INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

DESIGN 2004

APPLICATION AND EVALUATION OF A METHODOLOGY FOR CANDIDATE TECHNOLOGY SELECTION IMPROVING PRODUCT DESIGN PROCESSES

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Keywords: engineering knowledge management, product design process

1. Introduction

In order to be competitive in modern and growing markets, companies have to improve their production processes (shorter *time to market* and minor *product costs*) and reach increasingly higher quality standards. To this aim, PLM solutions propose methodologies and tools that support a more closely integrated management of product lifecycle engineering activities with process planning and manufacturing aspects. Within this broader view of product development and integration of its various aspects, Engineering Knowledge Management (EKM) has proved to be a key strategy, able to reduce lifecycle costs and time, improving quality and helping to ensure safe products [Cugini 2002]. *EKM* technology improves product design processes since it allows integrating design rules and process knowledge with product data, creating automatic product configuration, choosing and dimensioning the most suitable components from databases, in which it is possible to store also rules and procedures. Databases can be shared and understood by different users belonging to several company's departments, and can be used in several design contexts. Geometric models can be automatically analyzed and modified in real time.

In this context, we have applied and evaluated a methodology for candidate technology selection improving product design processes. This methodology aims at supplying engineering teams with methods to identify knowledge lacks in the product development cycle and criteria for selecting the most suitable tools for overcoming such knowledge lacks. As a validation of our approach, in this paper we present, as a test case, the design process of a changing-tools group that is part of a numeric control machine tool, designed and manufactured by an Italian company. We have firstly analyzed the actual design process (*As-Is* modelling) also measuring some indicators like activity times and risks. Then, we have identified the most appropriate *EKM* technology by re-formulating the process models and considering the selected *KBE* technology (*To-Be* modelling).

The resulting To-Be models have also been implemented. Then the indicators have been measured and compared to the ones of the original process. The paper is organized as follows. Section 2 presents the methodology developed for the selection and the evaluation of the efficiency of PLM tools in product development processes. Section 3 and 4 describe the case study developed for validating and tuning the methodology. Finally analysis of the results is presented in Section 5.

2. The methodology

Two issues have to be considered for the adoption of new EKM methods and tools within the product lifecycle: 1) how to select appropriate and effective methods and tools; and 2) how to estimate benefits and impacts before adopting and/or integrating those methods and tools. The first issue is related to the identification of the best technology that meets the requirements for the improvement of a specific product development process. The second issue deals with the critical aspect related to the estimation of the benefits derived from the possible adoption of the new technological solutions identified, before actually making investments and changes within the company organization.

The IKE research project (www.kaemart.it/ike) has studied a Roadmap proposing a sequence of activities aiming at supporting companies in providing answers to the issues defined above [Bordegoni 2003]. The various steps of the roadmap are shown in Figure 1.

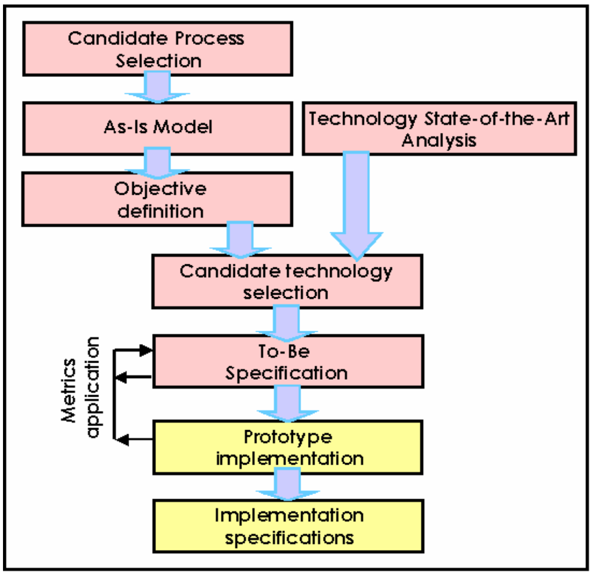

Figure 1. Roadmap

In order to *select the most appropriate methods and tools* (Issue 1) the following activities are planned by the Roadmap: Modelling of the product development process, selected as candidate process, as it is currently implemented in a company (As-Is process modelling); Identification of critical issues related to EKM, to point on the necessity for improvements; Analysis of current and emerging technologies for knowledge and innovation management; Definition of a method supporting the selection of the most appropriate technologies to be adopted and integrated within the actual product development process.

