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Process optimization based on knowledge flow in engineering change

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Abstract

In order to improve the efficiency of engineering change (EC) processes, the mechanism of knowledge flow in EC process is described via analyzing knowledge transformation and transmission between knowledge carriers. Given the parallel and discrete feature of EC activities and the tacit/explicit status variation of intellectual content, a modeling approach based on improved Petri net is proposed for the knowledge flow in EC process. The four kinds of knowledge activity unit (KAU) are used to depict the tacit/explicit status change in knowledge transmission process. A knowledge–flow–oriented Petri net (KF-OPN) model is established subsequently. Based on the KF-OPN model the knowledge transfer path searching algorithm is proposed, and the EC process optimization framework is constructed. A case of EC process in an aircraft manufacture enterprise was studied to illustrate the effectiveness and feasibility of the proposed method.

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Keywords: knowledge flow; engineering change; process optimization; Petri net

1. Introduction

The nature of product development is a problem solving process based on knowledge, which is also a process of continuous evolution of knowledge while moving from designers to the physical product. [1, 2] As an inevitable part of product development, engineering change (EC) processes are the external manifestation of evolution and orderly movement of product design knowledge. An EC can be considered as "an alternation in the approved configuration of a product related item" (US Military Standard 480B, 1988).[3] A related item varies in physical component of the product structure, Bill of Material (BOM), Computer Aided Design (CAD) model, blueprints or other forms of documents, but essentially is a knowledge carrier. Product design knowledge evolves and flows between those related items and triggers evolvement of other knowledge as the EC process moves forward.

ECs have a significant impact on product performance, manufacturing cost and product delivery, thus should be properly planned and managed.[3] It has been proved that the costs of an engineering change grow by a factor of five to ten as one moves from early design to manufacturing. [4] On the other hand, a recent study shows that the lead-time of EC processes may possibly reduce 20-40% while the quality of the processes increase. [5] An optimized EC process is efficient and effective, which helps accelerating implementation procedure of EC solutions, reducing possibility of EC propagation and decreasing EC cost. These insights serve as the motivation for this paper to maximize the total efficiency of EC process to bring profits for organizations to the utmost.

EC is a complex process reflected in the complexity of disciplines and functional organizations involved, therefore there is a common agreement that a well-structured process is particularly important for EC management (ECM). [6, 7] The majority of the EC processes suggested in literature and also used in industry generally include the four stages of identifying, evaluating, implementing and auditing ECs. [8-10]

2. Literature review

There is abundant literature in the area of EC process improvement. Two approaches are mostly carried out specifically EC solution evaluation and EC process reengineering. Research on EC solution evaluation focuses on

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the potential impact on related elements in order to reduce the risk of change propagation. The other approach aims at the EC process composition to achieve the goal of improving process efficiency by restructuring process activities, thus ensure efficient implementation of EC solutions.

A literature review identified that EC solution evaluation is a well-established research area encompassing a diverse range of approaches, among which change consequences on product and organization are two main objects mostly focused on. In order to improve the changeability of products, Fricke and Schulz (2005) [11] proposed four key aspects as flexibility, agility, robustness, and adaptability as product design guidance. Elezi et al (2015) [12] proposed a methodology for conception of a platform system that is robust to internal and external dynamic changes. Yang et al (2011) [13] established a change propagation model to evaluate the influence of EC on product characteristics to optimal selecting of feasible solutions. Conrad et al (2007) [14] described a Failure Modes and Effects Analysis based methodology to assess impacts and risks of changes. Koh et al. (2008) [15] extended the Change Prediction Method (CPM) proposed by Clarkson et al. (2004) [16] to consider the ‘knock-on’ effects on the product attributes. This theory was subsequently extended by Edwin et al (2009) [10] to examine the change propagation effects on both the product and the organization using a matrix-based approach. EC may impact many aspects of organization. To improve the transparency of knowledge required for EC tasks stored in heterogeneous systems, Doerfler et al (2013) [17] described a collaborative environment based on file systems and task management mechanism to facilitate the EC solution evaluation process. Rios et al (2006) [18] presented a matrix-based methodology to address the cost impact analysis with the occurrence of ECs. Browning et al (2002) [19] integrated cost, schedule, and risks of rework into a single model to improve the efficiency and predictability of product development processes.

Comparatively, EC process reengineering have not received due attention. Researches on this issue have been carried out generally by two approaches: reconstructing EC processes and adopting new theory to improve current processes. The former approach normally aim at complex circumstances where the current EC process is insufficient. The latter mostly take the strategy by absorbing advanced ideas and achievements in other fields to achieve the process optimization purpose. Chen et al (2002) [20] presented a hierarchical and distributed framework to meet the challenge of increasingly difficulty of ECM in allied concurrent engineering. Feng and Li (2003) [21] put forward a new management model based on manufacturing BOM in distributed environment to ensure a single data source. Wasmer et al (2011) [5] proposed a cross-company ECM framework that standardized product data communication and workflow task collaboration between information systems. These strategies proposed above may be a high risk for organizations since many unforeseen problems and unconsidered situations may exist. Consequently, most organizations prefer minor enhancements based on current EC processes. Mehta et al (2008) [22] put forward an information-theoretic approach to compare attributes between past EC knowledge and proposed EC request. Keller et al (2005) [23] proposed a multiple view strategy to visualize complex change data and allows designers to assess the implications of changing components. Riviere et al (2003) [24] and Shiau et al (2009) [25] enriched the EC solution attributes so that association information between related objects can be carried which enabled the complex information mining. Bergsjö et al (2008) [26] implemented a service-oriented architecture to support cross-functional process control in ECM. The foregoing literature mostly focus on improving efficiency of a particular activity, mostly at product design stage, rather than enhancing the whole EC process which limits the total effect of process optimization. Meanwhile, EC knowledge has been taken as a static resource rather than a major participant of the entire process.

3. Knowledge-flow-based EC process optimization

3.1. Knowledge flow in EC process

There is no generally accepted definition for knowledge flow so far. According to the definitions proposed by Zhuge (2002) [27], and Zhang (2005) [28], three main elements are involved in knowledge flow definition which are knowledge carrier, intellectual content, and knowledge flow direction. Knowledge carriers are classified as senders and receivers. Intellectual content refer in particular those can be expressed, conveyed, and comprehended by different carriers. Knowledge flow direction is an irreversible directed transmission from senders to receivers. In this paper the knowledge flow is defined as a process of directed transmission of intellectual content between knowledge carriers when transferring conditions are met.

According to whether expressed explicitly, intellectual content can be divided into tacit knowledge and explicit knowledge. Tacit knowledge cannot be transmitted between carriers until expressed by coding systems like language, mathematical formula, mechanical graphing specifications et al. In the process of knowledge transmission, intellectual content shifts its status between tacit and explicit according to carriers. For the further research on knowledge status transformation mechanism, Nonaka and Takeuchi (1996) [29] presented a knowledge activity model consists of socialization, externalization, combination, and internalization activities (SECI) through which knowledge status changes.

In the EC process, evolved product design knowledge change its status while transmitting between knowledge carriers engaged in EC activities. EC activity along with knowledge sender and receiver engaged are defined as a knowledge activity unit (KAU) in this thesis. Referencing the SECI model, KAUs are categorized into four types as follows.

- Socialization Activity Unit (SAU)

SAUs allow transmission of tacit knowledge between carriers within the unit. These unit usually involve personnel that carries knowledge. Activities such as identifying possible EC solutions, exchanging experiences or ideas by convening a meeting can be categorized into SAU.

- Externalization Activity Unit (EAU)