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Pareto process optimization of product development project using bi-objective hybrid genetic algorithm

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ABSTRACT

Overlapping and iteration between development activities are the main reasons to cause complexity in product development (PD) process. Overlapping may not only reduce duration of a project but also create rework risk, while iteration increases the project duration and cost. In order to balance the duration and cost, this article presents four types of time models from the angle of time overlapping and activities dependent relationships based on Collaboration Degree Design Structure Matrix (CD-DSM) and builds the cost model considering the negation cost. On basis of the formulated model, a hybridization of the Pareto genetic algorithm (PGA) and variable neighborhood search (VNS) algorithm is proposed to solve the bi-objective process optimization problem of PD project for reducing the project duration and cost. The VNS strategy is implemented after the genetic operation of crossover and mutation to improve the exploitation ability of the algorithm. And then, an industrial example, a LED module PD project in an optoelectronic enterprise, is provided to illustrate the utility of the proposed approach. The optimization model minimizes the project duration and cost associated with overlapping and iteration and yields a Pareto optimal solution of project activity sequence for project managers to make decision following different business purposes. The simulation results of two different problems show that the proposed approach has a good convergence and robustness.

1. Introduction

As competitive pressure increases and time to market compresses, companies are outsourcing some design activities to more professional organizations and paying more attentions to core design activities for shortening the cycle time of PD process. At the same time, development activities of complex products are increasingly undertaken by multidisciplinary team members from geographically distributed departments in a virtual and collaborative environment [1]. And modern product structure is increasingly complex and PD process presents the trend of integrating, networking and distribution [2]. Thus, PD process will be more strongly time-oriented and collaborative, while still focusing on cost and quality. As a result, how to better manage and enhance PD processes to cater for various customer requirements becomes a core issue for each single manufacturing enterprise.

The PD process can be regarded as an organized group of related design activities involving project initiation, task assignment, product design, process design, etc. Traditionally centralized and sequential product design, planning and scheduling activities are inadequate to respond to the dynamic variations in new PD cycles [3]. Iteration and overlapping of design activities are the fundamental characteristics of complex PD process [4]. Iteration usually leads to rework risk [5], while overlapping activities usually impact project duration. Iteration implies redoing or revising the related design results, which makes the PD process more complex due to the coupled and intermixed activities. Overlapping involves the concurrent execution of two successive activities and allows the second activity to begin before the first one is finished. Overlapping activities also increase communication and excessive information exchange [6]. It is well known that good collaborative and concurrent performance can help to achieve shortened project duration and reduced costs. However, the downstream activity has to iterate to accommodate changes throughout the iteration process, which will lead to additional time at a small amount of rework cost. In this way, the activity sequence of PD determines the development cycle time and cost to certain extent. In addition, overlapping between activities is a good strategy to reduce total project duration. However, the development cost is added because of reworks of downstream activity caused by overlapping with dependent upstream one. Therefore, how to optimize the PD process to reduce the rework delay time and added cost of development activities and improve its concurrent and collaborative capability amongst distributed cooperative members is an important issue. Consequently, an analytical and optimal model of the trade-off between

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the total project duration impacted by iteration and overlapping and the total development cost is needed in PD.

The remainder of this paper is organized as follows. The next section reviews the relevant literature related to process optimization of PD. The problem description and mathematic model of process optimization of PD are developed in Section 3. Section 4 details the proposed hybridization of PGA with VNS to approximate the Pareto optimal solutions. An application case of a LED module development process in an optoelectronic enterprise is demonstrated in Section 5 and conclusions are given in Section 6.

2. Literature review

Process model is the set of tasks and the related information flow between them that sum to produce the final product [7]. Structuring the PD process is essential for scheduling the PD activities to execute effectively, and thus reducing iteration and rework times. Much research has been done about time-computing, cost-computing and process improving approaches to the PD process. Generally, two problems need to be solved to optimize PD process. One is focused on how to construct the mathematical model of PD process optimization problems. The other one is on how to apply intelligent algorithms to achieve the optimal solution of the process model.