Furthermore, in order to evaluate the benefits, the impacts and costs related to the adoption of new and innovative solutions (Issue 2) the following activities have been performed: Definition of a To-Be model of the product development process integrating the selected solutions; Definition of an evaluation metric; Application of the metrics to the As-Is process model, to the To-Be process model, and their comparison.

The methodology developed for candidate technology selection is based on the well-known Quality Function Deployment method [QFD]. Basically, the method starts by considering the results of the analysis of a product development process and the related critical aspects, and from the analysis of the state of the art of current and emerging technologies. The results of these analyses are reported in the following two matrices:

Matrix 1 reports the importance of knowledge management activities with respect to the product development process activities.

Matrix 3 reports the relevance of specific technology with respect to a set of functionalities related to knowledge management.

In order to select the candidate technology that at best meets the requirements for improving the considered product development process, *Matrix 3* should take into account information coming from the product development process analysis, and therefore from data included in *Matrix 1*.

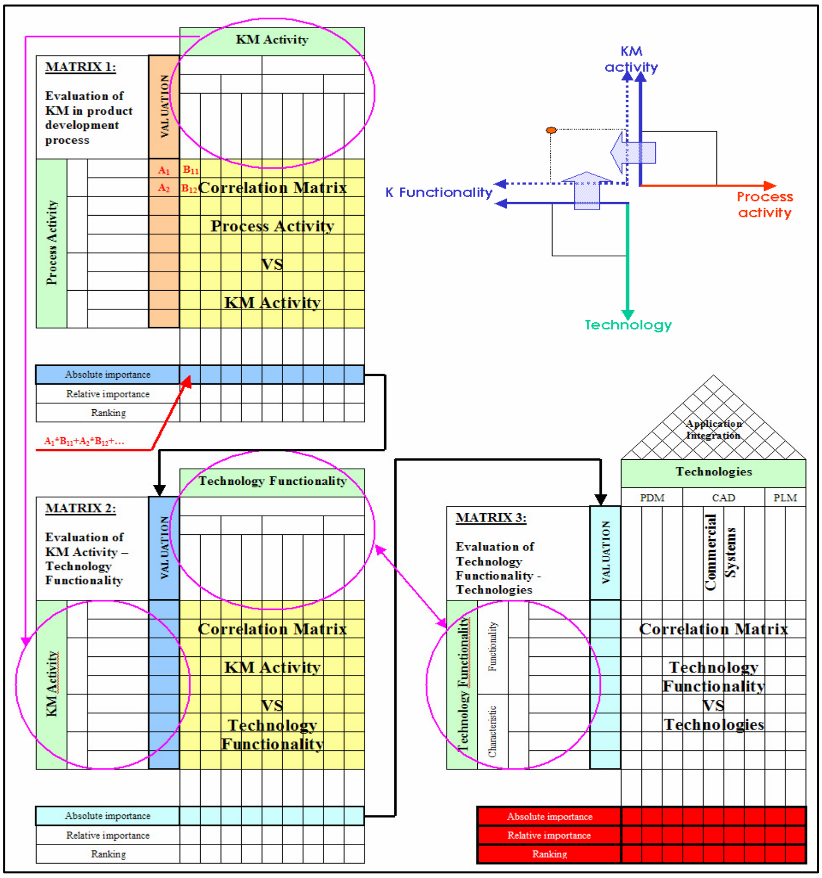

Figure 2. Method for candidate technology selection

A correlation matrix, named *Matrix 2,* is filled in by process experts together with technology experts, and reports *EKM* activities along the rows and technology functionalities along the columns. *Matrix 2* shows the importance of K-functionality of technology related to a specific process. For each K-functionality we sum up the values measuring its relevance with respect to all EKM activities (weighted with respect to a specific process) and, therefore, we obtain a ranking of the technology functionalities. Figure 2 shows the selection process.

3. Study case selection and modelling

In order to test our technology selection methodology, we have applied it to an industrial design process, in collaboration with an Italian company that designs and produces 3/5-axes operating machines and automated milling systems for the aerospace, car industry, general mechanical and energy sectors.

According the methodology, the candidate process is the design process of the tool-changer of a machine tool. In accordance with customers' requirements, designers define a general layout that, once approved, is further detailed, covering four macro design activities: *Standard Groups Design*, including standard components design and their resizing to be applied to several orders, stored in unique archives; *Offer Definition*, including the definition of layout and offer for customer; *Machine Design*, including new components detailed design activity; *Standard/Specific Groups Processes Design*, including the definition of the production process and documents creation. The design process of the changing group has been analysed and modelled with IDEF0 diagrams [FIPA 1993]. The analysis of the current process highlights it has some deficiencies, and that it might be improved. For example, activities related to the modification of previous designs should be made more efficient;

design practices within the company should be collected, formalized, and made available to the all design team; design knowledge should be managed in more efficient mode, providing reliable and simple way for information retrieval and re-use; the risk of errors and requests of validation should be minimized along the entire development process. Furthermore, design errors due to inexperienced designer should be minimized.

