PSS Innovation: Discussing Knowledge Based Tools

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Abstract
Product-Service systems (PSS) introduce the alternative for manufacturing firms to address sustainability in early development. In aeronautic industry, sustainability is an issue that challenges the innovation capabilities. The question if engineering tools and software are apt to manage innovation aspects guides the study in this paper. The study embarks from tools which can be categorised as knowledge based tools, and concludes that there are constraints that delimit the use in innovation projects. However, some of the constraints are more related to the approach rather than to the tools as such.

Keywords:
Product-Service Systems, Innovation, Life-cycle, KBE, KBS, knowledge based engineering, knowledge based systems

1 INTRODUCTION

A Product-Service Systems (PSS) solution is commonly seen as a life cycle commitment, since the manufacturers take extended responsibilities to deliver the agreed performance. This is a complete different business model compare to selling goods as standalone products. In recent time, environmental and sustainability concerns have become a vital part in product development. Thus, adding to the complexity of managing the 'well known' aspects of shortening lead time, reducing costs and improving quality. PSS is a change towards a result-oriented perspective [1] and is an opportunity for manufacturing firms to integrate several perspectives in early development. PSS is foreseen to open up for sustainability aspects, where for example, a change in usage patterns is triggered by a PSS vision, and in turn this reduces waste [2]. In the aerospace industry, the sustainability opportunities and also a possibility to include maintenance into the business can be a reason for adapting towards PSS [3]. Airline companies spend on average USD 870 per flight hour in direct maintenance costs [4], where the engines represent over 40 %.

Though, to reach a PSS vision, the voice of the customer has to be understood in depth, i.e., to address the use of the product the customer's goals and intentions have to be understood by the development team [5]. Typically, a life cycle commitment is contracted on the characteristic to provide "functions per unit", e.g., power by the hour or thrust on wings. The PSS providers also agree to meet such need on the basis of a long term contract. Obviously, the identified basic need can be met by different solutions over time; hence companies have to deal with innovation in a different way compared to a traditional business model.

For the roll-out of a PSS innovation strategy, lessons can be learned from an open innovation approach [6]. Even though open innovation is promising, such an approach still has some complicated issues to tackle, e.g., to change mindset [7]. Still, it is suggested that companies need to be more open to position themselves in future collaborative provision of products [4]. Thinking, seeing and doing first are three ways to decide about the future [8]. Where seeing and doing are important when you have vague information to act upon, as in the case of PSS where the customer information is becoming more abstract. For instance, computer aided design (CAD) tools are a vital part of the engineering activities, such tools allows the engineer to visualise the product. Service/product engineering is identified to have a great advantage if implemented into typical engineering tools [9]. The focus for such tools seems to be to support the engineering area to deal with the service parts in PSS. Thereby, supporting service innovation, so, still, the possibilities for typical engineering tools to support technology innovation are interesting. Hence, the purpose in this paper is to contend with the question how engineering tools are apt to manage technological innovation aspects in a PSS situation.

2 DELIMITATION

In this paper, the engineering tools and software are refereed to those commonly used by engineers in manufacturing companies. In particular knowledge based tools are in focus. A distinction of typical information system tools and knowledge based systems is done in this study. Information systems are seen as used for monitoring, coordination and control, while knowledge systems (or tools) support the development team to take design decisions. Thereby, also knowledge and some of its dimensions have to be managed in this paper.

A presentation of the tools, for what purposes they are used and in what stages of early development they are used will be done. But, first, the method for gathering data for this study is shortly outlined. Second, a theoretical framework that includes different perspectives on the innovation concept is presented. The theoretical framework is based on the constraints of the research project, namely innovation, knowledge sharing and support for engineers. In this paper the theory serves as a point of view for the discussion.

3 METHOD FOR DATA GENERATION

The study builds on empirical data from a manufacturing company. The data has been generated by studying internal document, knowledge systems inclusive its use. Data has also been generated by applying a participative

action research approach [10]. This means that the researchers have been part of the studied phenomena making reflections in practice, one as an industrial PhD student, thus having close access to the day-to-day work.

The empirical data set has been analysed in the light of a literature study on knowledge and innovation strategies.

4 THEORETICAL FRAMEWORK

The theoretical framework builds on three parts, namely some dimensions of knowledge, innovation and implications, knowledge based engineering.

