, Store, Search & Locate, Access, Share, Reuse

pointed out that, *"I think we should have some better tools for catching knowledge generally. But it is the big question how to form these tools more effectively"*. The case company has the customer support personal at the customer sites, to assist answering questions that are outside the available documentation. All the requests from the customers in the product life cycle are documented in a database where they usually document the background material for the change. People often claim that the current database has a lot of file numbers in more structured way of lists and it is often difficult to figure out how the decision was taken, what the common issues are and who makes the changes, etc. As one IT informant put it: *"I think we locked-in too much traditionally putting them in a document system like to die. Someone said that those traditional document systems are graveyards and I think they might have a point"*.

Knowledge Store, All internal working documents and the supplier information are stored in document management systems (DMS) and shared spaces with a lot of 'meta data', which allows them to have a more formal way of structuring the documentation. They usually store operation details, problem reports, and project documents in the system. They have classified the document type in several classes like open, internal, and to OEMs, etc. Furthermore, they have described the rules related to how they should save them, what they should do with them, and how they should alter them, etc. However, for unstructured data types, they lack of document type and do not have any specific rules. In that case it is up to the person creating the document to decide whether it is open or internal. One of the project informants said, "*When I do a new project, how can I use this information that is stored today? And there are quite a lot of issues because the information is stored in different systems and it is not presented in a way that I can use. If I get an issue, maybe I need to know what are the issues in previous project, how was the manufacturing process at that time, or materials that were used, what people were involved etc. I need to collect all the required data from different systems to understand the whole issue"*.

Knowledge Search/Locate, In the case company the free text search is not likely to straightforwardly bring to the expected documentation from a previous project in the DMS, because they have to know which area it is about, and find out if there are any restrictions on accessing that area. Informants found the use of their document management system solid in many aspects, but poor in facilitating search and retrieve functionalities. Due to access rights the search functionality is too restricted for efficient re-use of knowledge. One experienced informant pointed out that, *"We have a huge organizational memory of 80 years, but we do not have the possibility to search in it. We have to find a way to make it available and to get something from it"*. He further added, *"Today we do not have the time to search and retrieve the information. We want it like that. Instead of spending time on searching for, we create it once again, even if it is already somewhere in the cyber space. On the other hand, sometimes people forget to put 'meta data' with the documents, and then it's difficult to locate them in the databases"*.

Knowledge Access, The information lies in separate databases and they have different levels related to access and security. If somebody does not have access, then they might not find the required information. In the aerospace domain, the engine provider has many customers on several development programs, they might not be able to exchange/share the information in between them. Once they finish the project, they are not able to access the documents. One project informant described that, "*For example, if you do the lessons learned report and after a year you want to get access, even if you have written them by yourself you are not allowed because the project is closed. You maybe need some special access, we have a very rigid system to get access to, and it is unclear who has the access to do that"*.

Knowledge Share, as noted before, quite a lot of information today is restricted to a few people. As the company is not normally the OEM, they depend on the tools their customers offer to collaborate externally. They have been working excessively on describing the business processes, standards and instructions in the existing tools, but these tools do not have that much functionality for commenting and other forms of relatively unstructured information. One design informant said, "*In previous project we were designing according to the customer's design system and they own the system, and we cannot* *share it with anybody else in the company. That's a problem getting documents from such a project because it is limited to the persons in that project"*. Another problem that informants highlighted was that, *"….information secrecy part is a bit tricky, people don't really know what they can share or not.….Some persons say if they have access to more than one system, it's very supportive in their work, otherwise they just see their own information. That's a little difficulty when you think about knowledge sharing*". As they are 30 to 40 persons involved in the project, sharing information among team members and across different systems is a major concern. As one design engineer pointed out, *"If I want to share information between systems, how can I ensure what requirements I need to present to the provider?.... It is difficult to share the data within the company. If you want to be able to share the data outside to the different providers there are some more things to do"*.

Knowledge Reuse, Many engineering companies are having a hard time reusing the information from the existing enterprise systems. If they have rigid access rights, it is hard to find them even with a brilliant search engine. As one of the informants noted, "*We don't have a good integration between different systems. So we have to look for all the documents/data in different systems from project name, materials numbers to identify the requirement numbers for those features you are interested in, and then you go into other systems and look for the capability data and the capability of the system*". A process owner informant highlighted that, *"I think we need to be stronger in taking care of lessons learned and make the lessons learned available for reuse in upcoming projects. From each project we should update project lesson learned documents once you reach a gate. But today we are not extremely good to take that information and actually feed it back to the system"*. All service knowledge from customer sites is stored in databases in the form of documents. This knowledge can be helpful in the earlier phases of other upcoming projects, but they do not have any regular activities for re-using this information and they do not have good practice at the company.

