Overlapping in Distributed Product Development

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Abstract

Market and technology changes have brought about new characteristics of product development. One of the most significant changes from the traditional to the new paradigm is the change from sequential and collocated product development process to overlapped and distributed process. This paper explores the appropriate overlapping policy in distributed product development. Firstly we developed a system dynamics model for overlapped product development in which upstream evolution, downstream sensitivity, and resource constraints are explicitly simulated. Then the analysis is done based on the model and the data from a mobile phone development project. The simulation results show that it is very dangerous for a company to develop innovative products with distributed teams. Not only coordination difficulty but also wrong overlapping policy makes delay unavoidable for the distributed and highly innovative projects. The simulation results are empirically proven by our experience in the consumer electronics companies and previous literature.

1 Introduction

The practice of geographically distributed product development (DPD) is ever increasing because of the globalization of markets and the complication of products. DPD is also facilitated due to advances made in the communication technology, particularly the creation and growth of the Internet. Siemieniuch and Sinclair (1999) reported that 40 – 80% of an automobile was developed by suppliers. Designs outsourced in PDAs, notebook PCs and mobile phones were 70%, 65% and 20% respectively (Engardio and Einhorn, 2005). A survey done by Booz Allen Hamilton and INSEAD shows that about 36% of projects were conducted across two or more sites in the 186 companies from 19 countries (Doz et al., 2006).

Distributed product development teams can incorporate different expertise, technologies and facilities in different companies and may have the potential to offer high performance, but they often fail to realize that potential and face more coordination challenges (McDonough III et al., 2001; Sosa et al., 2002). This may stem from the divergent cultural values, functional barriers, goal incongruity and geographical distance of distributed teams (Doz et al., 2006), which can lead to difficulty in developing a task strategy (Anderson 1983), resolving conflicts constructively (Kirchmeyer and Cohen 1992) and building cohesion (Watson et al. 1993). While achieving effective cooperation is not a simple task even among teams which are geographically proximate (Benson-Armer and Hsieh 1997, Donnellon 1993), it is more difficult for teams come from different cultures and are geographically dispersed to achieve effective teamwork (Benson-Armer and Hsieh 1997). Consequently, the product development cycle time is much higher in a distributed environment than in a conventional project management environment.

In order to reduce project cycle time, overlapping is becoming the widely used method for product development. Lawson and Karandikar (1994) reported that 96% of the respondents in their survey were planning or implementing concurrent engineering. Clark and Fujimoto (1989b) recognized the coordination difficulty for overlapped and distributed product development process. To facilitate overlapping, they recommended frequent and face-to-face communication between teams to exchange critical information (Clark and Fujimoto 1991). However collocated cooperation may be not easy for distributed projects. For example many international companies develop their products by the teams in different countries. It is almost impossible to ask them to frequently fly between the countries. These recommendations are useful to facilitate overlapping, but coordination difficulty still exists for most overlapped and distributed projects. Much previous research has focused on the development of technologies and methods to support distributed or cooperative product development (Smith and Blanck, 2002; Dahan and Hauser, 2002; O'Sullivan, 2003). Different from these studies, we examine the effect of coordination rate on overlapping policy based on a system dynamics model.

Some previous research has studied overlapping policies for product development. Clark and Fujimoto (1989a) observed that project lead time was reduced in auto industry by overlapping development activities. Roemer et al. (2000) developed an analytical model without including coordination and proved the "overlapping rule" that project lead time always decreases when overlapping degree increases. The optimal communication frequency in overlapped process was proposed by Loch and Terwiesch (1998). However the relationship between coordination rate and optimal overlapping policy is not studied in their research. Therefore our research seeks to answer the following questions:

1) How will optimal overlapping policy changes with the change of coordination rate?
2) How will upstream evolution and downstream sensitivity affect optimal overlapping policy in distributed product development?

The rest of the paper is organized as follows. In Section 2, we develop a simulation model for distributed product development process. Section 3 analyzes the relationship between project performance and overlapping policy with the data from a mobile phone development project.

After that the sensitivity of optimal overlapping policy to the values of the parameters is analyzed. Conclusions are summarized in §5.

