A Novel Hybrid Engineering Methodology to Enhance Collaboration during the Design and Development of Meta Product Services

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Abstract. Since the Product-Service System (PSS) is accompanied by a paradigm shift towards the sustainability of the production process, it demands an advanced level of collaboration throughout the design and development process. This poses new challenges to enhance collaboration among cross-sectional, multi-disciplinary design teams in order to incorporate a variety of interdisciplinary services in a complex service-oriented system. Therefore, a new collaboration methodology is needed to reduce barriers to collaboration in a cross- organizational structure domain. This research work aims at highlighting the collaboration challenges that Meta-Product design teams face and also proposes a novel methodology to enhance collaboration among multi-disciplinary teams. The proposed methodology is a hybrid engineering model designed by integrating an Information Delivery Manual approach with a traditional software development process along with three interlinked collaboration services.

Keywords: Meta Products. Product Extension Services. Product-Service Systems (PSS). Information Delivery Manual (IDM). Business Process Model Notation (BPMN). Collaboration.

1 Introduction

The need to adopt sustainable and environmentally-oriented production and consumption processes led to the idea of transferring the physical products to digital platforms, or to intelligent products and services, called "Meta Products" and "Meta Services" respectively. Essamlali *et al.* [1] and Rubino *et al.* [2] defined the concept of Meta Products as "*dedicated networks of four elements: services, products, people, and environments"*. Alongside Meta Products, the Product-Service System (PSS) has recently emerged as a competitive, added value strategy to impel manufacturers to offer a set of products and services as a whole [3], called Product Extension Services (PES). These services offer to achieve sustainable growth by providing high value service solutions based on the product, such as product maintenance, support, repair, energy management, upgrading and recycling [4].

The complexity and diversity of the PES design and development process, however, demand the integration of diverse skill sets and a wider span of expertise in product design teams. This requirement is by no means surprising since strong collaboration among team members, in the end, defines the quality of PES. The

production of large and complex systems usually requires coordination and collaboration among many individuals including designers, developers, marketing staff, standards' experts and customer representatives. Often, these individuals are spread among the numerous divisions of a corporation or amongst different sectors. Collaboration among these actors is extremely crucial in order to synchronize various system development activities. Therefore, collaboration among multidisciplinary teams is recognized as one of the challenges in creating complex product extended services.

In the same line of thinking, Rubino *et al.* [2] highlighted "*connection among stakeholders"* as a critical challenge to the exchange of information among potential stakeholders. Similarly, researchers from different domains [1], [5], [6] articulate that due to the involvement of multidisciplinary design teams in creating complex products, an advanced level of collaboration is required to incorporate a variety of diverse services to accelerate the product development process.

Therefore, in order to enhance and promote collaboration in the design and development of complex product services, this paper proposes a novel collaboration methodology with integrated advanced communication services to facilitate the effective exchange of information across all domains.

2 Literature Review

Recent research work, underpinning the concept of complex Meta Products or Meta Services, highlights *collaboration* as a main challenge in the enhancement of coordination among multi-disciplinary teams [5]. Lots of methods and infrastructural technologies have been developed and applied to support system integration and collaboration for Collaborative Product Development (CPD). For instance, Szykman *et al*. [7] proposed a product model to make design information accessible to users in a Web-based system. Similarly, Kim *et al.* [8] developed an ontology-based assembly design method that aims to make heterogeneous modelling terms semantically processed both by design collaborators and intelligent systems. Moreover, Chu *et al.* [9] implemented a 3D design environment where information with different levels of detail is transferred to different design engineers.

In addition , various examples of frameworks have also been proposed, such as the Multi-disciplinary Collaboration Simulation Optimization Platform for complex product design [10], the Multi-domain Collaboration Model [11] and Complex Product Development based on Concurrent Engineering [12]. However, what is still missing from the literature is the mapping of tools and actors to their corresponding design phases in the complete workflow process, the integration of advanced collaboration services (such as communication, cooperation and coordination in one development platform) and, finally, the integration of process, information, organization and technology in one comprehensive collaborative portal to support complete Meta product development ecosystems.

