The Role of Knowledge Based Engineering in Product Configuration

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Abstract Digital design and manufacturing are critical drivers of competitiveness but only few companies and organizations have the capability to support digitalization across the whole Product Lifecycle. In several cases the information flow is discontinuous, the roles and the issues are not properly defined, the tools are heterogeneous and not integrated in the company organization. An approach that considers an appropriate data and information organization, an efficient internal organization and the availability of integrated software tools that are implementing the industrial best practices, could innovate important and critical aspect of the industrial processes. This paper gives an overview of the main themes related to Knowledge Management in industrial context, focusing on product configuration process. The current role of the knowledge in product configuration will be discussed. Then, a brief overview on Knowledge-based Engineering will be presented. Regarding Knowledge Based methodology, acquisition and formalization techniques and tools will be analyzed. Finally, an application focused on assembly lines configuration will be presented.

Keywords: Product Configuration, Automatic Configuration Process, Knowledge Based Engineering, Knowledge Formalization

1 Introduction

"Creating a knowledge society in Europe is a necessity if we want to remain competitive in the global economy and sustain our prosperity… If we want to sustain our European way of life, and we want to do so in an environmentally-responsible way, we will have to engineer a paradigm shift so that we gradually move from the resource-based, post 2nd World War economy to a knowledge-based economy." Janez Potočnik, former Commissioner for Research, Science and Innovation of the European Union, said these words at the Conference on Structural Funds at Warsaw (13 February 2006). They assume today more significance after the financial and economic crisis. Skills and knowledge developed during the last century are essential resources of the industrial companies: this "heritage" plays a strategic role with respect to the production capabilities of the emerging countries, limiting the effects due to the high competitiveness in terms of production of these countries in the global market. It is fundamental to maintain, consolidate and improve this know-how, using proper methodologies and tools to work better and faster. From this point of view, the information management techniques can provide powerful methodologies and tools to realize computer applications able to assist the human experts to carry out fundamental activities for the companies, such as the product configuration and costs estimation. This paper gives an overview of the main themes related to knowledge management in industrial context, focusing on product configuration process. The current role of the knowledge in product configuration will be discussed. Then, a brief overview on Design Automation methods, focusing on Knowledge-based Engineering, will be presented. Regarding Knowledge Based methodology, acquisition and formalization techniques and tools will be analyzed. Finally, an application related to assembly lines configuration will be presented.

2 Product Configuration

The product configuration can be defined as a special design activity that given a set of customer requirements and a product family description, the configuration task is to find a valid and completely specified product structure among all alternatives that a generic structure describes [1].

Sabin and Weigel [2] state that the product configuration process consists in providing a complete description of a product variant according to customer's requirements. A configurator is a system that perform this process: it should allow a designer to engineer a product satisfying to customer's requirements and standards of the specific domain, even if the required product has been not yet developed in the past. Today, the development of product configurators is still an open issue for the scientific community [3].

One of the issues of the paper is the knowledge required when an expert performs complex industrial activities like the product configuration and how it can be represented in a computer system to assist or replace humans in certain situations. In that case is possible to define the "knowledge" as the necessary set of contents and cognitive processes elaborating solution that satisfies specific initial requirements. Modeling those contents and processes is an open challenge in computer science, which contributed to the development of the Artificial Intelligence. The modern computer techniques are perfectly suitable for the management of enormous quantities of data and information, but they are still less adequate to represent cognitive activities. The "expert" is the main actor of the product configuration process; he or she usually owns "general knowledge and skills", for example communication skills and capability to understand documents of different types. Moreover, he or she has a lot of technical-scientific experiences and a specific industrial know-how related to products and processes as described by [4]. The product knowledge concerns the architecture of the product itself: it is inferable at high level from the assembly representation and/or BOM. The process knowledge concerns the sequence of the activities necessary in our case to configure a product, with the definition of the inputs and outputs, resources, tools, controls and responsibilities of each activity. The product configuration integrates the execution of some complex activities (e.g. the choice of a part, customer requirements analysis, selection of existing parts, evaluation of different accessories, …) and detailed elaboration of the product architecture. Now, in some industrial contexts (for example, companies producing components for power transmissions, oil and gas plants, industrial fans, manufacturing and assembling plants) the role of product configuration is crucial for the competitiveness. To improve this activity is crucial to acquire and formalize knowledge, mainly the tacit one (i.e., the knowledge stored in the experts' brain), define the "best practices", develop tools to aid expert or automate the process and to avoid loss of knowledge and know-how. In the next section, methods for the acquisition and formalization of the knowledge will be discussed with the objective of save and transfer knowledge.

