
Representing and sharing process knowledge in PLM systems design

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Abstract: The main aim of this paper is to contribute in leveraging the rate of success of BPR in a Virtual Enterprise environment by proposing a framework supporting PLM system designers in selecting the best communication tool to be used in reengineering. The aim of the framework is to enhance interoperability between users, process owners and knowledge experts in design, by proposing a set of guidelines for the use of process modelling languages when dealing with the definition of PLM system specifications. This work has been conducted within the EU 6th Framework Programme VIVACE Project (Value Improvement through a Virtual Aeronautical Collaborative Enterprise) with the purpose to support the design and implementation of a Knowledge Enabled Engineering system able to improve product development process performances by leveraging past design experience.

Keywords: PLM, BPR, Enterprise Modelling, Interoperability

1 Introduction

In the global economy, customers are demanding more customization and responsiveness, ICT technologies are proliferating at an increasing rate and the product life cycle is getting shorter [1]. These factors imply inevitable changes in the company's organizational structure, forcing industries in shifting from co-located and monolithic design teams to a concurrent engineering working paradigm, merging knowledge from different national, disciplinary and personal skill-based perspectives [2].

In such a context, the introduction of Product Lifecycle Management (PLM) systems may help in managing efficiently the product development process in its entirety. Their design and implementation, however, is a complex and labor intensive operation, which need to be coupled with a Business Process Reengineering (BPR) [3-5] project in order to better deploy technologies and/or methodologies and to target the system development on the real company's needs.

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2 Issues in PLM systems implementation

The successful adoption of a PLM solution in a Virtual Enterprise [6] environment remains an ambition rather than a reality, far from being a piecemeal task which organisations can easily undertake. Recent surveys estimate, in fact, the percentage of BPR failures to be as high as 70% [7-10].

Many authors recognize that this low rate of success is often related to the way reengineering has been conducted, in terms of lack of strategic vision, not well established and shared objectives and diverging directions for improvement [11-15]. From a closer point of view, the lack of stakeholders active participation in BPR is advocated as one of the key factors for the unsuccessful deployment of PLM technologies and methodologies in industry.

A marked confusion still exists in practice about what can be done to alleviate this lack of commitment. One possible way is to involve all the potential stakeholders in the early steps of the PLM redesign process, persuading them in contributing both to its formulation and implementation. Linguistic, cultural and organizational barriers may limit, however, people's active participation in the project.

Graphical process models are typically adopted to overcome these limitations in the As-Is and To-Be analysis of the new solution as well as during the implementation and testing activity. Selecting the right technique may be not so intuitive, since enterprise models are heterogeneous and no official accepted standards exist in this area [16-17]. Each step of reengineering is influenced by different critical factors and involves people with different roles and backgrounds. The notation is requested, on one hand, to be flexible enough to satisfy those stakeholders interested in a quick, intuitive and concise representation of process behavior, while, on the other hand, it should support developers in the detection of inconsistencies among the partial information provided by the users.

3 Motivation and objectives

The adoption of graphical modeling techniques in BPR has the purpose of enhancing the degree of *interoperability* between people participating in the redesign activity, supporting stakeholders in eliciting, formalizing and sharing their own knowledge resources, making them available for decision making.

This paper focuses, therefore, on the investigation of the interoperability barriers encountered by BPR participants in the PLM system design process. The final aim is to propose a set of solutions for interoperability able to enhance communication, coordination and collaboration between user, process owners and knowledge experts involved in the project. As a result, the authors propose a framework supporting PLM system designers in selecting the best modeling language to be used at each step of BPR.

4 Methodology

A BPR process is a knowledge intensive activity which requires a strong *interoperation* between all its participants. Within the present work, the authors refer to the definition of interoperability given by Chen and Doumeingts [18] which define it as: "the ability of a system (technical or human) to exchange information and services in a heterogeneous

organisational and technological environment". Interoperability is not just a problem of incompatibility concerned with ICT aspects, but it refers to other dimensions of the enterprise as well. Increasing interoperability means removing those communication barriers that may exist between two heterogeneous "human systems" too.