The work presented in this paper provides a new approach to overcome the barriers to communication and leverage the enhancement of collaboration between different domain experts by continuously exchanging the ideas at each stage of the

development process. It also offers an opportunity for the industrial partners to continuously engage with the production process, to frequently discuss the achievements and milestones, regularly monitor the current status of the development process and eventually, approve the final product.

3 Research Approach

The work that is presented in this paper conducted as part of EU research project, ProSEco. The objective of the research is to provide a novel methodology and a set of ICT solutions for collaborative design of cyber-physical based product-services. Collaboration among multi-functional teams is identified as one of the main issues towards the design and development of complex products and services, such as, Cyber-Physical Systems (CPS), Product Service Systems (PSS), and Product Extension Services (PES). This section articulates the steps that have been followed to propose a solution to solve collaboration issues in the design and development of PES. Since, this study is directly related to the industrial partners who are the key stakeholders of the project; the starting point for this research is the analysis of real industrial cases than theoretical study. However, to relate the work with the existing knowledge, the authors conducted search in relevant academic databases to find peer reviewed papers in the area of PES, collaboration, collaborative process, and barriers to collaboration in the design and development of PES. In the course of finding relevant material they studied available collaboration models, commercial as well EU projects, tools and platforms available in the market with the aim of capturing state of the practice solutions that claim to enhance collaboration for PES design process.

At more advance level of research, face-to-face meetings have been arranged with industrial partners who are involved in this project as well as research and development (RTD) teams to capture basic requirements of the collaborative PES development platform. The purpose of the meetings was to capture those collaboration issues that were not anticipated before and also to discuss the best possible solutions to overcome the collaboration barriers.

Later, in order to propose a new collaboration model, the authors studied the traditional Software Development Life Cycle (SDLC) methods, Agile framework, and Information Delivery Manual (IDM) approach together with Business Process Modelling Notations (BPMN). The initial prototype of the framework is designed, developed and agreed among the team member at this stage of the project. However, further, improvements are expected along the progress of the project when more advance level of requirements will be identified.

4 Collaboration Services

Collaboration services were identified in the CoSpaces project [13] as three distinctive yet interlinked services required within a collaboration service platform. These services are: communication services, coordination services and co-operation

services. These services form an important part within the PES collaborative development portal.

4.1 Communication Services

Communication is an important attribute to define the quality of team work which is highly dependent on information exchange, knowledge acquisition and knowledge representation. Communication helps to get deep understanding of the evolving ideas, to discuss the complicated issues, to develop new solution and at the end to approve results.

In this context, as part of the communication services, the proposed PES collaboration methodology provides advance integrated communication tools that help users to develop a mutual understanding of the project. The proposed collaboration methodology facilitates all different modes of collaboration such as, co-located/synchronous (same place, same time), distributed/synchronous (different places, same time), co-located/asynchronous (same place, different time) and distributes/asynchronous (different places, different time). The communication services that are provided in the proposed collaboration methodology are; audio/video conference tool, brain storming session through eco-observation wall, and project management through Oobeya tool as presented in Fig. 1.

4.2 Coordination Services

Coordination is defined as exchanging information and altering process activities for mutual benefit and for a common purpose [14]. Coordination builds on networking (the exchange of data/information) by adding behaviour, and modifying activities and foci, bringing forward mutual benefits and a common purpose. Coordination increases the efficient use of resources and the ability to meet community needs.

The proposed collaboration methodology provides coordination services through integrated workflow engine. Assigning roles to the corresponding users who are responsible to initiate and complete the workflow activities are part of workflow services. Workflow services are designed to configure and customize PES workflow process. This also helps to trace the current status of the ongoing development process. Furthermore, workflow services also control events by notifying the development team about the current status of the process or the actions that need to be taken to accomplish a task. Step-by-step workflow activities that are needed to develop a complete PES are illustrated in Fig. 1.

