

# Research on Coordination Strategy of New Product Development Teams Based on Task Overlapping

Ting Lu

School of Management, Jinan University of China, Guangzhou, China

Email: mia\_luting@163.com

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## Abstract

The paper took the most upstream and downstream task in enterprise new product development as the most typical scenario. Then deeply analyzed the task characteristics and theoretically refined the causes and processes of task overlap and coordination. On this basis, this paper proposed the upstream and downstream ability level functions. The downstream's rework function was given based on the influence of the random modify of the upstream. Furthermore, a coordination model is constructed in order to minimize the total development time. Correspondingly, the optimal start time, coordination times and coordination time interval are calculated. The effectiveness of the model is verified by an enterprise example. The paper found that coordination can effectively reduce downstream rework. The characteristics of development tasks and downstream task interdependence have important effects on the optimal coordination strategy.

## Keywords

Coordination Strategy, Ability Level Function, Task Overlap, Rework Function

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## 1. Introduction

With the rapid change of consumer demand and the continuous renewal of technological means, product competition between markets becomes more and more fierce. New Product Development (NPD) has become the key for enterprises to survive and maintain competitive advantage [1] [2]. It often takes more than six months for an App to put on sale from customer demand analysis. The long development cycle not only increases the operating cost of an enterprise,

but also has a negative impact on product profits. Therefore, under the condition of limited product life cycle, accelerating development speed not only helps enterprises to reduce costs, but also prolongs product sales time to a certain extent, making enterprises occupy a higher market share and sales profits [3]. However, the successful development of products requires not only the cooperation of team such as concept, prototype design, process, trial production and inspection, but also the rational division of labor and efficient coordination of such complex development tasks. It cannot satisfy the needs of product development when follow the traditional model of labor division. Therefore, it is necessary to explore a deeper coordination mode in theory.

Based on theoretical research and enterprise practice, this paper argues that coordination is essential way to manage the development tasks, and the goal is to promote the organization's operational efficiency. The research on task overlap mostly involves the related content. For example, Guangleng [4] argues that by overlapping some sub-tasks, downstream work can make use of the information provided by upstream in time. Takeuchi [5] also pointed out the key to development lies in the transition of different stages, which facilitates communication and feedback and promotes coordination and cooperation.

However, task overlap often results in an additional rework while shortening the product development period [6]. Reviewing the relevant research, we first focus on overlapping scheduling problems, such as Liyan, etc. [7] introducing iterative learning rate and combining the upstream and downstream information interaction mode with its impact on rework volume to build project schedule calculation model; Jing [8] dividing task overlap into natural and compulsory cases, and using DSM, overlapping task time factor matrix and overlapping rework impact matrix to quantify overlap and overlap. The impact of rework is on time and resources. However, the above considerations are mainly about the determination of task duration and rework time. Subsequently, some scholars considered the impact of overlap on rework and task duration, such as Wang [9] through the construction of a multi-upstream and multi-downstream design task group, to study the impact of different overlap degrees on downstream rework volume; Wang [10] through considering information evolution and change sensitivity, analyzed the impact of complex project lead time on rework volume. However, there is no consideration between task overlap degree, rework amount and total working time, so it's hard to reflect the basic law of task coordination.

Communication strategies between overlapping tasks are another research focus. Terwiesch [11] constructed a coordination model in parallel tasks to consider the impact of information uncertainty on downstream processes; Zhaoyun [12] used information accumulation function to describe the upstream information progress model and the accuracy of information transmission downstream, and reflected the impact of information transmission strategy on rework volume and total time by setting thresholds that caused information transmission be-

tween the two sides; Qing [13] based on Multi-communication-risk overlap model optimizes downstream rework caused by upstream information changes and explores communication strategies during overlap. However, the above studies either only consider the impact of overlap on rework time without further optimization of rework time, or only explore the impact of communication strategies on the optimization of rework volume under certain overlap degree. In terms of joint optimization of overlap degree and communication strategy, Lin [14] considered the impact of upstream task changes on downstream in the context of overlap of manufacturing tasks, and aimed at maximizing the net benefits of overlap, explored the optimal downstream task intervention time and information transfer interval; Youling [15] constructed a knowledge potential function to represent the upstream and downstream task process, and calculated it according to the rework probability function. In order to maximize the amount of effective knowledge transfer, a mathematical model is constructed and solved by simulation. However, these studies have not paid enough attention to the characteristics of tasks or explored the specific impact of characteristics on rework and total working time.