The investigation of the interoperability problems occurring in BPR has been conducted making use of the Interoperability Framework [19] developed within the INTEROP Network of Excellence [20]. The framework is intended as a collection of *best practices* and *design principles* able to overcome interoperability limitations between two heterogeneous systems. The interoperability issues have been first classified into the framework and then solved extracting general solution principles from the analysis of the practices belonging to the same class of problems. Then, once improvements have been evaluated, the process has been further iterated.

4.1 The Interoperability Framework

The Interoperability Framework (Figure 1) consists of three basic dimensions (*Concerns*, *Barriers* and *Approaches*) which serve the purpose of categorizing in a more rigorous way problems and solutions for interoperability [19].

The interoperability *Barriers* are conceived as a sort of 'incompatibilities' obstructing the sharing of information and preventing from exchanging data. They can be divided into barriers of *Conceptual*, *Technological* and *Organizational* nature.

These Barriers can be found at different *Concerns* of the enterprise. At *Data* layer main scope is to connect different data models and different query languages. At *Service* viewpoint the aim is to link independent and heterogeneous applications. At *Process* level main scope is to connect various process flows, while the *Business* level refers to practices adopted by people to work in an interoperable way in the organization.

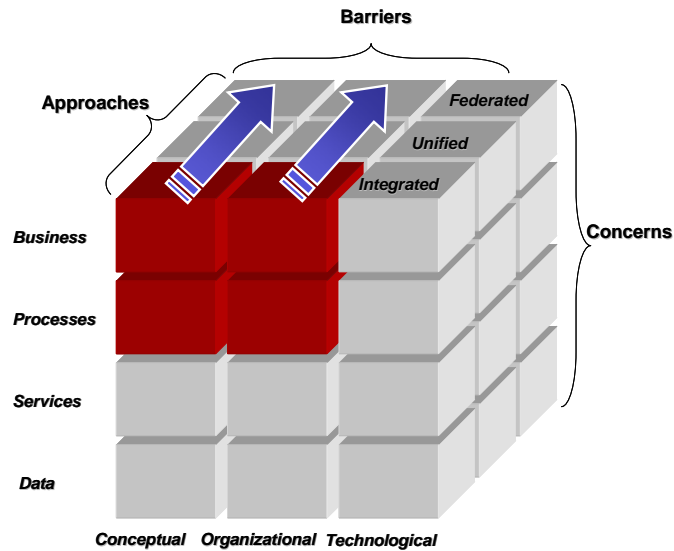
The third dimension allows categorizing knowledge and solutions (*Approaches*) able to remove the above-mentioned barriers. Following an *Integrated* approach the interoperability issues are solved adopting a common format agreed by all parties. *Unified* implies that the common format exists but only at a meta-level, while *Federated* means that partners do not impose their models, languages or methods of work and agree on a common ontology.

4.2 Principles to overcome interoperability barriers in BPR

As emerged from the interoperability analysis, the interoperability limitations in BPR are mainly concerned with *Conceptual* and *Organizational* incompatibilities (differences in language, roles and expertise) and typically refer to the *Business* and *Process* dimensions (differences in the methods of work). A literature survey has shown, moreover, that commonly adopted BPR methodologies [15, 21-26] try to overcome these barriers mainly promoting an *Integrated* approach (Figure 1). It means that the modeling tool is typically imposed by the consultants or the modeling experts, who force users, owners and programmers in communicating using a common pre-defined layout.

Only the *Federated* approach, however, can be considered relevant to develop full interoperability between two or more systems (technical or human). Partners are asked to dynamically adapt each other, without imposing a predefined language. A possible way to achieve an effective "human interoperability" is, therefore, allowing people in using a formalization they already know and not to impose exogenous models.

Figure 1 BPR interoperability problems classified into the Interoperability Framework



What the Framework suggests, as one of the main outcomes of the interoperability analysis, is to develop a common reference format just at a meta-model level and to transform the different diagrams using model mapping techniques [27].

