Advanced Engineering Informatics 33 (2017) 132–143

Contents lists available at ScienceDirect

Advanced Engineering Informatics

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

Full length article

A novel change feature-based approach to predict the impact of current proposed engineering change

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ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form 31 March 2017
Accepted 4 June 2017
Available online 26 June 2017

Keywords:
Engineering change
Change feature
Change impact
Impact assessment
Prediction

ABSTRACT

The past engineering change (EC) knowledge can be reused to evaluate the impact of current proposed EC, which is gradually accepted as an effective strategy for engineers to handle EC businesses in enterprises. However, the existing approaches to evaluate EC impact are still time-consuming and complex. So this paper proposes a novel change feature-based approach to predict the impact of current proposed EC. Firstly, the related concepts of change feature are defined. Secondly, the working flow of proposed approach is introduced. Afterwards, a mathematical model is constructed for the prediction of EC impact. Finally, an application case verifies the feasibility of the proposed approach, and the evaluation against two state-of-the-art approaches (namely Mehta's approach and k-Nearest Neighbor approach) has been done. The results of evaluation show that our approach is better than the two approaches in terms of three indexes: (a) the success rate of prediction, (b) the time of prediction, and (c) the loss function.

1. Introduction

An EC is defined as an alteration made to parts, drawings or softwares that have already been released during the product design process and life cycle [1]. Meanwhile, EC is an important business activity and driving force of product innovation. It is of great significance for correcting design error, improving product performance, reducing production cost, and raising market competitiveness. As an EC occurs, the impact of change will follow. Different change environments will cause different impact domains. For example, the literature [2] introduced the change and associated impact in a complex product 'Westland helicopter EH101' design. The product consists of many components. When the parameters of a component are changed, the change propagation phenomenon will occur in the components of product due to the interdependencies or interconnections between the parameters of different components. For the product level change, the change impact research mainly focuses on change propagation scope analysis and change risk control. Part is one of basic elements for complex products. A part level change usually is closely associated with manufacturability of the new part after change, cost on machine process, new required machines and tools, etc. Therefore, for a part level change, the change impact analysis mainly focuses on evaluating the impact on manufacture process. For instance, the literature [3] assessed the process impact of a part level change through a knowledge-based method. In other fields, e.g., software engineering, developers usually modify the codes of old software modules to complete new software development [4]. Such changes also propagate to related modules throughout the system due to logical link relations among different modules. In this paper, the research focuses on the part level change and its impact on the process.

As we all know, design change is an important section in Engineering change management (ECM). Moreover, design change is a main approach for new product development. Researches and statistical analyses show that about 40% products are designed through directly reusing the past components, about 40% are designed through changing existing components, and only about 20% are completely new designs in the new product development phase [5]. Additionally, new part design is an important component of the new product development. New part design also can be quickly completed through part change. To reduce the new part design cost and shorten the new part development cycle, many manufacturing enterprises directly modify the old part model to

Abbreviations: CAPP, computer aided process planning; CBR, case-based reason; CF, change feature; C-FAR, Change Favorable Representation; CFEM, change feature existence mode; DSM, design structure matrix; EC, engineering change; ECFDM, engineering change feature data meta-model; ECIA, engineering change impact evaluation; ECM, engineering change management; IAS, important attribute set; k-NN, k-Nearest Neighbor.

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http://dx.doi.org/10.1016/j.aei.2017.06.002
1474-0346/

complete the design of new part and meet the new requirements of customer or market. So there is a demand for quickly evaluating the impact of part change. The scope of part change includes the shape change, material change, etc. We examine a domestic aviation manufacturing company that is located in the ancient city of Xi'an, and find that the number of shape change has occupied about 60 percent of total number of part change in the past three years. Therefore, we mainly consider the part shape change as the research object to explore the new approach of EC impact evaluation, which will provide a theoretical basis for the development of automatic EC impact evaluation system or tool.

The literature [6] divided ECM into five processes: (1) identification of a change requirement, (2) evaluation of the change impact, (3) authorization of the change, (4) implementation of the change, and (5) review of the change. The literature [1] further subdivided the first process into two steps: (a) identification of the change reason, and (b) proposal of the change plan. In above processes, the change impact evaluation is considered as the most difficult part.

A seemingly simple proposed EC can have several effects, since it can affect various product lifecycle elements, such as associated assemblies, manufacturing processes, and end-of-life treatment plans [7]. Therefore, the process of dealing with an EC will cost plenty of time and money for enterprises in the aspect of ECM. For example, Watts [8] examined the EC issue faced by an American company that manufactured components of computer. Over 100 ECs occur per month and dealing each of these changes costs an average of 120 days to achieve a solution: 40 days for changes in the product design and development process, 40 days for the paperwork that is relevant to changes, and 40 days for the implementation of changes in the production stage. In addition, a survey from U.S. and European companies has shown that the average administrative cost of processing each engineering change is $1400 [9].