4.1 Some dimensions of knowledge

Knowledge is archetypically defined as 'justified true belief'. This definition has been a subject of controversial discussions, but in recent time the emphasis is put on '*justified'* rather than '*true'*. This shift has inspired firms to consider a wider range of knowledge dimensions than mere facts. Nowadays, a firm's intellectual assets commonly are said to encompass dynamic and humanistic dimensions of knowledge as well. Usually, knowledge is divided into two main categories, namely tacit knowledge and explicit knowledge. Tacit knowledge is not easily expressed, it is highly inherent in the human's experiences and actions, while explicit knowledge can be articulated and (relatively) easily formalized. A difference between theoretical and practical knowledge is also related to these categories. That is, people can posses the theoretical view, but not be able to apply the knowledge practically, and vice versa. In this perspective, a human can convey knowledge by intellect and/or by skills. Also, a distinction between information and knowledge is done. Information can be separated from context and humans, while knowledge is context dependent and part of a human's mind and body [11]. Though, knowledge has no direct value for the company if it cannot be transformed into performance. Thus, knowledge is from this perspective described as actionable information [12].

A company's knowledge base can be described as facts, rules and procedures gathered and organised into schemas [12]. Yet, it is understood that a firm's knowledge base is built up of more that what is produced in activities [13]. For instance, what is interpreted by individuals, given a new context, anchored in the beliefs and commitments of individuals are also part of it [11].

Four categories of knowledge assets, i.e., resources that create value for a firm, are [11]:

- Experiential – tacit knowledge shared through common experiences, e.g., skills, know-how, emotions, conceptions. These are difficult for others to imitate.
- Conceptual – explicit knowledge articulated through images, symbols and language, e.g., product concepts, design. Manifested in products etc., thus easier to grasp, yet still difficult to come to terms with what is perceived.
- Routine – tacit knowledge embedded in actions and practices, e.g., culture, every day practice. These are reinforced and shared through certain patterns of thinking in everyday business.
- Systemic – systematized and package explicit knowledge, e.g., manuals, databases. Can relatively easily be transferred, also the main focus for contemporary knowledge management.

These assets are interrelated, dynamic and constantly evolving and cannot be seen as a snapshot of all assets.

4.2 Innovation

Innovation is often seen as a key for companies to be viable in a competitive business environment. There exists several definitions of innovation; there are at least 15 constructs on the term 'innovation' and at least 51 different variants that can be related to these [14]. This points out that the point of view play an important role. Yet, since long ago, the characteristics for defining the term innovation lean on the idea that it is something *new* that has reached *a market*. Commonly, the definitions also highlight that the innovation should lead to some changes in that market. For example, one definition of innovation is:

"Innovation consists of the generation of a new idea and its implementation into a new product, process or service, leading to the dynamic growth of the national economy and the increase of employment as well as to a creation of pure profit for the innovative business enterprise." [15].

In recent time, the emphasis is on added value for those who should benefit from the innovation, thereby the perspective of customers or users are usually highlighted [16]. For product innovations (in the literature, a product refers to both physical goods and services or a combination) the point of view commonly includes market *and* technology to asses the newness of the innovation [17], [14]. The company's knowledge about market and technology is challenged by innovations, i.e., an innovation either sustains or disrupts established knowledge [18].

Also, the types or categories of innovation differ. In general, there are similarities in the descriptions, tough the name differs. Two of categories of innovation are [17]:

- Architectural innovation: existing knowledge of market and technology becomes obsolete due to the innovation. This kind of innovation disrupts established know-how. It can be described as discontinuous since it does not emerge in an iterative state; rather it seems to come from nowhere. High risks are part of the strategy.
- Regular innovations: improves existing technology and market relationships. Here, the firm's aim is to enhance an existing product, e.g., making the production more cost efficient or extend the shares of a mainstream market. These innovations build on the firm's established knowledge base and do not make market or technology obsolete. This strategy assures low risks.

There are similarities with architectural innovation and the concept of disruptive innovation [20]. Disruptive innovation, as is also architectural, supersedes the established technology or existing product. From a product development perspective, companies often strive to go beyond the 'normal' customer's need and exceed the expectations on the product. Usually, the outcome of disruptive innovation performs worse than the established technology when introduced to the market. Companies that introduce a disruptive innovation can become a strong competitor on a market that has overlooked the innovation opportunity. In a best case, the innovation is addressing undiscovered customer needs [20], thereby the needs can be met by different solutions over time.