This paper re-examines task overlap in new product development from the perspective of coordination. Firstly, taking the upstream and downstream tasks as the most representative research object, it deeply analyses the connotation of task interdependence, so as to refine and construct the evolutionary function of upstream and downstream ability level. On this basis, considering the probability of upstream modify, it compares and analyses the degree of overlap under different task characteristics. Through theoretical research and numerical analysis of enterprise examples, the optimal coordination strategy is obtained. While deeply analyzing the essential law of coordination in new product development, this paper also provides theoretical and methodological reference for relevant research.

## **2. Research on Coordination Strategy of New Product Development Teams Based on Task Overlapping**

### **2.1. Interdependence of Product Development Tasks**

In practice, enterprises often decompose the development task into a system composed of multiple sub-tasks [16], which usually includes creative collection, evaluation and screening, product design, production, trial selling, etc., and is completed by teams with corresponding profession. Because the degree of clarity of a task is closely related to the progress of related tasks, the team can not only master the knowledge required by his own tasks and ignore the learning of other knowledge. Referring to the concepts in literature [17] [18], this paper calls it task interdependence. However, the professional task needs of each team are gradually understood and mastered, and the difference in career and department between upstream and downstream may lead to a deviation in the understanding of the same task. Therefore, teammates must reach an agreement with re-

lated one in an effective way, to improve the overall ability level.

When the regular working time of upstream and downstream is fixed, the high degree of task overlap means that the downstream starts work earlier, which directly saves more development time. However, the downstream needs to transfer relevant work input from upstream, and the overlapping tasks need to integrate the working result of both stream through coordination. For example, the work of the functional design team is based on the customer needs and business processes transmitted by the requirement analysis team, but it is difficult for both sides to accurately judge whether they understand each other's tasks in the initial stage. When the design team works for a period of time, the feedback of the two steams will be clearer through in-depth discussion, exchange and learning, and other related coordination activities. The input needs of the business and the key points of the next step, and both steam will revise and update their own working results. Therefore, the degree of task overlap and the accuracy of upstream outputs transition at the beginning of overlap will greatly affect the subsequent development costs. The balance of time and cost becomes the focus of coordination.

## **2.2. Rework and Coordination Process in Task Overlapping**

This paper holds that the improvement of upstream ability level means that its understanding and description of the task is more accurate and reliable, and the transferred results is more accurate for downstream. The downstream accepts it and adjusts its own work, if some of the understanding transferred earlier is ineffective for completing the task, and additional time must be added to make up for it. Therefore, the lower the degree of overlap means that the later the downstream starts working, the less time directly saved by overlapping, but the higher the ability level in the upstream, the lower the total amount of transferred modify, thus reducing the risk of downstream rework.

Multiple coordination during the overlap period pre-responds to the risk of rework caused by overall overlap. However, coordination once understanding modify occurred will not only lead to the increase of costs, but also affect the completion of development plan. Therefore, upstream often choose to transfer the accumulated the times of modify in a period of time to downstream. That is to say, after determining the degree of task overlap, it is still necessary to optimize the upstream and downstream coordination strategy.

## **2.3. The Calculation of Rework Time in Task Overlap**

This paper assumes that the upstream first coordinates with the downstream at the beginning of overlap and transfers the understanding to the downstream at present, which is absorbed and internalized by the downstream as the basis inputs for his own task. After a period of time, the ability level of both sides has changed and the second coordination has begun. The upstream transfers the modified understanding during this time, and the downstream revises and improves the completed work accordingly. In addition, the changed understanding

will support the downstream work in the next period of time. By analogy, after a period of time, the next coordination will be carried out, until the upstream sub-task is completed, the task overlapping will end, and the downstream will continue to complete his remaining work.

Based on the above principles, the idea of calculating rework time in task overlap is as follows. Firstly, the ability level functions of upstream and downstream are determined (usually linear or exponential functions related to time); secondly, the intensity function of upstream modify is set to determine the total amount of understanding modify under different initial ability levels and overlap start times, and the times of coordination is determined. Task overlap is divided into sub-stages with the same length of time, and the amount of modify in each sub-stage is obtained. Finally, the sum of the product of downstream ability level growth and the degree of influence of these modify is the total amount of rework in the downstream, and the rework time is calculated accordingly.

