

Recent Advances in Concurrent Engineering Modeling

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Abstract - Over the last two decades, a number of studies have examined the trade-off involved in concurrent engineering (CE), time reduction versus additional effort for downstream rework. This study presents an overview of the recent CE modeling literature that examined this trade-off. We find that most CE models are built on the assumption that development stages are dependent where the principal information exchange between consecutive design stages is unidirectional, from upstream stage to downstream stage. According to literature review and field study, we believe such assumption is reasonable, because in many situations, current execution of design stages actually occurs within two sub-stages (Testing 1 and Development 2) which are sequentially dependent. In the future, we may also build analytical models based on interdependent stages so as to better understand the impact of project properties on best CE policies and product development performance.

Keywords – Concurrent engineering, overlapping, product development

I. INTRODUCTION

Over the last two decades, concurrent engineering (CE), the practice of executing dependent product development stages simultaneously, has become the common mode of new product development (NPD) because of the increasing importance of time-to-market (Terwiesch et al., 2002 [1]; Lin et al., 2012 [2]). Although large reduction in project completion time may be achieved by applying CE approach, empirical studies also show that CE is not applicable to all NPD projects (Terwiesch and Loch, 1999 [3]; Mitchell and Nault, 2007 [4]). For example, based on the empirical study of 140 development projects in the electronics industries, Terwiesch and Loch (1999) concluded that CE was effective only if uncertainty resolution was fast. This is because CE requires that downstream stages start on preliminary information, and thus rework is often necessary to accommodate upstream design changes. Therefore, a key trade-off involved in CE is time reduction versus additional effort for downstream rework.

This study presents an overview of the recent CE modeling literature that examined the aforementioned trade-off. Our objective is to summarize the models' main assumptions and findings, and to identify possible future research directions. The rest of this study is organized as follows. Section 2 provides a taxonomy for grouping CE models. Section 3 reviews the relevant literature on CE. Finally, Section 4 summarizes the concluding comments.

II. A TAXONOMY FOR CE MODELS BASED ON INFORMATION DEPENDENCIES

An information-based view of product development has been widely adopted in the literature of CE (e.g. Clark and Fujimoto, 1991 [5]; Lin et al., 2008 [6]; Love et al., 2009 [7]). From this perspective, there are three general types of information dependencies, as shown in Fig.1 (Eppinger et al., 1994 [8]; Yassine et al., 1999 [9]; Bhuiyan et al., 2004 [10]). If stages A and B could be performed simultaneously with no interaction between them, then the two stages are said to be independent. On the other hand, the two development stages would be dependent (or sequentially dependent), if there is a unidirectional information flow between them. Finally, it is said to be interdependent if the two development stages are mutually dependent and the information flows in both ways.

According to this taxonomy, we discuss the recent CE models in the next section.

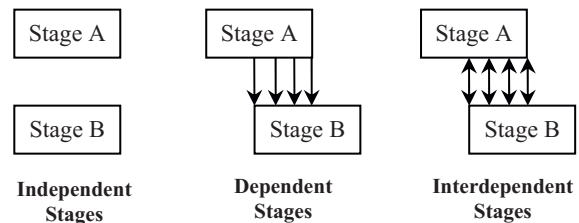


Fig.1. Independence, sequential dependence, and interdependence

III. RECENT CE MODELS

Most CE models are built on the assumption that development stages are dependent or interdependent. Therefore, we categorize previous literature into two groups. Section A reviews the CE models for dependent development stages. Section B discusses the CE models for interdependent development stages.

A. CE Models based on Dependent Stages

Quite a few analytical models in CE are built on the assumption that development stages are dependent and the principal information exchange between consecutive design stages is unidirectional, i.e., from upstream stage to downstream stage.

For example, Krishnan et al. (1997) developed an integer program to determine the optimal number of information transfer between two consecutive development stages, as well as the start time of

downstream rework, such that project completion time would be minimized [11]. The authors proposed that the optimal degree of concurrency should be determined by two properties of the NPD process, “upstream evolution” and “downstream sensitivity”, where “upstream evolution” denoted the speed at which upstream information narrows from an interval value to a final solution, and “downstream sensitivity” referred to the expected time needed for the downstream stage to incorporate upstream design changes. This principle was further developed by Loch and Terwiesch (1998), where they proposed that the optimal levels of concurrency and communication should be decided by the arrival rate of upstream design modifications, the impact of each modification (i.e. the percentage of downstream tasks would be affected by one upstream design change), and the downstream progress, i.e. the number of downstream tasks completed when the design change arrived [12].

Yassine et al. (1999) proposed a probabilistic model to determine the optimal degree of concurrency for a set of activities. Roemer et al. (2000) addressed the time-cost trade-off in CE and introduced an algorithm to determine the optimal concurrency level [13]. Chakravarty (2001) examined the optimal CE policies for three overlapping modes [14]. Roemer and Ahmadi (2004) examined the interactions between CE and crashing policies, and provided general guidelines for optimal CE and crashing policies [15]. Wang and Yan (2005) built an analytical model to determine the optimal concurrency level of two stages so as to minimize total cost [16].

