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Process planning for collaborative product development with CD-DSM in optoelectronic enterprises

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ABSTRACT

Coupled activities are the main reasons to cause collaboration in product development (PD) process. Previous modeling approaches such as Petri net, IDEF and DSM fail to represent the collaboration characteristic of PD process well. Considering the characteristics of optoelectronic PD process especially for demand of collaborative development, this paper proposes the process planning framework, establishes the three-dimensional collaboration model, and analyzes nine collaboration types among activities. The Process Collaboration Degree (PCD) and Activity Collaboration Degree (ACD) considering information delivery times and probability are defined to strengthen the modeling ability of DSM, and then the Collaboration Degree Design Structure Matrix (CD-DSM) is constructed to model the collaborative development process of optoelectronic products. In order to decrease the coupled complexity, PCD is applied to decompose the nested activities into atomic activities based on the information input/output points and ACD is used to express the value of the elements in the CD-DSM. Furthermore, the upstream and downstream relationship of atomic activities is optimized based on the CD-DSM to plan the collaborative PD process. Finally, the proposed framework is realized in a prototype system, and an example of LED display module development process is carried out in an optoelectronic company to illustrate the application. And the results show that the proposed method improves the process planning of collaborative PD effectively.

1. Introduction

Nowadays, most manufacturing enterprises are facing intensive competition from the global market. How to better manage and enhance their product development (PD) processes becomes a core issue for every single manufacturing enterprise. Global competition and distribution of markets, labors, and suppliers have driven manufacturing enterprises to distribute production sites, facilities, and associated engineering activities at different geographical locations close to the desired markets, labors, supply sources for low costs and quick responses to the market [1]. More and more manufacturing enterprises have realized that the ability to bring to market well designed and manufactured new products at competitive prices in a short lead-time is critical for them to survive in the keen competitive market [2]. Therefore, in the new distributed manufacturing environment, it is imperative to seek an appropriate way to carry out PD processes, which require shortening product lifecycle, cutting development cost, reducing lead time, achieving high quality and productivity, and quickly responding to the market changing to meet customer requirements [3]. Effectively planning the PD process is an essential factor to achieve the above requirements in the new manufacturing environment. Some of the existing PD modes and manufacturing philosophies, such as mass customization, concurrent engineering, virtual manufacturing, agile manufacturing, and networked manufacturing are employed to enhance PD efficiency and shorten the PD cycle from different sides [4]. As a result, the PD process in current manufacturing enterprises shows the following characteristics:

(1) Content of PD process keeps expanding. PD refers not only to the product design process, but also to include manufacturing, assembly, maintenance, sales process, while it is endowed with new connotation and significance, such as PD for mass customization and agile PD.
(2) PD process highlights the collaboration work. Modern product structure is increasingly complex and PD process presents the trend of integrating, networking and distribution. The entire development process requires collaborative process modeling, collaborative tasks scheduling and collaborative development environment to manage collaborative PD.

The PD process of modern enterprises, including optoelectronic ones, need to meet the collaboration requirements, allowing

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developers only focus on their portion of work [5]. The PD process of optoelectronic enterprises is often the joint effort of many team members from geographically distributed departments, and they depend on closely each other in design process. Therefore, the enterprises pay more attention to the collaboration ability between different development activities involved in PD plan, product concept design, product preliminary design, product detail design, tests, and improvement. The reasons are to improve the management level of product data and reduce cost from all around the way, while maintaining a high level of product quality at the same time. In addition, improving the effectiveness of the development process is crucial in the reduction of optoelectronic PD time and costs due to feedback and rework. Consequently, a collaborative PD process planning is required to provide support for management, and coordination of PD activities and product information sharing and exchange, between various stages of PD processes in optoelectronic manufacturing enterprises.

The remainder of this paper is organized as follows. In Section 2 the literature review on process modeling is outlined. The characteristics of optoelectronic products development processes are developed in Section 3. Section 4 describes the process planning framework of collaborative PD (PPFCPD). Implementation of the proposed PPFCPD is demonstrated in Section 5 and conclusions are given in Section 6.