### 3. Coordination Model of Product Development Team Based on Task Overlapping

#### 3.1. Upstream and Downstream Ability Level Function and Upstream Understanding Modify Intensity Function

Generally speaking, the ability level of the upstream and downstream reaches of the development tasks increases gradually with time, which is reflected in the continuous improvement of each person. In view of the different growth paths of ability level in the planned time, there are similar function expressions in literature [15] [19] [20]. On the basis of drawing lessons from their ideas, this paper proposes that the ability level functions of upstream and downstream in the planned task cycle are respectively:

$$f(t) = (1 - k_u) + k_u \cdot \left(\frac{t}{T_u}\right)^{\alpha_u} \quad (1)$$

$$g(t) = (1 - k_d) + k_d \cdot \left(\frac{t - t_0}{T_d}\right)^{\alpha_d} \quad (2)$$

$f(t), g(t) (0 \leq f, g \leq 1)$  respectively represent the ability level of upstream and downstream at time  $t$ , where upstream  $t \in (0, T_u)$ , downstream  $t \in (t_0, t_0 + T_d)$ , when  $f(t), g(t) = 1$ , it is considered that the task has been completed.  $T_u$  and  $T_d$  represent the scheduled completion time of upstream and downstream tasks respectively,  $k_u, k_d (0 \leq k \leq 1)$  represent the amount of ability needed to improve in the development process of upstream and downstream respectively. The larger  $k$ , means the lower the initial ability level of upstream and downstream, and  $k = 1$  indicates that the upstream and downstream have no foundation but can only improve their ability level in the development process. In order to describe the process of ability evolution from initial state to termination value during the upstream (downstream) task, the concept of ability level evolution degree of upstream (downstream) is proposed with reference to the idea of

reference [21], which is expressed by  $\alpha_u$  and  $\alpha_d$ , respectively. Among them,  $0 < \alpha < 1$  indicates that the level of ability is fast evolving, and the growth rate mainly occurs in the early stage of the task, then slows down gradually,  $\alpha = 1$  indicates that the level of ability increases linearly,  $\alpha > 1$  indicates that the level of ability evolves slowly, and the growth rate mainly occurs in the late stage of the task and increases gradually.

On the other hand, this paper assumes that upstream ability level will also affect the modify of understanding transfer. The number and time interval of upstream ability change in a period of time are random and uncertain, which need to be analyzed by means of stochastic process theory. Literature [14] [22] found that the change of upstream and downstream information transmission can be regarded as a time-dependent non-homogeneous Poisson process, which can be expressed concisely by means of the modify intensity function. Inspired by this, this paper proposes the following principles of modify, if the intensity of understanding modify decreases with the increase of ability level, it shows that the transferred understanding can quickly stabilize to the final state, and the probability of ability change decreases. Otherwise, it means that the probability of understanding modify increases after that. Therefore, the intensity function of modify based on the change of upstream ability level constructed in this paper is as follows:

$$\mu(t) = \mu \cdot [1 + \varepsilon \cdot (2f(t) - 1)] \quad (3)$$

The uncertainty of modify inherent in the development task is expressed in  $\mu$ , which is the main reason for the risk of rework in overlapping tasks. The factors such as the synthesis of customer demand, the changeability of customer demand and the rapid change of development technology lead to certain uncertainties in the process of development, which are generally determined by experience;  $\varepsilon (\varepsilon \neq 0)$  is the shape parameter of function,  $\varepsilon < 0$  indicates that the probability of modify decreases with the increase of ability level, and the transferred understanding can be rapidly stabilized to the final value, which belongs to rapid evolution, otherwise it belongs to slow evolution. In this paper, I argued that development tasks are gradually clear and perfect with the task process. For example, in the early stage of R&D, product managers make brief functional planning and build basic pages according to customer needs. The design is relatively vague. Then, developers gradually define the functions of specific modules and realize the functions of each module through coding. This process clearly reflects the characteristics of rapid evolution. Based on this, this paper rationally simplifies the process, and takes  $\varepsilon = -1$ .

### 3.2. Downstream Rework Function

Inspired by the rework caused by information changes in references [23] [24], this paper assumes that the impact of upstream understanding modify on downstream is a certain proportion of its completed work, which can be expressed by downstream's task interdependence  $m (0 \leq m \leq 1)$ .  $m = 0$  means that there is no dependency relationship between the two tasks and they can be completed

independently;  $m = 1$  means that there is a complete dependency relationship between the two tasks, and any understanding modify in the upstream will lead to the complete rework of downstream. Because these two extreme cases are very rare in practice, it is reasonable to set  $m \in (0, 1)$ .