5 Analysis and evaluation of communication tools in BPR

Basing on these outcomes, the authors propose an innovative BPR roadmap which integrates three well known modelling languages, such as IDEF [28], UML [29] and ARIS [30], together with Mock-up representations.

The roadmap is not based, therefore, on one single modeling technique, but it utilizes different representations at each step of reengineering. IDEF, UML and ARIS have been considered of special interest since they are well known also outside the boundaries of their specific domain of application, while early prototypes have been judged a good way to help user in “touching” the PLM solution before the final implementation.

5.1 Modelling perspectives in the roadmap

One way to increase interoperability between BPR participants (as suggested by the Framework) is to enhance the common understanding on current and future system requirements by representing the Use Case contextual knowledge [31].

Information (WHAT), *Execution* (HOW) and *Data* flows (DATA/OBJECTS) perspectives, in fact, give a little support to describe this Scenario information. Moving from the roadmap proposed by Cugini, Ramelli e Ruozi [32] the authors propose to enhance the stakeholders understanding of the process by adding a couple of new modeling dimensions, namely the PROCESS VISION and INTERACTIONS view. The first one aims to describe the high-level functionalities and the actors characterizing the system. The second one has the purpose of representing the information exchange between software components and people in the process.

5.2 *Languages evaluation*

As the history of enterprise modelling languages shows, IDEF, UML and ARIS come from different scientific areas, serve different purposes and represent various aspects of the enterprise processes. In order to understand which of these representations best fits each BPR step requirements, the authors has compared them on the basis of 5 different parameters, namely: *Formality extent of the modelling language, Easiness of understanding, Level of detail, Goals description* and *Process simulation*.

5.2.1 *Formality extent of the modelling language*

A modeling language is composed by a semantics and syntax which define the elements permitted in each diagram type and how they may be linked together.

IDEF diagrams, although characterized by a simple and concise syntax, suffer from semantics limitations which narrow their use in the ICT description field. IDEF0 and IDEF3, in fact, cannot be directly transformed into computer-executable models. Moreover, no effective constructs are given to model objects such as suppliers, customers and manufacturers or to describe interactions between people and teams [33-34]. UML syntax, although concisely defined and formal, does not include some basic business concepts such as control flows, cost items and organizational information [35-37]. In ARIS a number of semantics questions remains uncovered, since objects, connections and attributes are simply described in tables, a sort of tabular equivalent of a metamodel [33, 38]. Mock-ups consist of a sequence of slides, representing system interface screenshots, showing the way users can interact with the application. Therefore, their syntax and semantics is not formally defined.

5.2.2 *Easiness of understanding*

When choosing a modeling technique, process experts have to keep well in mind who will read and use these models. For instance, when different groups of people with different backgrounds are involved in a BPR step, models should be easily readable, in order to enhance communication and interoperability among the groups.

IDEF notation is simple and intuitive, and support modeling experts in the high-level description of a complex system. UML provides a complete picture of the system technical implementation aspects, which, however, may disorient newcomers and those people interested in a more concise representation. ARIS is a flexible tool which can be used both to sketch an enterprise process and to detail the system architecture. Mock-ups provide an easy and intuitive way to describe how the system will look like at the end of the implementation. Easiness of understanding is the main strength of such visual models.

5.2.3 *Level of detail*

A PLM system may be described at different detail extents, focusing on *Requirement Definition, Implementation Description* or *Design Specification* aspects.

The IDEF models, although scalable, show to be inadequate in order to describe the technical implications of a new PLM solution. The UML diagrams, on their side, mainly focus on aspects at the *ID* and *DS* level. The ARIS suite is composed by 50 different diagrams articulated on 3 different detail extents (*RD, ID* and *DS*), which can be used

either to give an abstract representation of company processes flows or to describe in detail the system technical features. Mock-ups are flat representations of the application interface which address the purpose of describing the system from a RD perspective.

5.2.4 Goals description

Sharing the high level design objectives and linking process flows descriptions with the reengineering targets may help in motivating all the BPR participants in moving towards a common goal, especially when dealing with the To-Be model development.