Also, there are similarities with regular innovations and the concept product innovations [17]. Since, both types aim to improve established markets and technologies, e.g., in terms of improving performance, lower costs, increase usability.

Different types of innovation can also be described on the basis of a market development life cycle [17]. In Figure 1, starting from the left, a new technology is introduced in the disruptive innovation phase. This technology is initially underperforming, but early adopters find it useful hence the technology has reached a niche market. Product innovation takes it into another level, i.e., the technology is being improved to perform better. As time unfolds, the technology reaches wider recognition and market, thereby insisting on process innovation to, e.g., make production processes cost efficient. At the "top of the hill" in Figure 1, experiential innovation is applied to, e.g., improve customers' perception of the technology. The subsequent state is marketing innovation, where the interface to customers is improved. And, "downhill" at the right side in Figure 1, business model innovation, e.g., reframes the value proposition or the established roles in the value chain. Here, in this declining state, next generation technologies are spotted, though they do not yet affect the existing technology. Before the end, at right, a gap between what is sold and what the market now wants appears. Last, in Figure 1, Structural innovation describes the end of the life cycle, thus the beginning of a new cycle starting from disruptive innovation. This phase capitalizes on the disruption and creates new industry relationships in relation to the new technology, e.g., the opportunity to offer a broader variety of products and services [17].

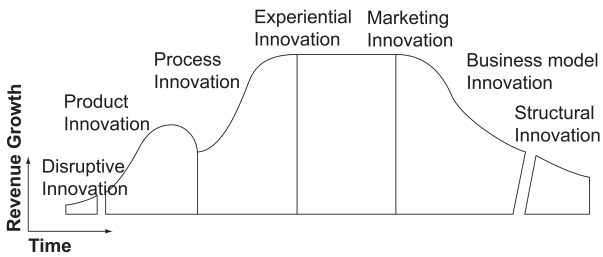

Figure 1. A market development life cycle, adapted from [17].

Companies tend to stay too long in the states for product innovation and process innovation, focusing on, e.g., minimizing cost and shorten lead times [19],[21]. The capabilities to continuously explore new technologies and new markets are vital for firms to be competitive, the same goes for the abilities to exploit the findings [21]. The explore and exploit capabilities relate to an innovation process. Such process is described as <u>*never*</u> being:

"…a one-time phenomenon, but a long and cumulative process of a great number of organizational decision-making processes, ranging from the phase of generation of a new idea to its implementation phase." [15] (p. 3).

Further, new idea generation and exploration includes ambiguity and uncertainty about the future. Companies can take three strategic postures vis-à-vis uncertainty [8]. These postures should not be regarded as applied at all the company performances; rather they are part of a portfolio for strategic actions to be applied where they are best suited. First, the company can choose to "shape the future", that is they can take a leadership in fundamentally change e.g., customer demands or how the industry operates. Second, the company can choose to "adapt to the future", e.g., by recognizing opportunities in existing markets, respond quickly and be first. Adapters are typically relying on pricing and effective execution, rather than on product innovation [8]. Third, the company can choose "reserve the right to play". The company makes investments that in the present put them into a privileged postion, e.g., by having superior customer – supplier relationships or possessing expertise. The company can then wait for the uncertainty to decrease and then design a strategy. This posture is a special kind of adapting and can only be used when the future is perceived to encompass at least a number of possible outcomes [8].

4.3 Innovation and knowledge creation

Within innovation processes, new knowledge is also created. A company's capability to knowledge creation is a vital part of making use of the exploration phases where something previously "not known" is searched for. In this sence, both tacit and explicit knowledge have to be understood. Based on the knowledge creation activities socialization, externalization, combination and internalization derived from the SECI model [11], the explore and exploit apporach are used to map innovation concepts [18]. In Table 1, the left column, show that technological breakthrough and major product/service innovation relates to the tacit knowledge domain, and market breakthrough and regular innovation relates to the explicit knowledge domain. This indicates that the interaction between innovation and knowledge creation is depending on balancing tacit and explicit knowledge to turn capabilities into products and services that add value for the customers [18].