If there is a modify in the upstream understanding in a certain period, the amount of ability that the downstream increases in that period  $\theta$  will decrease to  $\theta \cdot (1 - m)$ , two times to  $\theta \cdot (1 - m)^2$ , and so on. Then downstream rework is related to three factors: downstream increased ability, upstream transferred understanding modify times and downstream task dependence. Assuming that the latter is unchanged in the task process, the former two are related to the growth of ability level in the upstream and downstream periods, and the specific time point  $t_i$  is determined by two adjacent coordination time points.

According to the integral of  $\mu(t)$ , there are totally  $\int_{t_i}^{t_{i+1}} \mu(t) dt$  times of understanding modify occur in the upstream during the two adjacent coordination intervals. The downstream rework immediately after understanding modify, which is reflected in the instantaneous decrease of downstream ability after coordination. Then the understanding modify during this period will lead to the downstream increased ability  $\Delta g(t_i)$  dropped to  $\Delta g(t_i) \cdot (1 - m)^{\int_{t_i}^{t_{i+1}} \mu(t) dt}$ . Therefore, the amount of rework in the downstream during this period is  $\Delta g(t_i) \left\{ 1 - [1 - m]^{\int_{t_i}^{t_{i+1}} \mu(t) dt} \right\}$  and the rework time is calculated accordingly.

However, for calculating the total development time, the ratio of regular working time and rework time is not the focus of this paper, but the rework time over the planning period will obviously affect the total working time.

At the last time of coordination, the understanding from upstream to downstream will not modify anymore, and then the downstream will continue to improve the ability until the task completion. Then, by accumulating the downstream rework quantity in each sub-stage, the total rework quantity  $Q_r$  of downstream in the overlapping period can be obtained as follows:

$$\sum_{i=0}^{n-1} [g(t_{i+1}) - g(t_i)] \cdot \left\{ 1 - [1 - m]^{\int_{t_i}^{t_{i+1}} \mu(t) dt} \right\} \quad (4)$$

By deriving  $g(t)$ ,  $V = \frac{(t - t_0)^{\alpha_d - 1} \cdot \alpha_d K_d}{T_d^{\alpha_d}}$  is obtained which reflects the growth rate of downstream ability. This paper assumes that the downstream rework rate  $V_r$  is constant and not greater than its ability increasing rate  $V_r \in \left( 0, \frac{\alpha_d K_d}{T_d} \right)$ .

In addition, although each rework requires additional downstream working time to be supplemented after the coordination, the ratio of  $Q_r$  to  $V_r$  is called downstream rework time  $T_r$  in this paper for convenience of calculation.

$$T_r = Q_r / V_r \quad (5)$$

### 3.3. The Establishment of Coordination Model

Combined the process of ability level evolution and task coordination between

upstream and downstream tasks during overlapping, the regular working time of upstream and downstream tasks is  $T_u$  and  $T_d$  respectively. The beginning time of overlap is recorded as  $t_0$  ( $\underline{t} \leq t_0 \leq T_u, \underline{t} = \max(0, T_u - T_d)$ ). When the upstream task is completed, the total overlap time is  $T_u - T_d$ . During the overlapping period, the two streams conduct  $n+1$  times coordination (including the beginning and the completion time) and the coordination takes  $T_t$  per time. Then the time of each coordination can be add and calculate together. The total overlapping time is  $T_u - t_0$ . Thus, the time interval of adjacent two coordination is determined to be  $\Delta T = (T_u - t_0)/n$ .

In this paper, the model optimization is to minimize the total development task time  $Z$ , which includes three parts: regular working time  $t_0 + T_d$ , coordination time  $(n+1) \cdot T_t$ , and downstream's rework time  $T_r$ .

$$Z = t_0 + T_d + (n+1) \cdot T_t + T_r \quad (6)$$

It is worth pointing out that formula (6) is a general principle expression of objective function. In order to realize the analysis and calculation of specific function analytic formula, explicit expression must be obtained according to specific parameter characteristics. For example, when the ability level of upstream and downstream increases linearly and the rework rate is the fastest, so  $\alpha_u, \alpha_d = 1$ ,  $\varepsilon = -1$ ,  $V_r = \alpha_d \cdot K_d / T_d$ . So it can get the coordination model of upstream and downstream in the overlapping period of tasks by introducing the above various kinds and constraints (6):

$$\begin{aligned} \min Z &= t_0 + T_d + (n+1) \cdot T_t + \sum_{i=0}^{n-1} \frac{(T_u - t_0)}{n} \cdot \left[ 1 - (1-m)^{\frac{\mu K_u (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u}} \right] \\ \text{s.t. } &\underline{t} \leq t_0 \leq T_u, \quad \underline{t} = \max(0, T_u - T_d) \\ &n \cdot \Delta T = T_u - t_0, \quad n \leq \frac{T_u - t_0}{T_t} - 1, \quad n \in N^* \\ &t_i = t_0 + i \cdot \Delta T, \quad i \in N \end{aligned} \quad (7)$$