2 The Model

We follow the information-based view of product development (Clark and Fujimoto 1991) in which individual development activities are viewed as the information-processing units that receive information from their preceding activities and transform it into new information to be passed on to subsequent activities. Figure 1 shows the information transformation between two development phases. Preliminary information of the upstream phase is available at t_{Es} and is continuously modified until t_{Ls}. The downstream phase can start at any point between t_{Es} and t_{Ls}. To analyze the optimal overlapping policy for distributed process, we will model the process in detail. The performance measure in this paper is project lead time.

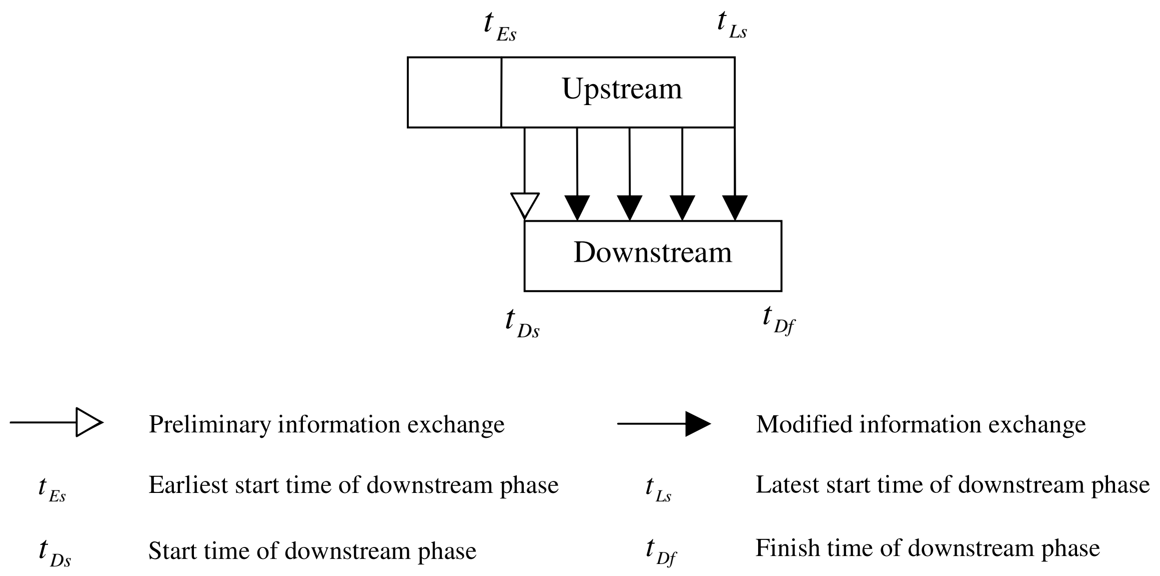

Figure 1: Overlapped product development process

2.1 Overview of the model

The gain from overlapping must be weighted against the delay for rework which results from the modification of upstream information (Krishnan et al. 1997). For example, a mould may be fabricated exactly according to the specifications. However, when the product design is changed, the mould will have to be revised or re-fabricated. Krishnan et al. (1997) developed a framework to study this phenomenon in which two concepts determine the overlap trade-off. "Upstream information evolution" is defined as the process of modification in upstream phase. "Downstream sensitivity" is defined as the rework needed to incorporate upstream changes. These concepts have had a strong influence on the literature on overlapped product development (eg. Roemer and Ahmadi 2004) and they are closely related to our model.

Our study focuses on the lead time of two development phases, upstream phase and downstream phase. The reader can picture upstream phase as detail design and downstream phase as mold fabrication. In order to describe the "upstream information evolution" and downstream sensitivity" we model the flows of upstream development errors and downstream tasks. Within the upstream phase development errors can either reside in the stock of *Errors Remaining* (E_m), the stock of *Errors to be Rectified* ($E_{t\gamma}$), or have been rectified and reside in the stock of *Errors Rectified* (E_γ). In the downstream phase tasks can either be in the stock of *Tasks Remaining* (T_m), the stock of *Tasks Completed* (T_α), the stock of *Tasks Corrupted* (T_β), or have been corrupted and coordinated, thus residing in the stock of *Tasks to be Reworked* ($T_{t\omega}$). We start to simulate the process from t_{Es} (time zero). The initial value of *Errors Remaining* is determined by upstream quality (*Q*). All the downstream tasks reside in the *Tasks Remaining* stock at t_{Es}. Thus, $E_m(0) = 1 - Q$, $T_m(0) = 1$, and $E_{t\gamma}(0)$, $E_\gamma(0)$, $T_\alpha(0)$, $T_\beta(0)$, and $T_{t\omega}(0)$ all equal zero.