Tacit knowledge *Socialization and externalization (Exploration)*	***Explicit knowledge*** *Combination and internalization (Exploitation)*
▪ Arhitecural innovation ▪ Radical innovation ▪ Major product/service innovation	▪ Niche innovation ▪ Modular innovation ▪ Market breakthorough
▪ Revolutionary innov. ▪ Major process innov. ▪ Technological breakthrough	▪ Regular innovation ▪ Incremental innovation ▪ Incremental product, service, process innovation

Figure 2. Tacit and explicit knowledge in relation to innovation, modified from [18].

In the early 2000's it was argued that the field of aeronautical engineering could find the opportunities for innovation in incremental technology and process innovation, due to the high expenditure nature of the products [22]. For example, by focusing on lowering cost in the manufacturing processes such innovation pays off. The innovation often comes from suppliers or emerging smaller firms, since they can allow the risk of innovating [22]. In the collaborative setting of aircraft engine industry, companies share risk and revenue among the partners [23]. Also, the knowledge creation for innovation is performed inbetween partners. This means that some parts of the processes are based on a virtual company structure, where other parts are not easily managed in the same virtual structure [23].

4.4 Knowledge based engineering

Knowledge based systems (KBS), Knowledge based engineering (KBE) and the combination Knowledge based engineering systems (KBES) are some of the terms that can be found within the literature.

KBS *"…refers to a special class of computer programs that purport to perform, or to assist humans in performing, specified intellectual tasks."* [24] (p.11). Knowledge based system focus on specialized knowledge related to a specific task [24]. Such knowledge has to be attained from people having expertise in the targeted area and the knowledge has to be transformed into "if-then" rules [25],

while the process of capturing knowledge resides outside a knowledge based system. Thereby, KBS opens up for the critique that these systems have to be maintained and upgraded 'manually' and constantly.

On the contrary, the capture and re-use of domain specific knowledge is part of KBE, making the systems more interactive. Knowledge based engineering is explained as: *"The use of advanced software techniques to capture and re-use product and process knowledge in an integrated way."* [26] (p.11). KBE specifically focus to support the engineers' design assignment by making expert knowledge organisationally available. Thereby, KBE in some aspects also have the intention to nurture the user's learning.

While, the combination KBES *"…aims to capture product and process information in such a way as to allow businesses to model engineering design processes, and then use the model to automate all part or part of the process."* [25] (p. 905). Hence, KBES focus on efficient engineering, e.g., shortening lead times, rather than knowledge sharing and a learning process.

KBE is recommended to not be used when, for example, the design process is unclear, knowledge is not available and technology is constantly changing. Also, the company must have the will and the resources to introduce KBE [26].

KBS, KBE and KBES all have benefits and are seemingly intertwined in some aspects. A proposal to integrate the traditional KBE and similar knowledge rich strategies can be found in the concept of Knowledge Enabled Engineering (KEE) [27]. KEE adds an additional view of a simulation approach that allows standard solutions to be generated, evaluated and reported iteratively. In this way, the development team can elaborate on several design alternatives at a low cost [27]. This approach emphasize frontloading, i.e., to define product solutions and their combinations upfront and capture that knowledge into a computer application. A methodological challenge is to provide users with necessary control and not make the KEE a "black box" [27], since one objective with KEE is support a learning process. Thus, the rationale and the rules have to be understandable to the users if they should learn from using KEE, as opposed to applying a KBS for routine/non reflective tasks.

A key for the development of knowledge based tools is to identify, capture and formalize knowledge [26]. Tacit knowledge is recognised as problematic, though qualitative methods are recommended to at least capture some dimensions of it [26].

Examples of knowledge based tools that can be categorised into KEE is a flange wizard tool that support analysing design alternatives [28] and a rear turbine structure analysis tool that support optimisation of structural performance in relation to design alternatives [29]. These KEE tools are developed within research projects, improved and implemented in the studied company.

5 EMPIRICAL DATA

The manufacturing company in this study acts in a business-to-business context within the aerospace industry. They are a business partner in a globally extended enterprise, thus have to possess the ability to act independently and with partners in the development of products. This business-to-business setting makes the company operate both as a supplier and as a client.

The company acts on contract, i.e., the provision of a product is initiated by a directive. Also, meaning that the product is sold before it is developed. The development process is divided into two main types. The first type is called technology development, and includes the early phases where knowledge and concepts are built in parallel. The activities or projects here range from improving existing products to breakthrough innovations. The second type is the subsequent processes to implement the result from the technology phase into a production process. In the latter phases, no breakthrough innovation regarding the product is searched for, but here an innovation perspective might serve to make the production more effective. The empirical data in this study focus on the technology development, though to align with literature, we call these early phases "product development" and the project is called "product project".