Currently, the businesses about EC impact assessment in enterprises are usually implemented manually by domain experts. The artificial way relies heavily on experts' individual experience, and it is less reliable and time-consuming. Hence, there is a need for an approach that can be used to quickly evaluate the impact of current proposed EC without specialized knowledge. The need motivates this research. To meet the need, this paper proposes a novel change feature-based approach to predict the impact of a proposed EC.

Similar features might have similar characters, so similar change features are likely to have similar impacts. As mentioned in the second paragraph, this research aims at exploring an approach to evaluate the impact of part change. Moreover, some part changes usually occur in the form of shape alterations. For a change that belongs to part change in shape, change features can be utilized to represent the EC. The similarity between ECs is computed based on similar change feature, which avoids the selection process of the important attribute set (IAS) [3] and saves the preparation time in the evaluation phase. In addition, the different characteristic parameter values of change feature may cause that similar ECs have different impact values. Therefore, quantifying and accounting for such differences in context of impact between change feature characteristic parameter values is a major challenge in developing an approach to predict the impact of current proposed EC based on change features.

The rest of the paper is organized as follows. In the second section, we review the related works. In Section 3, some basic concepts are presented. Section 4 provides the overview of our approach. Section 5 constructs the mathematical model for predicting the impact of proposed EC. Then in Section 6, an application case is utilized to verify the feasible of our approach. Section 7 evaluates our approach against two state-of-the-art approaches. Finally, we conclude the paper, discuss the other application of similar feature idea and present the future work in Section 8.

2. Related works

The engineering change impact evaluation (ECIE) has been an active research topic since the concept of design change was proposed in 1980s. Researches on the issue of predicting EC impact have been done by some scholars of EC research field, who have solved some problems associated with EC impact prediction from two perspectives: (1) change propagation, and (2) change knowledge reuse.

Based on the theory of change propagation, some EC analysis models and approaches are developed to evaluate or predict the EC impact. For example, the design structure matrix (DSM) has been used to model the EC propagation [2,10], and the EC impact can be assessed or predicted through tracing potential EC propagation paths. Although the DSM-based methods can provide a good model that simulates the process of change propagation, the predicted accuracy relies heavily on the granularity level of analyzed components in the product. Similarly, a property-driven development approach has been utilized to assess the impact of EC [11–13]. More specially, it involves a modeling framework used in analyzing the relationship between product properties and product parameters. The approach can obtain an accurate description about EC propagation, while it may be computationally intensive. For example, a simple change case of a shaft has analyzed 11 parameters [12]. Cohen et al. [14] presented a methodology called Change Favorable Representation (C-FAR). The C-FAR method uses an existing product information model to facilitate EC representation, help analyze EC propagation and qualitatively evaluate the EC impact. The change influence between any two entities can be computed by using matrix multiplication. The prediction precision is determined by the accuracy of C-FAR model. However, an accurate C-FAR model is constructed by engineers who have rich experience and engineering knowledge. Such approaches that rely heavily on personal experience and expertise are cumbersome and inefficient. In addition, these approaches based on the theory of change propagation are suitable to analyze the impact of product level change.

With the rapid development of knowledge reuse technology, the knowledge of existing EC cases has been utilized to evaluate EC impact by some scholars in the field of ECM. The ontology technology is utilized for retrieving similar changes that are utilized to evaluate the EC impact. For example, Lee et al. [15] presented a CBR approach to evaluate EC impact. The method includes the following three steps. Firstly, an EC model is constructed with five ontologies. Secondly, the similarity is computed between two EC cases based on ontology concept similarity. Finally, similar EC cases are retrieved to evaluate the impact of proposed EC. Guo [16] and Wang [17] have also done similar researches. Such approaches show an application prospect of knowledge reuse in the field of ECM. However, it is difficult to construct the ontology model of EC. Joshi [18] presented a simple majority voting method to predict the impact of a proposed EC based on past EC cases. But the approach does not account for differences in the context of impact between attribute values of EC. Mehta [3] systematically presented a knowledge-based approach to predict the EC impact. The approach provides a complete process from constructing standard EC data model to evaluating EC impact based on past similar EC knowledge. As stated in Section 1, the approach needs to spend some time selecting the IAS from all EC attributes, which will increase preparation time in the evaluation phase. The above approaches based on the knowledge reuse technology are applicable to part level change.