2.2 Upstream Evolution

Modified information is generated when upstream errors are identified and reworked. This process is modeled based on a simplified stock and flow structure shown in Figure 2. The stocks represent the accumulation of tasks and the flows represent the rates of different development activities (Sterman 2004). *Upstream Errors* can only flow into the *Errors to be Rectified* stock and be rectified when prototype is prepared. The *Prototyping Duration* is representented as D_ρ. The time step of the simulation is τ. Therefore *Prototyping Rate* (ρ) is:

$$\rho = IF(t \geq D_\rho) THEN(E_m / \tau) ELSE(0) \qquad (1)$$

The rate at which upstream errors are rectified (γ) is determined by the minimum of the rate allowed by the amount of *Errors to be Rectified* ($E_{t\gamma} / \tau$) and the rate which is related to the *Resources Available for Rectification* (R_γ) and the *Average Rectification Rate* (A_γ). R_γ is the remaining resources to rectify upstream errors. The total number of Upstream Errors decreases when some of them are correctly reworked. Incorrectly reworked tasks will flow back into the *Upstream Errors* stock. This rework process is firstly shown in cooper's models (Cooper 1980, 1993a, 1993b, 1993c). It has had a strong influence on the literature on modeling product development processes (e.g. Ford and Sterman 1998, Repenning 2001, Joglekar and Ford 2005).

$$\gamma = Min(E_{t\gamma} / \tau, R_\gamma \times A_\gamma) \qquad (2)$$

$$\gamma_s = \gamma \times Q \qquad (3)$$

$$\gamma_f = \gamma \times (1 - Q) \qquad (4)$$

2.3 Downstream Process

The development process of downstream phase is composed of initial completion, coordination, and rework. *Completion Rate* (α) is the minimum of the rate allowed by the *Tasks Remaining* (T_m / τ) and the rate determined by the *Resource Available for Completion* (R_α) and the *Average Completion Rate* (A_α). These relationships are represented in the following equations:

$$\alpha = Min(T_m / \tau, R_\alpha \times A_\alpha) \quad (5)$$

Based on the concept of downstream sensitivity (Krishnan et al. 1997), when development errors of an upstream phase are found and corrected after starting the downstream phases, some tasks may be corrupted. Krishnan et al. 1997 propose that *Tasks Corrupted* is related to the amount of changes of the upstream phase and the sensitivity of downstream phase. Loch and Terwiesch claim that the more downstream phase has progressed, the more tasks may be corrupted. Therefore the *Corrupting Rate* (β) is the product of *Rectification Rate* (γ) of upstream phase, *Sensitivity* (S), and *Tasks Completed* (T_α) of downstream phase. Note that corruption only happens when *Tasks Completed* is not equal to zero. These relationships can be presented as follow:

$$\beta = \gamma \times S \times T_\alpha \quad (6)$$

In our model the set-up time for communication is not considered because it is not significant for e-mail or phone call. This assumption is consistent with previous work (e.g. Ford and Sterman 1998). The *Coordination Rate* (μ) is the lesser of the the rate allowed by the *Tasks Corrupted* and the *Average Coordination Rate* (A_μ).

$$\mu = Min(T_\beta / \tau, A_\mu) \quad (7)$$

The *Rework Rate* (ω) of the corrupted tasks is the minimum of the number of *Tasks to be Reworked* ($T_{t\omega}$) divided by the time step (τ) of the simulation model and the product of *Resource Available for Rework* and *Average Rework Rate* (A_ω).

$$\omega = Min(T_{t\omega} / \tau, R_\omega \times A_\omega) \tag{8}$$

2.4 Resource Constraints

Resource constraints (e.g. the amount of engineers available) are included in our model, since it can strongly influence project lead time (Joglekar and Ford 2005). The total amount of resources for either upstream phase or downstream phase is set to 100%. Resources are allocated in the following order: first priority is given to coordinate the corrupted tasks; second priority is given to complete the tasks remaining; and any remaining resources are allocated to redo the tasks or errors. We assume the amount of resources needed for coordination is the same for upstream and downstream phases. These assumptions are consistant with our case study and previous literature (e.g. Repenning 2001). The resources used by coordination is the quotient of the *Coordination Rate* (μ) by the *Average Coordination Rate* (A_μ). Similarly the resources used by completion is the quotient of the *Completion Rate* (α) by the *Average Completion Rate* (A_α). Therefore mathematiclly:

$$R_\gamma = 1 - \mu / A_\mu \tag{9}$$

$$R_\alpha = 1 - \mu / A_\mu \tag{10}$$

$$R_\omega = R_\alpha - \alpha / A_\alpha \tag{11}$$

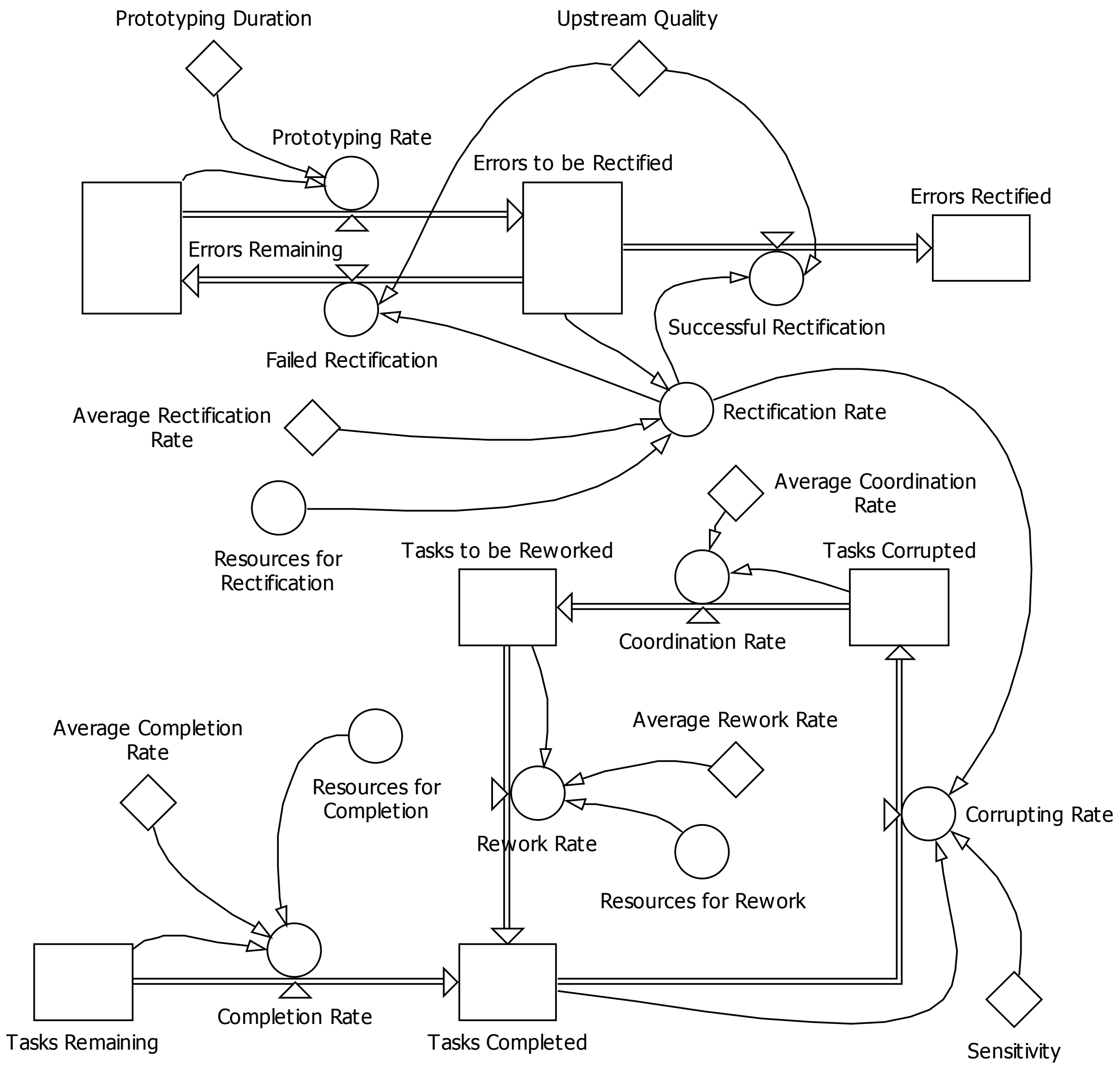

Figure 2: The detailed model

3 Base Case

Our case study was done in a mobile phone development company. This company operates in a business-to-business market, meaning that its customers are other companies, not end users. For each development project, four distributed development teams from different companies are involved. The team from the customer company provides the requirements for the product. Then the design company develops the product accordingly. After that the tooling company fabricates moulds and manufactures the components. Finally original equipment manufacture assembles the mobile phones and tests their performance. Our focus is specifically on the overlapping of detail design and mold fabrication phases, since these phases are done by distributed teams and overlapping of these phases is used to reduce project lead time:

1) *Detail Design:* According to the requirements of the customers the development company designs the mechanical components and the electrical circuit. After they are initially completed the prototypes are made. Then the design team tests the mechanical and electronic performance of the product. Modified information is generated when the development errors are identified and rectified.

2) *Mold Fabrication*: The molds of the components are developed according to the information from the detail design phase. The mold fabrication is very sensitive to the changes in detail design. For example, Figure 3 shows the dimensions related to slot A and slot B. There are four dimensions for the slots, so that the change of one dimension accounts for 25% of detail design. However the change of dimension 2, 3, or 4 will cause 50% of the slots changed and the change of dimension 1 will corrupt all the slots.

A typical project with coordination difficulty is selected to study the relationship between overlapping and coordination difficulty. The detail design phase of the project is done by the design company, which is located in Shanghai China. The molds are made by one of their suppliers, which is located in Shenzhen China. The distance between these companies is more than 1000 kilometers. The data listed in Table 1 was obtained based on the interviews with the project managers, mechanical engineers and quality engineers who take in charge of the project.

We assume the development errors must be solved before the product can be launched to the market. The purpose of our study is to minimize the duration from t_{Es} to t_{Df} through appropriate overlapping of the phases.

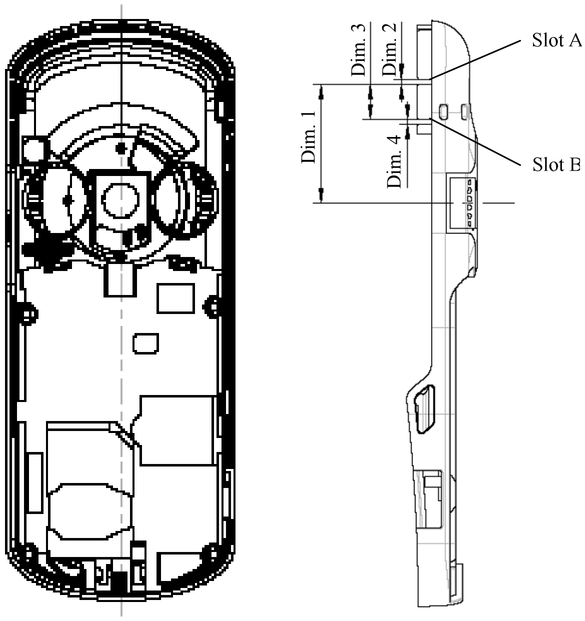

Figure 3: Base rear of a mobile phone

Table 1: Model Parameters

Parameters	Definition	Value
D_p	Prototyping Duration of Upstream Phase	1/12 per day
Q	Upstream Quality	0.55
D_r	Rectification Duration of Upstream Phase	1/28 per day
D_c	Completion Duration of Downstream Phase	1/30 per day
S	Sensitivity of Downstream Phase	1.6
D_k	Coordination Duration	1/30 per day
D_w	Rework Duration of Downstream Phase	1/20 per day

The simulation results are shown in Figure 3. From traditional point of view, managers usually try to overlap as much as possible when the time-to-market is urgent. For example the engineers in the case company usually ask the tooling company to start mold fabrication as soon as initial information is available. This is because the company wants to avoid the delay which happens for most product development projects. However the simulation results show that excessive overlapping may not only increase rework of downstream phase but also increase project lead time. The rule that overlapping can always reduce project cycle time may not work for the projects with coordination difficulty. This increases the difficulty for the application of overlapping policy. Then further question arise. Is the "overlapping rule" not suitable for all the projects with coordination difficulty? In the next section we will examine the sensitivity of the optimal overlapping policy to the changes of coordination rate, upstream information evolution and downstream sensitivity.