6.2. Lightweight collaborative tools support in engineering activities

The case study has outlined an increasing interest towards using lightweight collaborative tools in engineering product development activities. The research work highlights several promising areas where a bottom-up approach can show a significant impact especially in early phases of product realization. In the aerospace domain, the early phase of the development process is a complex exercise including numerous participants from global networks. Web 2.0 technologies can enhance the co-ordination and provide clarification on needs by providing considerable amount of collected information among heterogeneous and distributed partners, which could help integrate the decision-making process in an effective way. As cross-functional teams have to realize life cycle demands in the earliest phases of development projects, many of them have different views on how to design and develop a product with a full life cycle view. Approaches like open innovation and enterprise crowdsourcing platforms can help organizations with collecting the ideas, insights and feedbacks from employees and even from customers, suppliers and external partners in the early phase of the development process [6, 12]. These tools make organizational knowledge visible and harness the power of diverse individuals to collectively contribute to the project in a collaborative enterprise context. As highlighted by one of the experienced managers, *"...the major difficulties during product development were that we are not using social networking tools as much as we can. We are not utilizing forums, blogs and wikis in great extent……We need to get a level where we can support standard enterprise systems with wikis and blogs for co-ordinating and feeding informal information from the coffee room conversations and departmental /personal meetings. Then we bring the discussion into more open shared space where other persons can address relevant questions, give comments, and follow more open dialogues and moreover we can increase the network around certain area/issue"*.

The case organization is trying to get everyone to engage in more social/bottom-up behavior around existing platforms, including the creation of alerts, tags, RSS feeds etc. In their personal shared sites, everyone has the possibility to create a blog and a wiki if they like, and they have a shared document area where they can add documents and create temporary workspaces etc. Additionally, they also have a colleague tracker where they can add colleagues and follow their new documents and new blog posts. The case company found benefits from using a blog as an open and shared platform across functional and organizational boundaries. One of the project informants said, *"The product development team needs to spread the information more in the projects, so respective designers know that first part went to workshop, manufacturing sequences and milestones etc.... It's more about getting design feedback and making sure that the design team is getting the feedback about the product in later stages of product development, etc."* They are trying to encourage design teams, supplier teams and operators to post in the blog as well. Another informant added, "*Now if something happens during the manufacturing, the people can now go back and read about what happened at that time. We are also encouraging to put in the tags for easy searching and retrieval*".

Web 2.0 tools encourage ways in which employees in organizations collaboratively create and share the content into a more easily searchable knowledge base through, for example, tags. This bottom-up approach helps the users contribute continuously to the collective knowledge base [19]. By connecting web based mashup platforms to processes, information and knowledge can more easily be integrated across functional boundaries, which eliminate handoffs and lock down processes. Lightweight collaborative tools can facilitate networking capabilities and create social communities and collaborative spaces where teams can team up to accomplish tasks through coordinating activities and sharing knowledge [15, 16]. For example, a wiki system could support more of a day-to-day process instead of waiting for a project gate. In that way it can support the gate passage and lessons learned process, to catch all potential lessons learned from different perspectives and then co-ordinate the information more towards possible process improvement in projects. Currently, the case company is developing a design practice system where there is an activity description of design process, how to do design iterations and criteria for selection, etc. One design informant pointed out that, *"the wiki can make some distinction here, and it can act more or less as an informal collector of different opinions and knowledge about practices. Therefore, having a wiki system connected to each activity, lesson learned and experiences are beneficial…we could document all design stages even better, so others can see and share their experiences*". Social networking may support newcomers in exploiting the network of connections that typically distinguish more experienced engineers, finding expertise inside and outside the company [18]. By accessing the social profiles one can access their documents, list projects they have participated in, etc. This increases organizational awareness within distributed, heterogeneous organizations, which enables team members to find one another and work together. A real opportunity in moving to the PSS paradigm lies in the ability to capture life cycle information as it is created through the delivery of life cycle services [7, 9]. For example, when customers have concerns about the product/service, these collaborative environments allow for new ways of communicating to immediately respond to their questions and offer external support with regard to their issues, as well as to immediately feed such knowledge into the product development process for the benefit of current and future projects. Companies can provide desired and relevant information to the customers through these technologies, making it easier to develop contacts and improved connectedness. This nurtures a collaborative knowledge management practice between cross-enterprise knowledge workers where they jointly create and maintain the knowledge assets. This can help transcend formal bureaucratic hierarchy structures in organizations and create informal communities to foster communication across organizational boundaries.

7. CONCLUSIONS AND FUTURE WORK

This paper emphasizes the importance of the creation of a collaborative environment where cross-functional teams can manage and reuse knowledge smoothly and informally across functions and corporate boundaries in a PSS context. The empirical findings from the case study support our argument concerning the limitations of current enterprise systems for knowledge creation, sharing and publication in heterogeneous and distributed networks, and emphasize how the cross-functional knowledge can be leveraged through the support of a more bottom-up and lightweight collaborative approach. Managing knowledge in early phases of PSS development processes and getting feedback from service operations to design are two areas where bottom-up technologies seem to complement the existing enterprise systems. Although several benefits were found with a bottom-up collaborative approach, several industrial obstacles were noticed in the fieldwork, such as: (1) establishing a culture that encourages working with unstructured information, (2) bridging the generation X and Y gap concerning adoption of social software, (3) making a cultural shift from sharing of information to sharing of knowledge, (4) allowing for more two-way communications than one-way communications, (5) motivating people to take active part in open dialogues. The collected needs and constraints from the case study will enhance our understanding to move further in the development of a lightweight collaborative demonstrator tool in the proposed knowledge life cycle perspective.

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