Traditional solutions to face the product configuration are not able to ensure the current need of the companies. KBE (Knowledge Based Engineering) systems can profitably help to solve this problem both from a commercial and technical point of view simplifying and automating, at least partially, the process configuration [5].

3 Knowledge Based Engineering

Among the objectives of the industrial organizations, a dynamic and active management of the technical knowledge plays a relevant role. The availability of intelligent systems able to assist and replace the human experts, suggesting the best reliable solutions is a strategic aspect of primary importance for the success of the company. In this view, in the last decades several research activities have been conducted in order to develop intelligent systems focused on different activities in the product lifecycle development process. The IT methodologies and tools used for this purposes are coming from the domain of Artificial Intelligence, CAD/PLM, and mathematics. Expert systems, agents, parametric models coupled with other programming languages, graphs and several others techniques have been used for the realization of prototypes able to manage some of the tasks done by human experts during the product lifecycle, from the conceptual design to the production, post-assistance and maintenance. One of the most relevant contribute in this field is provided by Knowledge Based Engineering (KBE). It is a methodological approach and a category of tools for the development of applications originated by the Object-Oriented methodology, focusing on an abstract model of product and components. UML class diagram presented in the last section are object oriented models. KBE is a system based on object-oriented tools, finalized to the modeling and representation of the knowledge of a specific domain. In literature, different definitions of KBE are reported. An appropriate one is “computerized system that uses the knowledge about a determined domain to find the solution of a problem in the same domain. The solution is the same reachable by an expert in the same domain” [6]. It is important to highlight the difference between KBE applications and tools; application is a software system developed to solve a specific design problem, for example automatically design a specific machine family. Currently, the authors are applying this methodology to the domain of product configuration and cost estimation, where are more important the needs of “work better and faster”, limiting costs and time of the process.

4 Acquisition and Formalization of the Knowledge

The development of a KBE software for product configuration needs the acquisition, formalization and representation of the knowledge used by a human expert. The key players in acquisition and formalization are the experts of the product and process and not the IT technicians. This statement is very important because the focus will be on description and consolidation of the company best practices, rather than methods and applications.

As stated before, an organization often doesn’t manage the knowledge in optimal way: it is usually orally transmitted and sometimes not shared. During the acquisition step the knowledge is gathered and organized, enabling the reuse for future activities. The acquisition requires documents arrangements (e.g. book parts, manuals, scientific and technical publications, norms, catalogues, drawings, CAD models, notes and sketches): this concerns the explicit knowledge. The acquisition of the tacit knowledge is more complex; it requires interviews of experts that explores strategic and not formalized aspects. For these reasons, it is important to find ways and languages to extract more efficiently the information from the experts. The knowledge engineer is an emerging professional figure, able to operate in these practices. The knowledge has to be acquired from all the experts, from the highest levels, regarding the sequence of certain activities, to the details regarding specific technical choices. The results of these activities must be expressed in documents. Techniques, such as the mind maps, facilitate the digital storage of all acquired documents [7].