4.3 Cooperation Services

Interaction among all the participants, who may belong to different sectors or different functional groups, to achieve a common task defines cooperation services. Cooperation services in the proposed methodology will be provided in terms of:

- Managing actors according to their roles, and
- Managing activities corresponding to each engineering tool

The proposed collaboration methodology is designed to manage all the users according to their roles and it also ensures the seamless integration of all the engineering tools into the portal to provide comprehensive support for the design and development of PES solutions.

The cooperation services encapsulate the engineering tools' services, the sharing of data between tools and also the brain-storming services where ideas raised by participants can be discussed.

Fig. 1 demonstrates a comprehensive PES Collaborative Development Portal with an integrated proposed collaboration methodology that facilitates the design and development of a sustainable PES solution for industrial sectors.

5 Modelling PES Collaboration Environment

This proposed collaboration methodology (designed by the integration of the IDM approach and traditional software development methods) presents a process model which details the steps, milestones and phase dependencies where several functionalities are integrated corresponding to a particular phase of the ongoing PES development process.

The PES Development Life Cycle (PESDLC), described in this paper, is tailored to the traditional standard Software Development Life Cycle (SDLC) approach which starts from requirement gathering to software deployment. A traditional software development life cycle (Waterfall [15], Spiral [16], Agile software development [17], rapid prototyping [18], incremental [19], and synchronize and stabilize) is composed of a number of clearly defined and distinct workflow phases which are applied by system developers to plan, design, develop and deploy software systems.

However, due to the complex service-oriented nature of the project and also to incorporate a variety of services in terms of knowledge management, context modelling, intelligent data analysis, security enhancement etc., it has not been not possible to follow the exact sequence of a traditional software development life cycle (SDLC). Also, to keep the software applicability traits aligned with the business orientation, where a number of actors/participants will be involved from different organizations/backgrounds, it has been decided to follow an interdisciplinary approach. This approach combines the IDM methodology with the traditional software life cycle approach to provide a mutual understanding of the model in all sectors.

Information Delivery Manual (IDM) Methodology. The Information Delivery Manual (IDM) methodology specifies the process and the actors that are involved in creating, consuming and benefitting from the information as well as what information is created, exchanged and consumed [1]. It intends to help software vendors to cope better with the specified individual process-related information requirements of the clients [15], [16].

While creating a PES, the exchange of requirements defines exactly which artefacts are created during which activities, who (actor) is responsible for the tasks, and what the consuming activities are. So, the IDM methodology, in the case of PES development modelling, will help to reduce the communication gap among PES solution providers and the business partners and allow them to exchange information smoothly and flawlessly.

The IDM methodology is deployed by using a standard notation called Business Process Model and Notation (BPMN).

Business Process Model and Notation (BPMN). The Business Process Model and Notation (BPMN) is a standard for expressing process maps which are flow-oriented representations of business operations. This provides a common tool and method for process modelling and mapping. BPMN aims to bridge the communication gap that frequently occurs between business process design and implementation [17]. BPMN models are mainly used to facilitate information exchange and communication between project participants to support decision-making based on various analysis techniques and to provide input to software development projects. Furthermore, the BPMN models are also used to specify the information nuggets being shared or exchanged in the process map; subsequently, it would be possible to identify the required software features in the systems' development effort [18].

Software Development Life Cycle (SDLC). At a higher hierarchical level, the main stages of the software development life cycle (SDLC) are: Requirement Gathering and Analysis, Software Design, Software Development, Software Deployment/Implementation and Software Testing and Maintenance. However, due to the complexity of the PES design and development process, these traditional phases of the model are tailored and mapped to the phases of the PES development process as shown in Fig. 1. Since, the informal testing of the software development will be carried out, in a collaborative session, at the end of each phase of the PES development life cycle; therefore, testing and maintenance phase of the traditional software development life cycle is not included explicitly as a separate phase in the PES development life cycle.

