Computers in Industry 61 (2010) 15–28

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

ADVICE: A virtual environment for Engineering Change Management

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ARTICLE INFO

Article history:
Received 15 October 2007
Received in revised form 5 November 2008
Accepted 19 May 2009
Available online 9 July 2009

Keywords:
Engineering Change Management
Change Propagation
Sequential Pattern Mining
Virtual Reality
Virtual Collaborative Design Environments

ABSTRACT

In this paper, we analyze Engineering Changes (EC), which are modifications in forms, fits, functions, materials, or dimensions in components constituting the design. We propose a new approach for processing these changes within a Virtual Collaborative Design Environment. This environment, named Active Distributed Virtual Change Environment (ADVICE) offers an Engineering Change Management solution by merging graphical and parametric data involved in the process into a virtual platform, which improves the comprehension of users and hence decreases the time required for review. ADVICE provides smart user support for predicting Engineering Changes to be triggered due to a specific change and for offering priorities to Engineering Change Requests. This is managed by employing Sequential Pattern Mining techniques to process captured Engineering Change history with Prioritization and Change Propagation mechanisms. For verifying these mechanisms, experiments involving synthetic data are conducted. The experiments present the capability of ADVICE to facilitate Engineering Change Management.

1. Introduction

In today's highly competitive environment, companies consider the effectiveness of design process as their primary concern for survival. In order to ensure the conformity to customer requirements and decrease the possibility of contradictions, it is a common practice to provide early involvement of functional departments such as production, quality, planning or purchasing into the design process. Today, the involvement of customers and suppliers in the product development stage is essential in order to design more complete products at the first attempt. Concurrent engineering, supply chain management and make-to-order are philosophies and/or techniques that ensure/require the cooperation among departments, customers and the suppliers [1,2]. However, the globalization of the business world can result in the geographical dispersion of parties involved in design. Companies outsourcing and expanding their operations over various locations need a medium for assuring effective communication amongst team members. Not only the ideas are shared through collaborators, but also the tasks such as Engineering Changes (ECs) are handled in the same fashion. This issue, bringing together the needs of the business world with novelties offered by research, resulted in the utilization of the emerging technology, Virtual Reality (VR), for supporting collaborative work, which is referred to as "Virtual Collaborative Design Environments" [3,4].

There are applications in literature utilizing Virtual Collaborative Design Environments (VCDE) for supporting conceptual and embodiment design that occur in the development stage of the life-cycle of a product before a design is released for production [3,5,6]. However, design is not restricted to the development stage. A product's configuration can go through changes to improve and refine the design continually throughout the life-cycle of a product. These changes, which are defined as modifications in form, fit, function, materials or dimensions in design parameters, constituting the design, are referred to as Engineering Changes [2]. This paper focuses on the Engineering Change Management (ECM), which is the process of organizing, controlling and managing the workflow and information flow for ECs. The ECM process involves three main phases: Request, Approval, and Notification and Execution.

- In the Engineering Change Request (ECR) phase, the need for a change emerges and is placed in an ECM system by an initiator. The initiator may be a department or an engineering team member concerned with the design parameters who believes there is room for improvement [2]. An ECR contains information about: which component to change; which attributes to change; the reason for the change; and an attached technical drawing representing the change.
- In the approval phase, a team, sometimes referred to as Engineering Change Board (ECB), involving members from various functional departments, must review and accept the

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doi:10.1016/j.compind.2009.05.008

change. This phase also includes the identification of components that are affected by a change, and resolving the propagated changes accordingly; thus change propagation is one of the most critical sub-processes involved in an ECM cycle.
- After the request for change is approved by all ECB members, the coordinator determines the departments to be informed and distributes an Engineering Change Notification (ECN) involving textual and graphical information regarding the change for execution.

In the literature, the ECM process is recognized as one of the complicated and problematic processes in an organization [7]. It is reported that ECs consume one-third to one-half of the engineering capacity [7,8]. Moreover, despite the capacity devoted to the process, the value-added time in the ECM is as low as 8.5%, which implies that an ECR spends most of its life-time for further processing [9]. Major difficulties involved in the ECM process may be summarized as follows:

- The complex and multidimensional nature of the ECM process requires investigating interactions and consequences of the EC in a diligent manner, and the contribution of various decision makers in the ECB for reviewing and authorizing the change.
- Some of these decision makers are non-technical staffs who have difficulty in comprehending complicated technical drawings defining the change, which creates important errors and negligence.
- The review and authorization process is time-consuming even for technical people, as ECs involve both parametric (numerical and relational) information and graphical information (technical drawing of the change) that should be communicated simultaneously throughout the ECM process, resulting in the duplication of tasks [10].
- During the review, the decision makers have to identify and handle the other ECs which are triggered by the initial ECR; this is referred to as Change Propagation. Change propagation analysis is difficult to accomplish and results in the prolongation of the cycle time for an EC.
- As cycle times get longer, the number of simultaneous changes increases and a mechanism for coordinating and prioritizing these changes is required. Prioritization involves consideration of many aspects and is not a straightforward process.
- History may repeat itself: an ECR, already analyzed and concluded in the past, may arise again without realising the existence of the previous one. This is possible in two cases: (i) different product families; (ii) a rejected ECR. In both cases, the knowledge of the past experiences would save valuable engineering time.

For providing a solution to the problems stated above, we propose an intelligent approach (requiring knowledge acquisition and management) for modeling an ECM process within a Virtual Collaborative Design Environment, incorporating Sequential Pattern Mining techniques for offering user support. The primary purpose is to improve the ECM process by providing both textual and graphical information. In this way, we provide a tool for users, which assures a fast and accurate comprehension of the change [11], aids organizing and accelerating the process, and offers intelligent assistance by utilizing the history of similar changes to form a knowledge-based mechanism to direct and manage the process itself. With the use of such a tool, we can avoid overlooking the fit and aptness with other elements and decrease the cycle time of the EC. The proposed ECM system, embedded in a distributed VCDE, provides a shared, real-time, simulated 3D representation of EC and data mining mechanisms for predicting change propagation and determining the priority for change requests. The provided information enables decision makers to analyze the product families that may be affected by the requested change promptly, accurately and on time.

The proposed ECM solution is based on the past experiences. The existence of similar ECRs and storage of their detailed analysis in databases are required in order for ADVICE to provide accurate "advice"s for the decision makers. For the cases where no similar past experience is available, companies still need to look into the functional dependencies of system components and use expert opinions. On the other hand, as Stojanovic and Stojanovic [12] highlighted, saving 10 min of engineering time via faster access to the information could easily save $100 million per year in a large engineering firm. The ADVICE is modeled to access the complex EC data and retrieve the knowledge (Prioritization and Change Propagation) that, otherwise, engineers would spend noteworthy time and effort to retrieve (and at the end they might still not be able to reach the knowledge with the same accuracy).

The remainder of this paper is organized as follows. Section 2 provides a brief summary of related work. Section 3 describes the proposed environment, ADVICE, and discusses the smart data mining mechanisms employed by ADVICE. Section 4 involves experiments conducted in order to validate the use of Sequential Pattern Mining algorithms. Section 5 summarizes conclusions and potential enhancements.

2. Related work

Our literature survey is focused on three key areas: Engineering Change Management, Virtual Collaborative Design Environments and Sequential Pattern Mining algorithms.

Most of the work on the ECM concept involves survey research and industrial case studies. Survey studies emphasize the significance of improving the ECM process and attempt to identify the problems associated with changes ([13,14]; Tavčar and Duhovnik [7]). In his survey paper, Wright [15] summarizes the ECM case studies specific to large system integration design, discrete electronic circuit design and naval vessel design problems. Other case studies include a climate control system design [16] and military aircraft design [17]. A more generalized tool for processing ECs is offered by Huang et al. [18] based on relational database queries using SQL offering web forms for processing the EC.

The literature on the change propagation mainly focuses on the identification of functional dependencies. These studies either attempt to build synthetic models of product information or focus on describing the relationship between system components in qualitative or quantitative forms [33]. Once the system components and their relationships are well defined, efforts are given to develop efficient analysis tools to identify EC propagations. There are some studies which focus on aiding the user in performing change propagation in a systematic way. In their work, Yang et al. [19] and Clarkson et al. [20] define dependency of components on each other by a group of experts during the product development stage and utilize this information throughout the product life-cycle to determine changes to be triggered. In these works, the definition of dependencies is based on subjective decisions made during the initial product development; they do not change through time. On the other hand, we know most of the designs in key industries such as automotive, aerospace and defence have long life-cycles and go through thousands of changes, which trigger others, some of which do not correspond to dependencies defined by the initial design team. Rouibah and Caskey [2] developed a parameter-based approach to the ECM to deal with the collaborative product design. In this work, design parameters and their relationship are established during the design phase and summarized in a parameter network which includes the results of previous projects.