Knowledge Management by means of documents, in traditional or digital format, is a “static” type of management. This one often requires direct intervention of experts for the research of the proper information, acquisition and application to the specific case. Computer techniques allows the management of the knowledge to be done in a “dynamic” way. In that case a software tool searches the solution, which is proposed to the expert (assisted design) or directly implemented (Automatic Configuration). The development of an application with such characteristics is based on a proper representation of the knowledge with computer techniques. In fact, from the state of the art [8, 9], it is reasonable to consider applications for automatic configuration limited to specific products, or product families, not to the development of whatever product.

The development of a software application for assisted or automatic configuration requires the representation of information and knowledge with proper IT tools [10]. The contents of the technical documents need to be translated in order to be implemented easily by means of a computer. The natural language is not an efficient tool to reuse and share technical information and knowledge. Hence, the translation, using proper languages, is needed; this procedure is called “formalization”. Different languages, mostly graphical, have been developed by several researchers; for example, the flow chart for the documentation of algorithms.

The experiences of the authors in the field of Design Automation led to consider two main graphical languages for the formalization of process and product knowledge. The formalization of product architecture could be done by using the “Class Diagram” of the Unified Modeling Language (UML) [11]. The concept of class is used to represent an elementary component (e.g. a screw) rather than a complex one (e.g. an engine). The attributes correspond to the parameters of the component (e.g. the type, the diameter and the length of the screw or the number of cylinders and valves for the engine). The methods permit to execute operations using previous parameters (e.g. computation of engine power).
The modelling of product configuration process is usually performed by IDEF0 diagram (http://www.idef.com). All the activities involved in the configuration process are represented in a hierarchical structure of layers, from the top general level to the most detailed one. The IDEF0 diagrams are easily understandable; this characteristic makes it a good tool for the sharing and the diffusion of information among experts of different background (for example experts in product development or software developers).

The theme of the acquisition and formalization of the knowledge in the industrial organizations and in technical domains is complex and articulated and would need a deep study. Actually, activities in this research field are focused on other interesting approaches, especially ontologies.

5 Application of KBE to the product configuration

A meaningful example of KBE in product configuration and quotation is presented in this section. Several manufacturing companies are producing several standard products, combining part families, like in the case of power transmissions (joints, gearboxes, etc.). Other companies are producing and selling using the approach of the Engineering to Order (ETO), for example producers of manufacturing systems and machine tools. Both these situations require the product configuration, followed by the definition of the economical offer for the customer. Configuration and quotation are complex activities, that today use computer systems for the direct interaction with the customer (like web sites with digital catalogues). The process from the request for quotation to the order confirmation is one of the strategic processes for the industrial competitiveness and its efficiency. In several cases the information flow is not continuous, roles and the issues are not properly defined, the tools are heterogeneous and not integrated. An approach that considers an appropriate data and information model, an efficient internal organization and the availability of integrated software tools that are implementing the industrial best practices, could innovate this important and critical aspect of the industrial processes.

The case study was proposed by an important industrial partner and we are developing a software prototype based on KBE approach and tools. The application deals with the automatic configuration of assembly lines for automotive domain.

Figure 1 shows the information flows and the general structure of the configurator. The information contained in the request for quotation are the input of the application. They are processed by “Customer Requirement Processing” module. Thanks to a set of rules, the application selects all the options relatively to the regional characteristics: they are related to both the customer (e.g. local supplier)

