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Integration of engineering change objects in product data management databases to support engineering change analysis

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ABSTRACT

This study proposes a product data management (PDM) database that can support engineering change analysis (ECA). It can integrate ECA with the existing main product development process managed by PDM systems. Since engineering change (EC) history is a key EC data element that enables ECA, this study extends PDM databases to represent the EC history with existing entities for ECs and associated products and their product structures. To show the feasibility of the proposed PDM database, this study integrates a prototype PDM system with on-line analytical processing (OLAP) tools and a data mining module for ECA. It also applies the implemented tools to two typical ECA applications, EC evaluation and EC propagation problems. The illustrative application examples show that the proposed PDM database can support ECA through multidimensional data analysis with OLAP and data mining with association rules.

1. Introduction

Engineering changes (ECs) can be defined as modifications to dimensions, fits, forms, functions and materials in products or components after the product design has been released [1,2]. In order to maintain product data consistency, manufacturers establish strict company-wide engineering change management (ECM) that controls the processes and associated product data for ECs.

ECM usually consists of the EC request, approval and execution with notifications [3]. In the EC request phase, a request for a change is submitted in the ECM system, which proposes a change to existing components with its management information along with the reason for the change and the candidate target components with their changed attributes and associated engineering documents. In the approval phase, stakeholders in product development from different functional departments review and approve the request. In order for reviewers to study the proposal, the ECM should provide engineering change analysis (ECA) tools. For example, analysis that predicts the effects of the proposed change on other components helps reviewers identify and prepare for the effects of the change on the components they are in charge of. After the request is approved, EC notifications are distributed to the functional departments involved for execution of the EC.

ECs are labor-intensive activities, but their efficiency is relatively low. Tavcar and Duhovnik [4] reported that engineers expend 30–50% of their efforts on ECM, and only 8.5% of their efforts represents value-added activities. They put most of their efforts into just gathering and processing related data to support information required for various decision-making. In order to enhance the efficiency of the process, information technology should be introduced into ECM to automate the non-value-added activities in the process.

Most manufacturers are equipped with computerized information systems such as product data management (PDM) or product lifecycle management (PLM) systems in order to efficiently manage and share their main product development data and process with dispersed engineers and stakeholders. To support efficient ECM, many properties of ECs managed by the information systems should be shared with ECM support information systems. The properties usually include those for the associated engineering documents, participating products and change histories of ECs (see Section 3 for more details on EC properties and models). By using EC data in the support information systems, ECM allows manufacturers to efficiently manage EC information and align EC activities to their main product development processes. In product development, ECM supports decision-making that requires a tremendous amount of product data related to ECs.

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ECA is one of the core functions of ECM. It provides base data processing for evaluation of ECs and predicting EC propagations, which can support various decision-making during ECM. Since EC is an engineering process that contains uncertainty, the information systems supporting ECA should be flexible and expressive enough to support analysis of unstructured and uncertain EC processes.

Among the tasks in ECA, typical tasks addressed in research include EC evaluation and EC propagation [5–9]. EC evaluation allows engineers to prioritize proposed EC requests using various decision criteria. EC propagation, which points out changes that occur due to relationships within the system, allows engineers to anticipate additional changes that will be needed in order to implement the current change.

The goal of this study is to provide an integrated PDM database that can support both operational product data for product development and EC records for ECA. The integration enables engineers to develop better products and to accelerate product enhancement through efficient ECM supported by comprehensive and consistent company-wide product data management. To increase the applicability of the proposed PDM database, this study builds a PDM database model that follows an international standard for product data models. In addition, the database should support data cubes, a specialized multidimensional database for decision support, with on-line analytical processing (OLAP) that allows interactive and flexible product data analysis required for in-progress ECA.

In order to accomplish the goal, this study suggests the following three-step research procedure:

First, this study proposes EC objects that represent ECs in information systems such as PDM or EC databases. The EC objects should support both operational functions for ECM and data requirements for ECA. The representation includes detailed properties and behaviors of EC history objects, a key element of EC objects that can support core data for ECA.