Recently, Gerik and Qassim (2008) developed a mixed-integer model for determining the optimal crashing, overlapping, and substitution policies [17]. Based on the general assumption of nonnegative upstream evolution, Lin et al. (2009) developed an analytical model to derive the optimal degree of concurrency and functional interaction [18]. Lin et al. (2010) explicitly captures the interaction between project progress and CE and information exchange policies, and presented a model to derive optimal CE and communication policies [19]. Qian et al. (2010) proposed an analytical model to determine the optimal amount of time spent on upstream and downstream testing, as well as the optimal level of concurrency [20]. Lin et al. (2012) built an analytical model to determine the priority ordering of initial development and rework, and the optimal concurrency between development stages. They show that it is optimal to do the rework (resulting from upstream design changes) after the completion of initial development when learning effect exists.

The aforementioned studies are insightful in many ways, and are built on the assumption that development stages are dependent and the principal information exchange between design stages is unidirectional. However, many empirical studies argue that development stages are often interdependent for product development projects (e.g. Clark and Fujimoto, 1991; Bhuiyan et al., 2004; Lin et al., 2008). It is necessary to explain the contradiction of these two groups of studies. To do this,

we reviewed the studies which include in-depth case studies and describe the information flows between development stages in detail.

Clark and Fujimoto (1991) were, perhaps, the first who systematically analyzed concurrent product development based on their field study in the world automotive industry. They investigated the information flows between two consecutive development stages, the design and development of dies for body panels. Wheelwright and Clark (1992) studied many other industries and generalized the process of new product development [21]. Swink et al. (1996) identified three levels of concurrency existed in the product development projects. The concurrency at the stage level was denoted as project phase concurrency which involves simultaneously developing market concepts, product designs, manufacturing processes, and product support structures [22]. Based on dozens of case studies in world class companies, Cooper (1994, 2007) concluded that flexibility is one of the key factors of the third generation stage-gate product development processes, i.e. projects can precede into the next stage even though the previous stage has not been totally completed [23, 24]. Bhuiyan et al. (2004) described the information flows and decision points in concurrent processes based on a study of six product development projects in a Canadian firm manufacturing printed circuit boards.

The above studies cover hundreds of product development projects in different industries. Although these studies may break new product project into different number of stages (typically four, five or six in number) and the content of each stage may be different, the information flows involved in two consecutive development stages are similar. Figure 2 shows a generic product development process adapted from Clark and Fujimoto (1991), Wheelwright and Clark (1992), Cooper (1994, 2007), Swink (1996), Bhuiyan et al. (2004), Mitchell and Nault (2007), and our experience in three consumer electronics companies. It is clear that the upstream stage and the downstream stage are interdependent. The downstream starts on the preliminary information of the upstream stages and the change of upstream will affect the progress of the downstream. On the other hand, the downstream supports feedback information to the upstream. However if we take an in-depth look at the development stages, we can see that concurrent execution of design stages actually occurs within two sub-stages (Testing 1 and Development 2) which are sequentially dependent. Therefore, if we can optimize the concurrency between Testing 1 and Development 2 and reduce the total development time of them, the project cycle time will be reduced accordingly.

The product development process shown in Figure 2 is generic and common to many organizations. Therefore, we conclude that concurrent execution often occurs between two dependent sub-stages and project cycle time can be reduced by optimizing the concurrency of these sub-stages. This conclusion supports previous CE studies based on dependent stages.

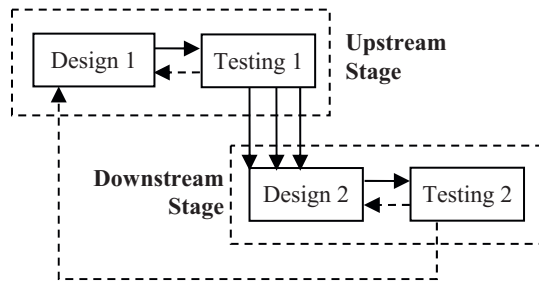


Fig.2. Information flows between two consecutive development stages

B. CE Models based on Interdependent Stages

Several CE models are built based on interdependent stages where the information flows in both ways. For example, Joglekar et al. (2001) proposed a performance generation model to determine the optimal degree of concurrency with the goal of maximizing project performance with deadline constraints [25]. Bhuiyan et al. (2004) proposed a discrete event simulation model to study the impact of CE and functional interaction on project performance. Lin et al. (2008) proposed a Dynamic Development Process Model for managing overlapped iterative product development, and validated the model with an in-depth case study at a handset design company.

IV. CONCLUSION

In summary, most CE models are built on the assumption that development stages are dependent where the principal information exchange between consecutive design stages is unidirectional, i.e., from upstream stage to downstream stage. According to literature review and field study, we believe such assumption is reasonable, because in many situations, current execution of design stages actually occurs within two sub-stages (Testing 1 and Development 2) which are sequentially dependent.

Several CE models are built based on interdependent stages where the information flows in both ways. Because of the complex information flows among interdependent stages, most of them use simulation to explore the linkage between CE policies and product development performance. In the future, we may build analytical models based on interdependent stages so as to better understand the impact of project properties on best CE policies and product development performance.

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