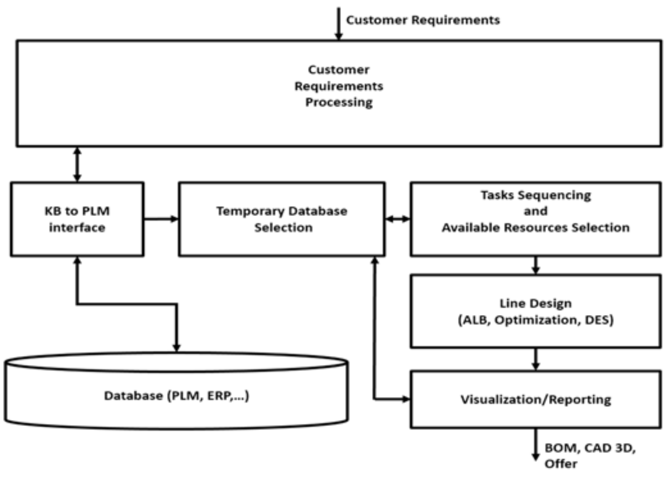

Fig. 1 Information flows involved in KBE configurator

and the country in which the assembly line is going to be installed (e.g. safety standards, electric energy frequency and voltage, and so on). Furthermore, the type of product being assembled (e.g. a cylinder head) drives the list of tasks (not ordered) that have to be performed to obtain the final product. Then, the “KBE to PLM interface” module extracts a subset of information stored in the company databases (i.e. PLM) useful to the product configuration. A set of rules allows the “Tasks Sequencing and Available Resources Selection” module to aggregate the resources able to perform the specific assembly task (e.g. it defines a workstation with the selection of robot, end effector, control equipment, and so on). The result is a matrix in which the rows are the tasks (not yet ordered) and the columns are the resource (i.e. aggregation of parts). Then, the application executes the tasks sequencing (i.e. the list of tasks is new ordered) and Assembly Line Balancing (ALB) (i.e. it assigns a unique resource to a single process taking into account technological constraint) depending on required throughput, sizing eventual inter operational buffers. During this stage, a multi-criteria optimization could be performed to achieve an optimal design and a Discrete Event Simulation (DES) validates the results. Finally, the “Visualization/Reporting” module generates the BOM of the machines and equipment, producing also 3D CAD models (Figure 2) of the plant, 2D drawings and, finally, it performs the costs assessment.

The application may represent an interesting example of the potential connected to the development of intelligent application in a complex industrial process that integrates different functions [12]. The application is still under development.

6 Conclusions

This paper gives an overview of the main themes related to knowledge management in industrial context, focusing on product configuration process. As said before, there is the need to engineer a paradigm shift from resource-based to knowledge-based companies. A brief analysis of the main concepts of Knowledge Based Engineering has been discussed: two fundamental aspects of Knowledge Management that are acquisition and formalization have been analyzed. Then, the main relevant issues related to the integration of “Intelligent” application with the company infrastructure and the knowledge sharing have been argued. The devel-

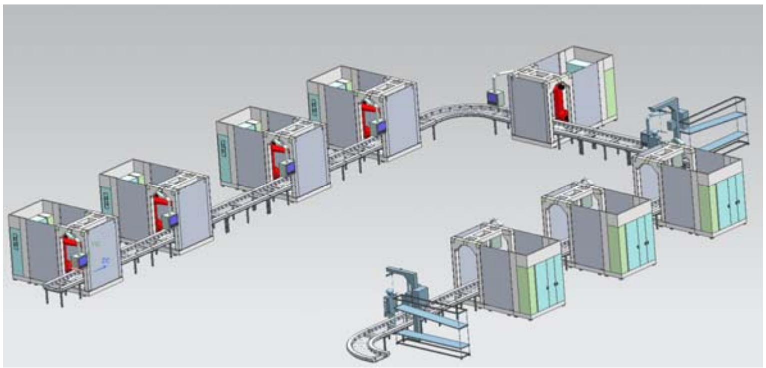

Fig. 2 Example of 3D model automatically created by the KBE application.

opment of an application that allows the configuration of assembly lines to be performed automatically proves the suitability of the KBE approach and proposes a generic framework to foster knowledge sharing across different function of the companies. Furthermore, this approach encourages the “first time right” solution which leads to cost and lead-time reduction.

A relatively new approach for distributed and cooperating knowledge-based engineering systems is based on ontologies. Ontology based tools allow people or software agents to share common understanding of the structure of information, make domain assumptions explicit as well as intelligent search and retrieval in internet.

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