Briefly, the product development processes embark from an internal order including a technical specification. In some cases, also the technologies, e.g., expertise, tools, know-how and methods, needs to be developed in relation to the product development. This is particularly true when the product project focuses to find new solutions. The development teams usually consist of a spectrum of disciplines, which disciplines to include depends on the type of the project. Typically, competences from manufacturing, design, quality and purchasing are needed in a product project. Also, resources from external sources are involved in product projects, for instance suppliers, subcontractors, consultants or other firms possessing additional competences. Further, the flux of team members is common in product projects. This flux, people going in and out of the project, depends on, for example in a best case, the progress in the project, where next level of expertise enters the project, or in a worst case a specific expertise is prioritized to other projects.

The company develops components for jet engines; this is a branch where security is of utmost concern. In turn, this makes it necessary to certify the technologies, the processes, the production and the use. Computer supported tools play a significant role in this context, since they inherently have the ability to enable people to store, retrieve and disseminate information. But, also they provide traceability of the performed activities.

The company has a long tradition in the aerospace industry, the roots goes back to 1930. Starting in the 1970's, the company has gone from providing engines only for military purposes to also encompass civilian engines. Hence, the experiences of aerospace industry have been established over the years, but also the company has been challenged by entering a new market. Moreover, in the business partnerships the company have initialized to incorporate a PSS business model based on extended business contracts. Still, the goods are not developed in respect of a PSS development process. The lack of computer support is recognised as contributing to that situation. Especially the ability to simulate business and product features simultaneously to make decisions in early development for how to offer the solution, i.e., as a product with supporting services or a life cycle commitment, seems important. A jet engine is of high total capital expenditure, it is expensive to develop, as well as buying. Typically, the life cycle for a jet engine is around 30-40 years. In order to reduce the descent in performance it is necessary to upgrade it over the life cycle, also the time loops for the periodic maintenance are highly related to its working environments and operating parameters. For instance, differences in the pilots' behaviours, as well as the conditions at different airstrips, have an effect on the jet engine's life cycle.

In recent time, the traditional development stands in front of a change of trends, where fuel economy and emissions are found challenging the innovation capabilities. As part of the aerospace industry, the company has agreed upon a strategic agenda, commonly referred to as ACARE [30]. In this agenda, the goals for CO_2 and NO_X emissions are deliberately set lower than rules and legislation demands, i.e., the goals are set to a reduction by 50 % CO_2 per passenger kilometre and a reduction of NO_X emissions by 80 %. Obviously, the ACARE agreement is challenging and to reach the environmental goals it is not doable to improve the concepts of existing jet engines. Instead, completely new concepts for a jet engine have to be designed.

5.1 The knowledge based tools at the company

Innovation includes risks and radical innovation is a high risk task. Knowledge based tools are use to decrease risk by planning, simulating and visualising potential solutions before creating physical prototypes. Also, the use of full scale physical prototypes can be minimized.

Commonly, engineers involved in product development have expertise in specific engineering domains. Broadly, the support systems can be categorized in a similar way, i.e., they fulfill different purposes in relation to expertise areas. For example, Computer Aided Design (CAD) is used for model based development. CAD is tightly coupled with Computer Aided Manufacturing (CAM) thereby allowing integrated generation of 3-D and 2-D product and process models, drawings and machine tool sequences controlled by Computer Numerical Controlled (CNC) machines. Numerical methods such as the Finite Element Method (FEM) and the Computational Fluid Dynamics (CFD) method are frequently used for analyzing the behavior of engine components. Support tools used at the company combine these characteristics to provide for dialogue and learning, thus can be categorized as KEE.

Overall, the knowledge based tools are used to support analysis of two modes, namely during production and in-use, i.e. in flight. These kinds of tools are often developed internally and are a combination of different tools. Engineers are able to use the tools for design space exploration and to validate and verify design solutions. Benefits are identified in terms of, for example, faster, more efficient and robust design iterations that releases engineering resources or the ability to transfer product and process information upfront in the development process.