Comparing to the traditional software development life cycle phases, PES development phases are more advanced and complicated. This implies that design and development phases, in the PES development life cycle, are further divided into sub-phases due to the nature of the functionalities required to create a PES. However, these phases are tailored and mapped to traditional SDLC phases to keep the software development traits similar to the traditional development life cycles, as demonstrated in Fig. 1.

PESDLC constitutes of following stages:

- **Idea Creation:** this phase helps to analyse the existing products to find the hotspots, to realize the problem, to propose new ideas, and finally to conceptualize new business model.
- **Market Simulation:** this phase is to simulate the importance of proposed solution against its market value.

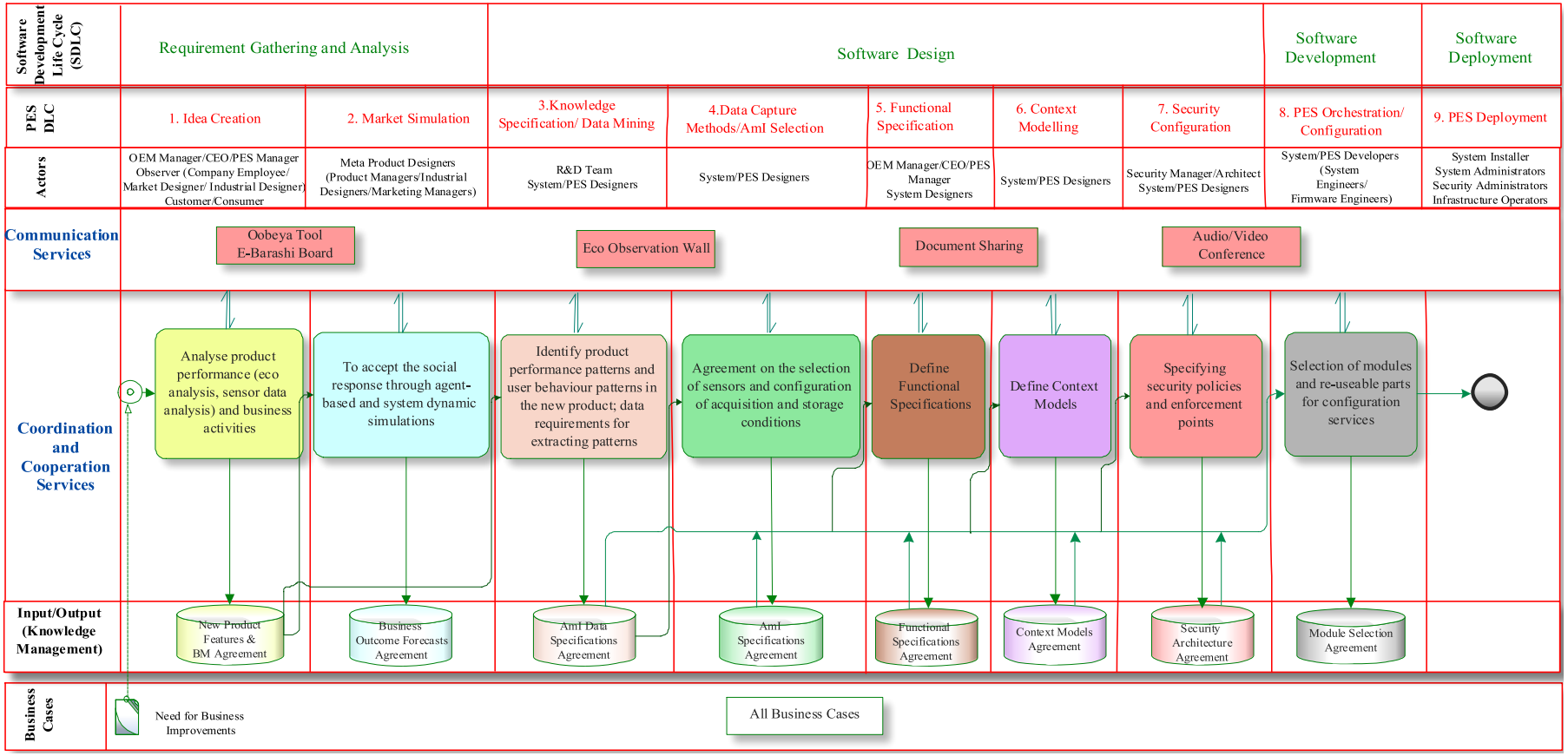

Fig. 1. The PES Collaborative Development Portal

- **Knowledge Specification/Data Mining:** this phase helps to define new data that is required to be captured in developing the proposed model. This also helps to find the useful patterns to take better future decisions.
- **Data Capture Method/AmI Selection:** once datasets are identified in the previous sections, this phase will support to find the corresponding sensors that are needed to capture data.
- **Functional Specifications:** this phase will create the documentation of the specifications of the new products or services.
- **Context Modelling:** This phase helps users to model the context for the product or service using ontologies and ontological reasoning methods.
- **Security Configuration:** this will enforce the security parameters during the design and development of services.
- **PES Orchestration:** this phase helps to specify the sequences of services in which they are going to be deployed.
- **PES Deployment:** at the end of PESDLC, all the services will be executed in the deployment phase.

Other extended attributes of the proposed collaboration methodology are: integrated advanced *engineering tools' services*, potential *users/actors* that are responsible for completing each particular phase of the whole process, and *output visualization* of each service with integrated advanced visualization tools.

As case studies, the proposed collaborative PES development environment with integrated advanced ICT services would serve in different sectors, such as, automotive, home appliances, shoe manufacturing companies and automation equipment to provide effective extensions to their existing products. For instance, in case of automotive company, collaborative PES development environment will be used to improve vehicle's design based on user's behaviour. This will be done by directly analyzing data patterns