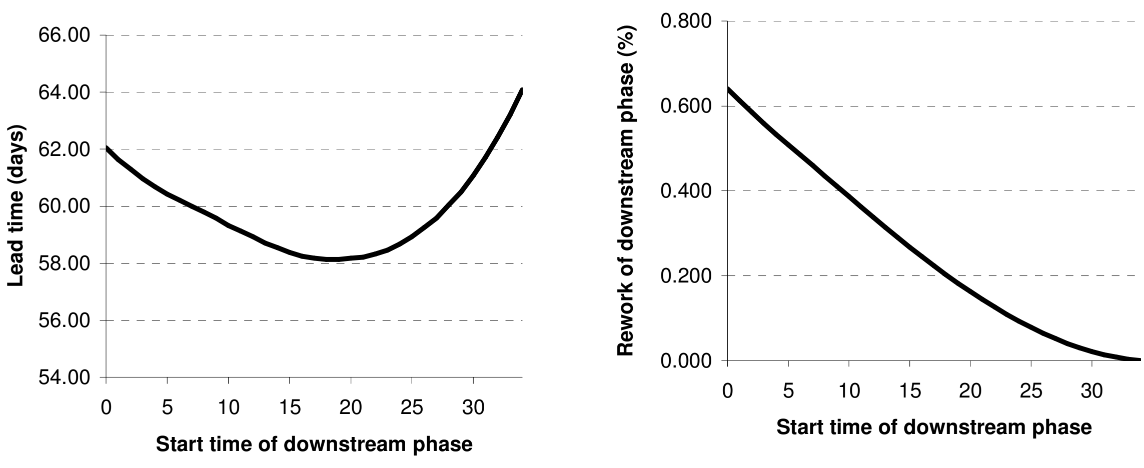

Figure 4: Impact of overlapping policy on project performance

4 Sensitivity Analysis

To examine the relationship between the parameters and the optimal overlapping degree, we simulated the model with different levels of coordination, upstream information evolution, and downstream sensitivity. Firstly we analyze how the optimal overlapping degree varies with the change of the coordination duration. As shown in Figure 4, the optimal starting time changes significantly with the change of coordination duration. When coordination duration is short, the optimal overlapping policy is to start the downstream phase as soon as preliminary information is available. We know most collocated product development projects do not have significant coordination problems. For these projects, overlapping is always related to less project lead time. It is observed by researchers, such as Clark and Fujimoto 1989, from different industries and proven by Roemer et al. (2000). However for distributed teams from different companies, the goal incongruity, cultural diversity, distance makes coordination very difficult. When the coordination duration is bigger enough overlapping may not works for reducing project lead time. As Figure 4 shown, when coordination rate is larger than 1/15 per day the overlapping rule keeps true. However the optimal overlapping policy is to start the downstream phase in the 16th days if coordination rate reduced to 1/25 per day.

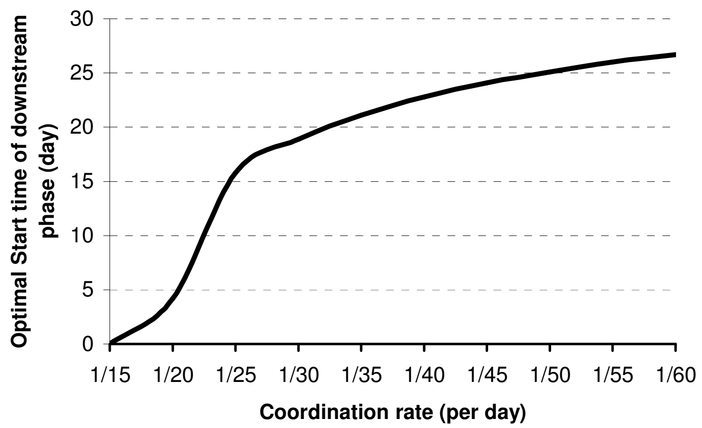

Figure 5: Impact of varying coordination duration

In Figure 6 and 7, we show the relationship between overlapping policy and the other parameters. All of these parameters are related to optimal overlapping policy. However the upstream quality has more significant impact on optimal overlapping degree. When upstream quality is good enough, we can simply reduce project time through increasing overlapping level.