The company have used knowledge based tools within a PSS business model for about three to four years, and the knowledge for how to use the tools to elaborate on design alternatives has increased. So, still the common engineering knowledge based tools are used, yet the parameters for evaluating the design solutions in a PSS context are different than before. For PSS, an upcoming work is to create the models that are needed to visualise these parameters in relation to others. Also, the visualisation is foresighted to include more ways than previously.

For the case of radical innovation caused by the strategic agenda that the company has agreed on, reoccurring analyses done on previous jet engine families probably will be needed also for the new products. As a whole the new jet engine might turn out to be a breakthrough product, but the development processes might not change radically. Thus, the company considers the degree of radical innovation for the internal processes. The challenging situation is thereby put in relation to how radical it will be to the company's contemporary approaches. Here, they have to judge how flexible the knowledge based tools need to be to adapt to the future. In this context, the knowledge based tools need to be improved to suit the new application area. Discussions of constraints and possibilities in relation to the knowledge based tools are inherent in organisational culture at the technology development department. The development of internally used knowledge based tools is part of the core competences at the company.

The company perceives that the ability to define and create knowledge based tools still relies on the availability of experts, so called Knowledge Engineers. A bottleneck for large scale implementation is the maturity of formal processes that the knowledge engineer can work with.

The knowledge based tools used at the company intends to assist engineers in design space exploration by capturing, formalizing and automating tedious processes within different engineering domains to a feasible extent. This allows for consequent optimization of products and processes and aims to relive engineers from mundane time consuming tasks, making them available for innovative studies not performed otherwise.

6 DISCUSSION

It can be argued that a successful product development process can be applied whatever the intended outcome. So, hypothetically, a development process can deal with innovation and does not need a specific process. Innovation processes are commonly described in innovation management literature as being an entity separated from product development. On one hand, the fact that radical innovation and incremental innovation leads to technology changes, indicates that an innovation process has to be intertwined into the product development processes. On the other hand, the fact that radical innovation is built upon a different knowledge base than incremental, the practice of an intertwined process becomes a challenge. Here, there are similarities with PSS development where products and services are based on distinct logics, yet they have to be integrated.

In a radical innovation approach the development team starts from a vague idea, or as is the case for the company in our study, they start from the insights that they have to do *something* completely different to reach the emission goals in the strategic agenda. So, we can argue that this is a really challenging case were they have to start from somewhere to make it. But, from where can the innovation process start? What are the competences needed? And, what can be carried over from earlier development cases? In the view of a market life cycle one can see that a different explore/exploit-focus is needed of the engineering team through each phase, but how does this model correspond to a company producing PSS solutions in a business-to-business market?

From literature, the arguments that companies tend to stay too long in incremental and process innovation phases [19][21], and that they should never regard innovation as a one-time phenomenon [15] are stressed. These are good advices, in particular for consumer goods. There are many examples of firms that have fallen into that trap, but when the product has a life cycle of 30-40 years this argument seems to be out of context. Also, an established incremental innovation approach can be a platform for a steeper learning curve, provided that the development team is supported to achieve that.

Learning from other disciplines is beneficial especially for PSS, though, as argued; the context for aerospace industry seems far away from the commonly business-to-consumer (b2c) perspective in literature. Typically, such a

b2c perspective emphasizes *one* relationship, namely that one between the company and a potential consumer market. The business environment for aerospace industry is within a business-to-business setting (b2b), where several partners work jointly to develop the product. The company in this study contributes with components, but is a partner in the overall product development process for the jet engine. This has two implications. *First*, the business relationships seem more complex. For example, the relationships can be describes as working jointly with

- suppliers to develop the components
- collaborative partners - the jet engine developer and affiliated suppliers
- the customer - the airline company

to meet the flight staff and passengers needs of safety and robustness. Working in a b2b setting means that some degrees of insights into each others knowledge bases are necessary for knowledge creation. Also, in general, collaborative efforts are based on the recognition that the own firms' expertise is not enough and additional competences is needed. For PSS, it can be argued that the experiences of working in complex business relationship are an advantage, since collaboration is identified as a prerequisite to service provision. For the use of knowledge based tools, such tools have to be apt to communicate cross-company despite choice of application systems. Accordingly, it will not be viable to invest in expensive and extensive knowledge based tools for the collaborative efforts. Further, the transparency between the tools has to be balanced to transfer just enough knowledge for the operation, but not too much.