4. Application of the methodology

4.1 Candidate technology selection

In order to select the candidate technology, we have applied the developed methodology described in Section 2. Basically, it identifies KM activities within the design process that have to be improved. These are related to a set of functionalities that the technologies are expected to provide. We have implemented a method that provides a list of available EKM applications satisfying the design process requirements and KM functionalities in a semi-automatic way. The application of the methodology to our case study has indicated RuleStream by RuleStream Corporation [RS] as one of the most appropriate technological solutions. RuleStream is an EKM framework that supports designers in defining and formalizing design rules formalized by the designer. RuleStream generates a Visual Basic code interacting with a 3D-modeller (in our application, with Solid Works by Dassault Systèmes). One of the most interesting features of RuleStream is the fact that, differently from most of KBE applications, the framework keeps separated K data and the 3D modeller.

4.2 To-Be model of new process adopting selected EKM technology

Before effectively using the selected RuleStream technology within the design process, we have re-defined the tool-changing group design process models (To-Be models, that provide information of the performances of the new process) including the use of RuleStream system for the design activities. In the new design process we can distinguish two kinds of designers: *Junior* and *Senior* users. The former are guided by the design system to the final product configuration following well-defined procedures. The latter, beyond following Junior's activities, manage information and rules and define the procedures that have to be followed during the design.

In the new process *TO-BE* models we can recognize five macro-activities: *Group Model Selection*, where both kinds of designers can choose an existing geometric model or create another new one (last activity is only for Senior Designer); *Group Model Defining*, where Senior defines design rules; *Group Defining*, where designers can configure products following design procedures already defined; *Model Checking*, where design are submitted by supervisors' reviews; *Documents Generation*, where documents useful for the production, user manuals and final product documentations are produced.

More information about *TO-BE* models is described in following Section together details about with testing phase.

4.3 Implementation of To-Be process

We have proceeded to implement and test the TO-BE process. To this aim, we have played Senior and Junior's roles by simulating new product design and product configuration. First, we have re-modelled existing changing-tools-group 3D parts and we have created the first design rules as a starting point. Then, we simulated two significant cases. In the former, we implemented the *Existing Geometric Model Configuration* case. In this case, we have been able to use only Junior's participation. We have collected information about original customer's requirements and have repeated the existing design experience using RuleStream. We have obtained existing changing-tools group configuration in a short time significantly less than the previous one. In the latter, we have implemented the *New Changing-Tools Group Design* case, using Junior and Senior's activities. In this case, after having simulated twice new customer's requirements to need to create two new configurations, we have modelled new components, new rules and new design procedures, according to Senior's activities. Then, following a new user interface created by the Senior user, we have configured two new products similarly to the previous case. The new geometric models created can be interfaced with a lot of tools, machines tools and tools warehouses. In particular, we have obtained two configurations that can be used in only vertical or horizontal axes directions. Layout definition, obstacle checking and components sizing are automatically made by RuleStream.

4.4 Measuring the considered indicators

To evaluate current and new design application in terms of performances and deficiencies, we have quantified some indicators chosen in accordance with interviews held in company: Process activities' *Time* and *error Risks*. *Time* is evaluated by considering the average time dedicated to each product development activity. The *Risks* indicator is evaluated by considering the following types of errors: use of incomplete and obsolete information; design loops; unevenness calculation methodology application; strong dependencies on connection to other people's availability; delays in information research.

5. Analysis of the results

During the testing phase, we have collected data about the process implementation (i.e. TO-BE models simulation). Specifically, we have collected data about activities development time and errors frequency. Subsequently, we have compared these values with the existing ones collected by company's designers. In Figure 3 and 4, Time and Risk analysis graphs are shown.
We can observe in the diagrams a strong decrement both in the time values (i.e.: Detailed Design, Preliminary Analysis and Detailed Development, where decreasing values reach 50% in some cases), and risk value (represented as area under best fitting curves of frequency and gravity errors) in many activities. In the Error Analysis graph, gravity and frequency values related to each error are represented as dots, and the best fitting functions are calculated interpolating the discrete points. Gravity and frequency evaluation is qualitatively specified with values from 0 to 5 (0 = harmless or non-existent, 5 = very serious or frequently).