In IDEF, goals and constraints may be associated to activities inside the model glossary or inside the dedicated explanation extensions. In UML, objectives can be easily formalized making use of the Eriksson-Penker Business Extension [35], which gives an “IDEF0 like” representation of the business process completed with the description of goal objects. ARIS House includes an Objective Diagram containing the description of goals and a list of functions supporting their achievement. This model, however, is structured as an “object diagram” and it may difficult to link goals with activities and people in the context of BPR. A Mock-up is a powerful tool to communicate users the impact of a requirement on their “daily work” and helps developers in representing the specific purpose of each module composing the system.

5.2.5 Process simulation

A preliminary quantitative measure of the process improvements may help designers in directing the reengineering effort appropriately and in selecting the design alternative which maximizes the input/output ratio. In such a context, Activity Based Costing (ABC) techniques offer several advantages over the traditional static accounting approaches.

IDEF0 and IDEF3 supports ABC, which is usually implemented inside the language extension tools. UML, instead, lacks of specific extensions dedicated to cost-effectiveness investigations. The diagrams in the ARIS House contain a very rich list of cost attributes, which can be used to evaluate the process performances via simulation. ARIS is directly linked to a number of software components which support ABC analysis too. Mock-ups cannot be directly translated into a simulation model and do not allow to perform a quantitative evaluation of process improvements.

6 Case Study

The methodology presented in this paper has been developed and applied within the EU 6th Framework Programme VIVACE Project (Value Improvement through a Virtual Aeronautical Collaborative Enterprise) [39] to support the design and the implementation of an innovative Knowledge Enabled Engineering (KEE) system in a Virtual Enterprise environment [40].

The KEE solution technical details have been specified following top-down approach: from the high-level objectives to low-level requirements. Then the system has been built following a bottom-up approach, by aggregating low-level service instances.

The design process has foreseen three main steps. In the *Conceptual Design* stage, enterprise models have served the purpose of identifying shortcomings in the actual system and of describing a set of possible To-Be alternatives from a functional

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perspective. In the *Detailed Design* phase, models have supported experts in defining the solution from an IT perspective. In the *Pilot Design* step, process representations have been used to formalize and share the solution prototype specifications.

Table 1 BPR steps critical aspects in the KEE design

| | CONCEPT DESIGN | DETAILED DESIGN | PILOT DESIGN |
|---|--|---------------------------------------|---|
| Number of people involved in the task | High (all the potential stakeholders, modeling and IT experts) | Low (owners, IT and modeling experts) | Medium (owners, users, modeling and IT experts) |
| Volatility of requirements | High | Low | Medium |
| Number of design alternatives to evaluate | High | Medium | Medium |
| Need for creativity | High | Low | Medium |
| Impact on the final system acceptance | High | Low | Medium |
| Loss in case of rejection at this point | Low | Medium | High |

Each of these stages is characterized by different critical factors, involves people with different backgrounds and has a different impact on the final implementation success, as summarized in Table 1.

7 A Framework for the use of communication tools in PLM systems design

The results of the analysis presented in section 5 are summarized in Table 2. If a modelling language fully satisfies a specific requirement (ARIS, for instance, fully support costing operations and simulation) it is marked with (+). On the contrary, if a language suffers limitations in a specific area (Mock-ups cannot be used to simulate process flows) it is marked with (-).

Table 2 EM languages and Mock-ups evaluation

| | MOCK-UP | IDEF | UML | ARIS |
|---------------------------|---------|------|-----|------|
| Formality extent | - | = | + | = |
| Easiness of understanding | ++ | + | - | = |
| Level of detail | - | = | + | + |
| Goals description | = | = | + | = |
| Process simulation | -- | = | - | + |

The reengineering activity is characterized by several critical factors, as outlined in Table 1. On the basis of these considerations EM diagrams and Mock-ups have been correlated with the Business Process Reengineering steps (Table 3).