2. Literature review of process modeling

Process modeling of PD is essential for planning the collaborative PD activities to execute effectively. The common methods for process modeling can be categorized as: (a) expression based on process modeling language, (b) static graphic representation, (c) state-based graphical modeling tool, and (d) expression based on project management theory and model [6]. Several representative process modeling methods which have its own characteristics and descriptive aims, such as: Petri net [7,8], IDEF (Integration Definition Family) [8–10], UML (Unified Modeling Language) [10,11], and DSM [12]. Petri nets are more powerful to represent dynamic behavior than other methods due to the changing number of token [8,13], and are complicated for modeling collaborative processes. IDEF3 is a static modeling method, not suitable for representing dynamic processes [14]. UML is syntactically rich, user friendly, and flexible. However, it lacks the formality required to support simulation and analysis [10]. DSM has very strong computing ability for representing and analyzing interaction relations among system elements [12,15].

DSM model can be divided into the following categories: component-based DSM; team-based DSM; activity-based DSM and parameter-based DSM [16]. Activity-based DSM (i.e. Task-based DSM) expresses the interdependencies between activities of PD, which can be applied to model and analyze the development process. In the activity-based DSM, tasks or activities are listed in the first row and the first column of the matrix. Off-diagonal cells indicate the interactions of tasks, the value decides if Boolean DSM (BDSM) or Numeric DSM (NDSM) (Fig. 1). Element values below the diagonal represent forward information transfer which affects the later activities. Element values above the diagonal represent information feedback or iteration.

Recently, the DSM is becoming a popular representation and analysis tool for system modeling, especially for managing the complexity of decomposition and integration in large engineering systems and complex PD processes. Some DSM based approaches were established to solve the iteration and feedback problems in PD process. Yassine and Braha [17] developed a unified modeling and solution approach based on the DSM method to describe four critical problems(iteration, overlapping, decomposition and integration, and convergence problems) in complex product development (PD) projects, and the proposed information exchange model allowed managers to represent complex task relationships to better plan and manage concurrent engineering initiatives. A comprehensive approach for product architecting using clustering of component-based DSMs was presented and demonstrated by Helmer [18]. It covered all relevant aspects, from data acquisition, and handling of multiple perspectives in DSM clustering, to a post-processing phase, where results were corrected with respect to technical feasibility. And the proposed method solved many deficiencies and problems neglected in previous literature. Moreover, Multiple-Domain Matrix (MDM) has been established to describe multiple element types and dependency meanings for dealing with more comprehensive system structures. Deubzer and Lindemann [19] developed an approach combining DSM and MDM approaches, to allow for the support of radical innovations by considering the overall product structure, different levels of detail and the analysis of a comprehensive solution space compared to the definition of discrete solutions delivered by common methods. It improved the limited innovative solutions delivered by automated mechanisms for supporting of design synthesis.

	A	B	C	D	E	F
A		1				
B	1					
C				1	1	
D			1			1
E	1			1		1
F				1	1	

(a) Activity-based BDSM

	A	B	C	D	E	F
A		2				
B	3					
C				5	2	
D			3			1
E	2			3		5
F				1	7	

(b) Activity-based NDSM

Fig. 1. Activity-based DSM.

In addition, some mixed DSM methods were also developed to capture the diverse characteristics (e.g. iterative, evolutionary, uncertain and cooperative characteristics) of PD process. Luh [20] established a fuzzy design structure matrix (FDSM) by quantifying the information flow of activity factors of new product development and employing the fuzzy clustering method to grasp the interactive information flow between each of the activity factors, and proposed partition and tearing algorithm to achieve optimum design process. DSM methodology explicitly incorporates the concurrent aspects of engineering design. However it has not been applied formally to an integrated, rapid design environment such as ICE [21]. For this, Avnet and Weigel provided a systems-level model of the space mission design process in the rapid and collaborative integrated concurrent engineering design environment. A DSM consisting of 172 design parameters and 682 dependencies was constructed to represent the typical process employed at the Mission Design Laboratory (MDL), an ICE facility at NASA Goddard Space Flight Center (GSFC). Analysis of the proposed model yielded an optimal sequence of design activities and revealed the five phases of the design life cycle. By following the process indicated by the partitioned DSM, the team could conduct each phase more efficiently. Karniel and Reich [22] extended DSM model presented formal definitions of the DSM method used for process planning, addressed the gap by a formal conversion of the ordered DSM (process plan) using the specific properties of the ordered DSM to a process-scheme model, the DSM net. It is proved that the resulting DSM net is equivalent to a WRI-WF net; thus, plan changes could be translated to process model changes without further check. Diepold et al. [23] proposed a three-phase modeling framework