Second, being one partner in an extended enterprise, like the one described above, means that, e.g., processes, methods and tools have to be compatible. This is particularly true for jet engines, for example because development activities and maintenance have to be traceable through out its lifecycle. For PSS, this might serve as a valid point of departure, since understanding of the whole lifecycle, including use and recycling, is vital. Though, one challenge for the realization of PSS is to capture and transfer this kind of knowledge into the early development phases. For knowledge based tools the challenge is to transform tacit knowledge into explicit. Here, the knowledge sharing can be supported of a focus on assessments in lack of real facts and figures, and as a complement the reasoning behind the assessed measurements. Knowledge based tools can be used to visualize and to jointly elaborate on rough design ideas, maybe complemented with a brainstorming tool. Here, the use should support idea generation and dialogue, rather than validation. This stage of explorations might be crucial to apply knowledge based tools in PSS; where a core question is how to create a product model of a service or of "functions per unit". Here, we argue, that the constraints are more a matter of *what* to model than *how* to model. A first step towards making tacit knowledge to become explicit is through a socialization process [11], e.g., to jointly reflect and formulate questions.

The company's and the entire extended enterprises' innovation capabilities are put to the test by the strategic agenda for lowering emissions. It is recognized that the next jet engine family cannot be built on an incremental improvement approach of existing concepts. Here, understanding of which design concepts and features that can be transferred are a real challenge. For PSS this situation can prove to be vital, since the innovation opportunity opens up the possibilities to take in the PSS vision into the development from start. For knowledge based tools the radical innovation approach puts pressure on the formal applications and systems, in particular how to update, change and adapt the tools. Also, some of the formal knowledge based tools might become obsolete in the same vein that technology becomes outdated in disruptive/radical innovation situations.

To be able to use contemporary knowledge based tools the engineers need to have information about the product, e.g., geometrical and physical properties. From this the design activities can aim to improve the existing product from the perspectives of robustness and utility, i.e. in flight mode. For PSS, the support for, first, a general understanding is needed and, second, the knowledge based tools have to support a team to generate a decision base to act upon in view of that holistic level. A key for going into a PSS business contract seem to be the capability to assess the development process related to such a business model beforehand. For example, besides insight into cost, properties and behavior, the engineers have to have support for the choice of ecologically sustainable material. They have to have knowledge for how the material is extracted, processed and how to recycle it, also the environmental effects from both the extraction processes and the machining processes has to be known. Further, if used in a PSS solution they have to have upgrading and replacement of the material in mind, thus taking a continuous innovation perspective into account for the development of the physical goods.

Traditionally, knowledge based tools are used for incremental innovation. Commonly, validation and verification are emphasized, meaning that a product model or a prototype has to be the base. For a PSS business, the life cycle perspective has at least two levels. First, a perspective on the existing PSS solution, and, second a perspective on the whole PSS business including several alternative PSS solutions and their life cycles. At a certain point in the PSS business life cycle, several solutions can correspond to the customers' needs. Here, the development team has to explore which solution to go or not to go for. In such a situation, the traditional use of knowledge based tools for validation and verification delimit the exploration phases. The use of the tools has to open up the design space and create several alternatives in two dimensions, namely the business model (traditional, extended or PSS) and the product (stand alone, added services or PSS) to provide. To support an innovative PSS solution a change in the use and the integration of different knowledge based tools seems to be needed, rather than totally new tools as such.

PSS in itself can be regarded as a radical innovation affecting the whole business. Thus, the first movement in that direction can be taken as small steps, rather than one huge leap. The company presented in this study has chosen a small scale approach for developing and implementing knowledge based tools within the organization where modular and generative properties are some of the tools' characteristics. This aims to increase the level of adaptability of each tool when it is being faced with new sets of requirements. One ambition for the company is that the investment in developing and implementing the tool should give the engineer an advantage at the first time of its usage as compared to not having the tool at hand at all. It is important that engineers can call upon and use the tools with minimum effort at any point in time, without depending on access to a Knowledge Engineer. For PSS, and for the use of knowledge based tools to support innovation, lessons can be learned from this approach. First, systems used are put together based on flexibility and exchangeable

applications. An object oriented bottom up approach combining standalone tools in an aggregated way also provide a platform for the development of a large scale system. Second, the approach to apply knowledge based tools is supported by a mindset of learning, reasoning and elaborating on alternatives.