Table 3 Framework for the use of communication tools in BPR

| | CONCEPT DESIGN | DETAILED DESIGN | PILOT DESIGN |
|----------------|----------------------------------|--|--------------------------------------|
| PROCESS VISION | UML Use Case Diagrams & Mock-ups | UML Use Case Diagrams | UML Use Case Diagrams & Mock-ups |
| WHAT | IDEF0 | UML Eriksson-Penker Business Extension | IDEF0 |
| HOW | IDEF3 | UML Activity & Statechart Diagram | IDEF3 & ARIS ERM |
| DATA/OBJECTS | | UML Class Diagram | |
| INTERACTIONS | | UML Collaboration & Sequence Diagram | UML Collaboration & Sequence Diagram |

On one hand, *Easiness of understanding* is the most important factor in the *Conceptual Design* phase, since many people coming from different company functions and with different backgrounds are involved in BPR. Diagrams should be easily readable and representations should be a few detailed to allow an easy and quick elaboration of process alternatives. In such a context, IDEF technique seems to be the right tool to provide a brief and concise description of the process to be reengineered. The UML diagrams, in fact, lack of constructs to represent initial business and functional requirements, while ARIS seems too much focused on the economic side of BPR to be effectively used in representing the knowledge-related functionalities of the new solution. Integrating Mock-ups with enterprise models may help, moreover, in introducing a sort of *Concurrent Engineering* on the new process definition, facilitating the requirements elicitation process and pushing everyone to give inputs for further improvements.

In *Detailed Design*, process representations are mainly used by system experts in order to specify how the different solution components will be combined and work together. At this step, the number of design alternatives to be evaluated decreases significantly and the diagrams need to be formal enough to provide an unambiguous description of the system technical specifications. In such a context, UML diagrams provide a very complete and unambiguous view of the company processes, particularly focused on the IT aspects [34].

The *Pilot Design* activity typically involves all the potential system stakeholders. In such a situation, the graphical notation is requested to be simple and easily understandable also without a technical background, while containing, at the same time, specific constructs to support gap analysis and costing operations. ARIS and UML diagrams may be used as a complement to the traditional IDEF0 representations, while the use of Mock-ups may enhance users and owners involvement in the definition of the Pilot testing environment from initial requirements.

8 Conclusions and open issues

The main aim of this paper is to contribute in leveraging the rate of success of BPR in a Virtual Enterprise environment by proposing a framework supporting PLM system designers in selecting the best communication tool to be used in each phase of

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reengineering. The main purpose is to enhance people interoperability in design, by proposing a set of guidelines for the use of process modelling languages when dealing with the definition of PLM system specifications.

The framework described in the previous section has been successfully applied within the Project VIVACE. In the initial design stage, Use Case Scenarios have been described making use of UML Use Case Diagrams together with IDEF0 representations [40]. UML models have been then adopted in the Detailed Design phase to represent the KEE system architecture with a higher level of detail. Finally, IDEF models and Pilot Mock-ups have been used to support knowledge elicitation, formalization and sharing dealing with the specification of Pilot features [41].

Final output of this BPR activity is a Context-Based application, named Knowledge-Enabled Solution Platform (KESP) [42], for the in-context delivery of applicable knowledge to engineers working in aerospace companies. The system prototype has been tested inside one of the partner design environment, and the results of piloting activity showed to meet the initial objectives of reengineering [43].

The application of the methodology in a real industrial case study showed, therefore, to be successful in removing interoperability barriers and in delivering a solution able to satisfy, in most part, initial user requirements. It proved to enhance communication and mutual interaction between stakeholders upon specifications really representing starting needs in an unambiguous, consistent, and complete manner.

In order to facilitate the adoption of such an approach, the authors are investigating the possibility to semi-automate the horizontal transformation between models by establishing a link at a meta-model level between the source and the target representations. IDEF, UML and ARIS, however, are very different in terms of syntax and semantic and a one-to-one mapping between objects in the models is often not allowed. Techniques coming from the ontology domain, such as merging, refinement or alignment are interesting to be explored to cope with this problem. Within the INTEROP NoE, moreover, a specific tool for model mapping, the Atlas Transformation Language [44], has been experimented to transform UML into GRAI models. Further researches will verify the possibility to adopt such tool in the IDEF and ARIS domain.

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