Research effort has been made towards developing process model and applying it to engineering problems over the last two decades. Minimum cycle time and cost are two common objectives targeting in the optimization of PD process. Concurrent engineering is one of the prominent tools often employed to reduce PD time. The advantages of concurrent engineering surrounding the task of speeding and improving the PD cycle were discussed in [8,9]. Moatari Kazerouni et al. [10] investigated the success criteria during different phases of the product lifecycle. The outcomes showed that managers do perceive the success of new PD differently depending on the perspective. Tatikonda and Rosenthal [11] enumerated the technological novelty, the magnitude of the design tasks, the interactions between the design tasks in the new PD project, and the balancing between projects as being the most important causes leading to project delays. Therefore, some methods were proposed to estimate the development time. Ahmadi et al. [12] formulated the structuring PD process as an integer program, presented two Markov models for estimating the total development time, and developed several procedures to minimize iterations during the development process which adversely affect development time and costs. Jun et al. [13]provided a heuristic algorithm that can estimate the lead time of a complex PD process by series-parallel network transformation and network reduction methods with estimates of the makespans of branch–merge types. Dragut and Bertrand [14] developed a mathematical model based on queuing theory concepts for the solving-time distribution of design tasks for new PD accounting for both structural design tasks technological uncertainties and human factor characteristics for the first time. Yan et al. [15] modeled the time characteristics in the concurrent development process and set up a time-computing model involving rework probability, and design time of uncoupled and coupled activities to estimate the rework cost and completion time of each of the activities.

Cost management is another factor for the success of PD project. Activities may have uncertain cost and duration, rework caused by changes in particular inputs, and reduced cost and duration in successive iterations [5]. Moreover, the cost of a product design will be strongly influenced by the correctness and accuracy of the product definition. A correct understanding of customer's requirements and a clear product definition will obviously result in a quick and cheap PD [16]. As thus, PD cost can be treated deterministically or purely as a function of process parameters such as process duration, activity rework rate and process changes. Various mathematical models of development process have been developed to study the cost modeling of PD process so far. Broadly, a PD cost consisting of product definition, design and sample production cost. In terms of the complexity of iteration and rework, some researchers ignored the information exchange cost between development teams throughout the PD process. For example, Shehab and Abdalla [17] estimated the manufacturing cost modeling of a product at the conceptual design stage of the product life cycle and the estimated cost included material, processing, machine set-up and non-productive costs. Yang et al. [18] proposed evolution and sensitivity design structure matrix to present the schedule and cost model associated with iteration, overlapping, and rework. Of course, communication cost was also discussed as the one item of PD cost in building the cost function [19]. In addition, Time-cost tradeoffs were also the focus in some existing literature [19,20]. Savin and Terwiesch [21] modeled the trade-off between the lost revenues resulting from a delayed launch and the lower unit-production costs. The results showed that a firm facing a launch time delay from a competing product might benefit from accelerating its own product launch, as opposed to using the softened competitive situation to further improve its cost position.

Another attention need to be focused on the various methods to optimize the PD process models. The common methods for PD process optimization can be categorized as: (1) Applying intelligent optimization algorithms. Meysam Mousavi et al. [22] presented a new model integrating the support vector regression (SVR) and the imperialist competitive algorithm (ICA) for time estimation in new PD projects. Tyagi et al. [23] estimated simultaneously the optimal amount of overlapping and communication to minimize PD lead time and cost for the entire PD process adopting the fuzzy goal programming-based approach, and then, proposed a novel approach of Gaussian Adaptive Particle Swarm Optimization (GA-PSO) to optimize the formulated objective function. Meier et al. [24] investigated the use of a competent GA: the ordering messy GA (OmeGA) for the information flow models of PD process to cope with the SGA deficiency. Tests confirmed the superiority of the OmeGA over a SGA for hard DSM problems. (2) Simulation-based method. For example, Abdelsalam and Bao [25] presented a simulation-based optimization framework that determines the optimal sequence of activities execution within a product DP that minimizes project total iterative time given stochastic activity durations. Yang and Lü [26] developed a discrete-event simulation algorithm for DSM to estimate the probability distribution of duration and cost so as to evaluate risk. Li et al. [27] proposed a process simulation based method to select the most economic propagation path for each design change, which can reduce the total process time for changes occurring in the complex PD process. Kang and Hong [28] adopted simulation-based method to evaluate the acceleration effect of dynamic sequencing of design process in a multi-project environment by introducing the factor of waiting time to model the design delays. Wang et al. [29] realized human-centered simulation of PD process based on multi-agent modeling principle considering the process evaluation indices, planning deviation rate, process risk, and design error level.

Significant research efforts in the modeling of PD process and development of optimization approaches have been made. However, few studies have been focused on obtaining the Pareto optimal solution of PD process. Thus, our work is different from the aforesaid works in two major aspects. First, this paper simultaneously establish the time characteristic model considering of overlapping and iteration in order to simultaneously minimize PD project duration and cost. Additionally, the novel approach of hybridization of PGA with VNS is proposed to optimize the formulated objective function (i.e., project duration and cost), which are