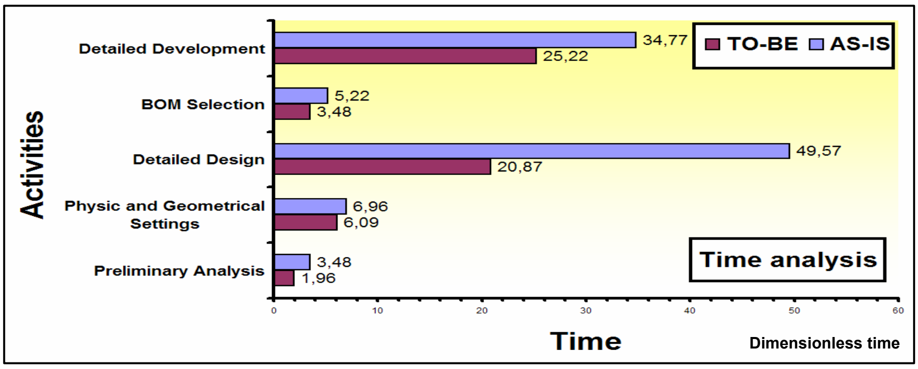

Figure 3. Time analysis graph

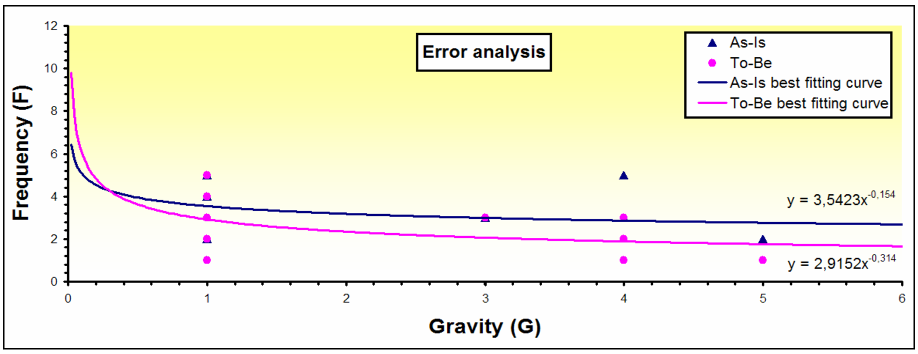

Figure 4. Risk analysis graph

We can note, from the observation of the two interpolated functions, that in the TO-BE case the error gravity values return lower frequency values than in the AS-IS case. That is, in general, every error in

TO-BE models is in general less recurrent and serious than in the AS-IS ones. Regarding this, it is important to notice that the difference between the subtended area values (describing the error risk) of the two resulting curves is negative when considered before the intersection point and it is positive after. Besides, the positive area is much bigger than the negative one: therefore, the resulting sum is positive, which means lower error risk values in new design processes.
Furthermore, taking into consideration the design process, we introduced well-defined roles and rules, improving its efficiency.

6. Conclusions

The paper presents the application of a methodology for evaluating the adoption of PLM tools in product development processes. The research work has developed a roadmap consisting of a sequence of activities for the evaluation of the impacts and costs related to the adoption of new and innovative technologies for knowledge and innovation management, within currently implemented companies' product development processes. A method, based on the Quality Function Deployment method, has been set up for the identification of technological solutions that may improve the performances of the process. The effectiveness of the roadmap and the methodology for the candidate technology selection has been demonstrated through the implementation of a study case related to machine tools.
In accordance with the developed Road Map, we first have modelled and analysed the product development process (AS-IS process modelling) and we have identified some critical issues. Then, after an analysis of current EKM technologies, we have applied our technology selection method to choose the most appropriate solution. We have defined TO-BE models considering new technology introduction and we have defined a metric to evaluate and compare AS-IS and TO-BE processes efficiencies, through some indicators selection. Finally, we have implemented the TO-BE process and have compared with the AS-IS models, testing application and collecting indicators values.
Form the study case we can conclude that use of an EKM technology, in particular a KBE technology, can improve a complex design process. Furthermore, the use of our technology selection methodology can help to choose the most appropriate technology, reducing times and errors and also well-defining designers' roles and design rules.

Acknowledgements

The authors would like to thank M. Ugolotti from Politecnico di Milano, G. Cascini, M. Cambi and D. Russo from Università di Firenze, S. Filippi from Università di Udine, F. Mandorli from Università Politecnica delle Marche and Marzia Fontana from Università di Parma for their contributions to the research and to the realization of this paper. Special thanks are dedicated also to Dr. Schiavi and Mr. Caminati from JOBS for their support on test cases implementation.

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