7 CONCLUDING REMARK

This study embarked from the purpose to discuss the question how engineering knowledge based tools are apt to manage technological innovation aspects in a PSS situation. On the basis of the limited data we cannot draw conclusions; rather we, have by twisting and turning on the issue, elaborated on a wider picture of the challenges of knowledge based tools for PSS innovation in b2b situations to find a platform for further research. Though, to sum up the discussion we here present an implication for turning into PSS businesses.

The realization of PSS should address the need for "functions per unit" over a long term period; this has to be built on a thorough understanding of the customers' goals and intentions. This is an extension in focus from incremental innovation of the existing physical goods to a radical innovation approach to explore upcoming technological solutions. We have discussed the interaction between incremental and radical innovation which seems necessary to both improve the running solution and to keep new ones into the loop. Further, within the frame of PSS we have discussed knowledge based tools and found that in some senses the tools as such can delimit the engineers to spot radical innovation opportunities, provided that radical innovation mostly rely on tacit knowledge and that the engineer does not have the possibilities to reasoning about the ideas with colleagues. Tacit knowledge is, due to the difficulties to express it, not formalized into "if-then" rules. Thereby, knowledge based tools are built upon formalization of explicit knowledge into rules. Accordingly, merely working the tools is not enough for technical PSS development.

The company in this study have implemented small scale systems of knowledge based tools that draws on technology which is traditionally used within engineering tasks. They have added a design exploration approach that allows alternative solutions to be discussed. We find this promising, since it can be a relevant first step towards the realization of PSS development. PSS entails that the development team have to manage to constantly switch from a validation and verification mood (of running product) to an innovation exploration mood (of future solutions) and back again. From our study presented in this paper, we can see that the existing knowledge based tools can prove to be useful for technical PSS development and needed changes relate more to the engineering practice and use than the tools as such.

8 FUTURE RESEARCH INTERESTS

In general, our effort has not been to distinguish between knowledge based tools to categorize them into KBS, KBE or KEE. Yet, the discussion has indicated some differences in the interpretation of the distinct concepts. For example, KBE seem to be a commonly used term though it does not fit into the definitions found in literature. In literature, KBE is outlined to not have the objective to deal with exploration of innovation opportunities, rather the focus seem to be on dissemination of knowledge to ensure that the chosen product concept will fulfil the specifications. This finding can be useful to investigate to develop a terminology or typology for the knowledge based tools, though for our future studies we find it more interesting to focus on the engineering practise. In particular, the themes presented in this paper will guide our future efforts. Namely, (1) how engineers manage incremental and radical innovation on a day to day basis, (2) how engineers will deal with the "fuzzy" customer information within PSS development, and (3) how engineering processes and their subsequent methods and tools will be affected by a PSS business model. Framed by this, the empirical study presented here has resulted in ideas for further research. Three main guiding statements and questions have been formulated:

1. In general, manufacturing companies are firmly acquainted with incremental innovation, and literature highlights that companies tend to stay in that state too long. Thereby, radical innovation is not part of the existing product development approach. For a b2b setting and a long product life cycle it is not clear *how* to integrate the radical approach, or *where* to integrate it. *What is radical innovation in b2b, and how does it affect the collaboration specifically?*
2. A change in how customers express their needs of "functions per unit" is at the heart of PSS development, in turn insisting on a different strategy to collect customer information. As a consequence of a changed approach a wider palette of customer information will be the result. Within such an encompassing information base, there are innovation opportunities to seek and there are high risks to avoid. *How will this affect the engineering processes, tools and practice?*
3. The balancing between tacit knowledge and explicit knowledge has similarities to the radical and incremental innovation approaches needed for PSS development, as well as the intangibility of services and tangibility of products. A product model is a requirement to apply contemporary knowledge based tools in technical PSS development. A complete PSS model has to be viewed from more than the technical dimension. *How does such a PSS model look like?*

We have in the study presented here excluded service innovation, but the work of how to integrate service simulation into knowledge based tools is of interest. Also, we find our engineering perspective delimiting our efforts to in depth investigate the service aspects. We have two suggestions. First, a joint research effort from both a service and an engineering perspective would enhance the results. Second, an effort to investigate the concept of radical innovation and incremental innovation within such a joint research project would be of great interest.

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