related to user's behaviour, weather, and pollution level over time and space in a given local and global context. This will help the design teams to discuss the possibility of changing car design that can lead to better driver performance. This can also help to reduced CO2 emissions as well as possible policy change that can enforce positive driver behavior or engine performance configurations and also can reduce pollution levels in the city.

6 Conclusion and Future Work

The proposed collaboration methodology, presented in this paper, acts as a bridge to minimize the communication gap between the technical solution providers and the rest of the stakeholders and allows them to exchange information smoothly and effectively in intelligent products' development ecosystems. The main advantage of the proposed collaborative PES development environment is to provide a comprehensive single platform with seamlessly integrated advance collaborative, engineering and visualization services at one place. It also provides integrated workflow engine based on collaboration design principles to coordinate the concurrent workflow activities. Furthermore, it correlates the workflow activities with its corresponding design and development phase and recognizes the actors who are

responsible to accomplish that phase. It provides the opportunity to analyze a designed artefact with one of the integrated visualization tool and discuss the results and future possibilities in a collaborative session to improve it further.

Moreover, depending on the functional capabilities/responsibilities of each particular participant, the overall workflow process shows the dependencies of business partners and technical expertise on each other, making the whole process a "Cross- Organizational Business Process Model". The PES development process does not initiate until an input is received from the business partners wherein they analyse the product requirements with technical team members who, at the end, provide the software solutions. However, one of the limitation of the proposed framework is it requires users to have proper relevant technical skillset to use the platform.

The first prototype of the collaborative PES development portal is achieved. Currently, the initial testing of the first prototype is being carried out in a laboratory environment. For this initial testing, the proposed solution will be tested for its functional capabilities, usability and likeability. Business benefits, however, will be tested in an industrial environment when a complete prototype will be achieved. The proposed solution will be validated using "Goal Question Metric" (GQM) approach [20] together with the "McCall Quality Model" approach [21].

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