Second, this study integrates the EC objects with the existing components of PDM data models. This study extends a data model to represent EC history properly and integrates the model into the existing standard specifications of ECs and other elements of product data models including the part list, product structures and engineering documents.

Third, to verify the feasibility of the proposed product data model, this study implements a prototype ECA system that consists of a PDM database, a data cube, a module for data mining and clients for data analysis and visualization. Implementation shows that the proposed product data model can be realized as integrated PDM databases that can support both operational product data and EC data for ECA. The prototype system analyzes synthesized EC examples though interactive multidimensional data analysis. It also shows how EC data in the PDM database can be converted into a data cube specified by a multidimensional data model, and how the EC data in the data cube can be analyzed using OLAP operations and data mining models. This study analyzes ECs interactively to support the two important ECA methods in ECM; EC evaluation and EC propagation.

The remainder of this paper is organized as follows: Section 2 reviews related work. Section 3 presents EC objects that represent ECs in information systems. Section 4 introduces representations of the EC objects with an international standard for PDM data models. Implementation of the proposed product data model including a PDM database, a multidimensional data model and ECA with OLAP and data mining will be introduced in Section 5. Section 6 discusses limitations and possibilities of the proposed approach. Section 7 concludes the paper with topics for future research.

2. Related work

Generalized information tools for ECM that retrieve and share consistent EC data have been suggested [10,11]. Huang et al. [10] proposed a web-based information system that allows dispersed engineers to easily access EC information through the Internet. Chen et al. [11] proposed a distributed ECM approach for the practice of allied concurrent engineering between an individual enterprise and the enterprise alliance. As generalized ECM tools, commercial PDM or PLM systems [12–14] provide information management functions such as the integration of related product data, workflows for EC approval and collaboration environments for dispersed engineers.

The author can classify the existing approach to ECA support tools into two different groups (see Fig. 1a and b), and can also add the proposed approach in this study as another group (see Fig. 1c).

The first group in Fig. 1a [15–19] establishes matrices or networks that represent dependency relationships among ECs and related items, functions or design parameters. They are separated from existing PDM databases that support operational product data for ECs and product development (see the PDM database in Fig. 1a). Since the relationships represented by the matrices and networks depend on the acquisition and representation of human expert knowledge, they cannot be implemented by fully computerized ECA systems [3]. If an EC request is submitted to the system, it processes the data and knowledge with the predefined matrices or networks through complicated steps that are fixed to specific algorithms or applications (see the EC request and result in Fig. 1a). If engineers want to answer different kinds of questions, it is difficult to modify the system since it requires changes to matrices and networks that depend upon the additional acquisition and processing of human knowledge from different experts. Even the approach is regarded as a rigorous and sound methodology, additional and time-consuming procedures with complex rules and associated data may impose excessive workloads for engineers who usually suffer from pressure for in-time product delivery [15].

The second group proposed by Kocar and Akgunduz [3] is different from the first group in that it aims to provide a fully computerized ECA support system (see Fig. 1b). Their objective is to design a database where all ECs are recorded in detail and to scan the database every time an ECR is submitted in order to evaluate the EC. They use the past EC data in the database to reveal the functional dependencies without defining the dependencies between design components. They also establish a 3D virtual modeler and data mining models that provide both input and output of the analysis to evaluate and estimate the result of the proposed EC request (see EC request and result in Fig. 1b). However, they use a separate EC database that collects various data from other enterprise information systems or participating engineers (see the PDM database and EC database in Fig. 1b). They even suggested additional data mining to build the EC database from the scattered product data. In addition, they provide their application-specific product data model for their EC database without considering operational product data which is essential for company level PDM systems, where the system receives a large amount of related product data for ECA. The separation also makes it difficult for engineers to use a large amount of product development data accumulated in online PDM databases.

Both the first and second groups provide pre-defined inflexible data supports for specific analysis methods. Since ECs are a part of engineering design processes that can be changed frequently, they require an interactive and flexible analysis environment to respond to various dynamic decision-making faced during ECs. Therefore, ECA support tools should provide flexible and interactive data management that can support different analysis methods during on-going EC analysis.