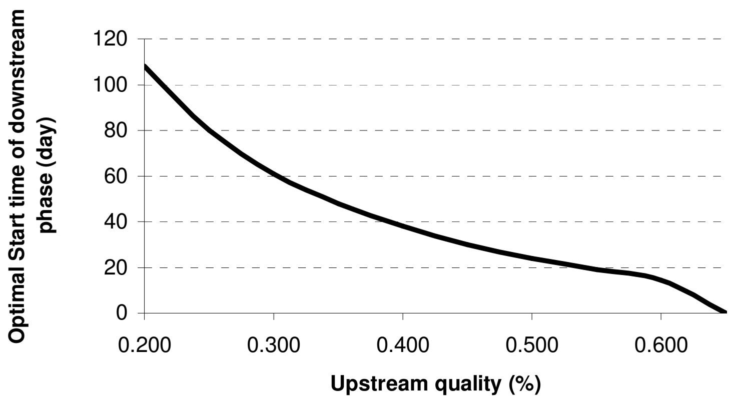

Figure 6: Impact of varying upstream quality

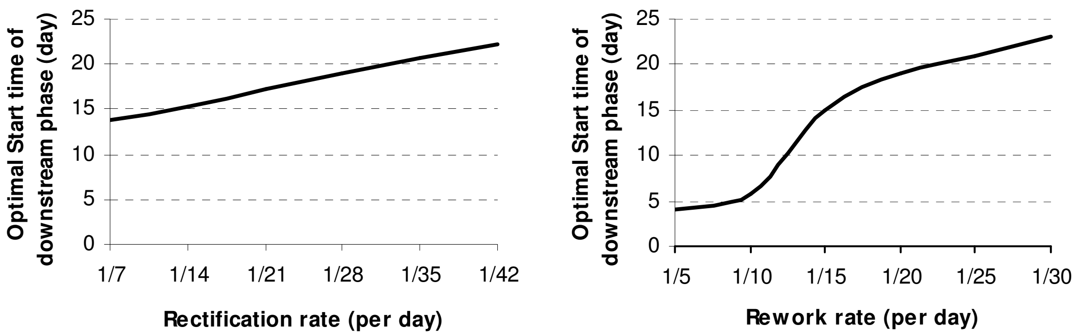

Figure 7: Impact of varying upstream and downstream rework duration

5 Discussion and Conclusion

We have developed a system dynamics model of overlapped and distributed product development. The risk associated with overlapping in distributed product development is examined based on our model. For collocated projects, the rule that overlapping reduce project lead time has been empirically and theoretical proven. However our study shows that it may be not the truth when coordination takes time. Furthermore optimal overlapping is very sensitive to the coordination rate. This increases the difficulty for project management. We also studied the change of overlapping policies in distributed product development when the evolution speed of upstream phase and the sensitivity of downstream phase change. It shows that overlapping policy is also very sensitive to the quality of upstream phase. When coordination rate and upstream quality are reduced, the optimal overlapping point leaves the maximum overlapping point and changes continuously with the change of the important parameters. It's almost import impossible to estimate the optimal overlapping degree in this case if we cannot get the exact value of the input parameters. Therefore our study suggests that it will be very dangerous for a company to develop products with high uncertainty in distributed teams with coordination difficulty.

While a major benefit of overlapping is the potential for reducing product development lead time, it may not work when coordination is difficult. The upstream evolution may take more time in overlapped process, because the coordination delays the rework process of upstream phase. The downstream rework process may be more difficult than initial completion if we take into account the effort of coordination for the downstream engineers. Therefore, when preliminary upstream information with high uncertainty is utilized by the downstream phase, the project lead time and development effort may be increased at the same time. This makes the empirical rule, overlapping urgent projects as much as possible, does not work in distributed product development process.

According to our analysis and previous research, the optimal overlapping policy is to overlapping as much as possible when coordination time can be omitted and performance measure is project lead time. Therefore some companies improve coordination through temporary collocation of closely related teams. A recent survey (Doz et al. 2006) jointly done by INSEAD and Booz Allen Hamilton shows that Automotive and Electronics and Electrical Engineering are likely to send staff to sit in partner organizations. Convergence and the complexity of product architectures necessitate temporary collocation as a mechanism to transfer complex and professional information from different industries.

We have kept the model as simple as possible in order to focus on structural results. Several aspects of this study merit further examination. Firstly, our model may be further developed to analyze resource allocation policies for overlapped phases. Secondly, we may need to extend our model to explore suitable policies for managing multiple overlapped projects. Thirdly, the model may be augmented to study the projects in which the downstream phase can detect upstream errors. In this case the overlapping policy will not only change the coordination and rework of downstream policy but also change the evolution of upstream phase.

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