It should be pointed out that task coordination is conducive to reducing downstream rework caused by understanding modify in overlapping period as much as possible. The time saved is  $T_u - t_0 - T_r$ , while the cost of coordination is  $(n+1) \cdot T_t$ . Managers need to balance the cost and benefit of task overlap and coordination. In the optimal case, multiple coordination reduces the amount of rework to zero, and the longest time saved by overlapping is  $T_u - t_0$ . Therefore, the times of coordination is always satisfies with  $n \leq \frac{T_u - t_0}{T_t} - 1$ .

To sum up, the decision variables in this paper are  $t_0, n$  and  $\Delta T$ , all of which have an impact on  $T_r$  and  $Z$ . It can be seen from the correlation like  $n \cdot \Delta T = T_u - t_0$  between them. For example, when the optimal  $t_0$  and  $n$  are determined, the solution of  $\Delta T$  can be obtained.

#### 4. Case-Based Numerical Analysis

As mentioned earlier, these decision variables are also affected by the type of



tasks (initial ability level, evolution degree, regular working time), the impact of modify (frequency, intensity) and other factors. Therefore, the discrete event system simulation method is used instead of the traditional mathematical analysis method to optimize the model. Firstly, a fixed time step is set, the continuous time period in the model is discretized into multiple time points, and the selection of overlapping start time is completely included in these time points. Secondly, the coordination times is set to be more than zero, which can be balanced by cost-benefit. The existence of the upper bound is strictly proved and the optimal solution is included in the range, so the value of the upper bound and the overlapping start time is simplified to a limited number of combinations. Finally, the optimal objective value and decision variables can be determined by comparing the corresponding objective value of each value combination.

So, this paper verified the optimization of the model for development time through an intelligent lighting equipment development project of an enterprise. The development project was completed by a product development department and a process design department of an OBM company. The product development department (upstream), with the assistance of the marketing department, summarizes customer needs and evaluates product develop ability, and designs after determining the design direction. The process design department (downstream) selects the appropriate process design based on the design scheme provided by the upstream, determines the product trial production process according to the existing conditions, and prepares the process tooling equipment to provide the type inspection and trial production review service after the product is trial-produced.

#### **4.1. Determination of Various Parameters in the Coordination Model**

As the product development department hopes to provide products with more new features to meet the changing and comprehensive customer needs. So they would lack of consideration for the realization of demand, the process design department is more concerned with product reliability, production process stability, and production revenue ratio. They hopes to use the original function as much as possible. In the context of the lack of professional understanding of others, the contradiction between the two streams has led to a decrease in the speed at which the two departments cooperate to deliver new products. After the product design department has modified the product design documents, if they are not coordinated with the process designers, the upstream and downstream will be repeated rework. Experts in related fields evaluate the parameters of the model based on the previous development experience of the company and the analysis of existing products.

1) The intelligent lighting equipment is an upgrade of the existing products. Based on the project records and development schedule documents of the previous product design, the regular working time of the upstream and downstream projects can be known.

2) The upstream is committed to the realization of specific functions and

product structures based on the determination of development needs. It is the main innovation stage in the development task and it's difficult to possess all the required ability for the task at the initial time and it takes a certain amount of time to accumulate. The initial level is low and the evolution is slow. The downstream focuses on the implementation of the design plan, and the relevant task ability is fully grasped. The initial cooperation with the upstream can quickly capture the upstream demand and achieve rapid progress, so the initial knowledge level is higher. And the evolution is fast.

3) The task interdependence of downstream to upstream is mainly analyzed from the degree of demand of upstream tasks to upstream output and the degree of influence of upstream understanding modify on downstream task processes. The specific values are jointly discussed and determined by experts from two departments.

The values of other parameters are mainly obtained by experts in relevant fields according to experience. The specific values are shown in **Table 1**.

In order to explain the impact of the above factors on the total development time, the following will use the Matlab R2016b software to analyze the combination of any feasible overlap start time and coordination time interval. Then calculating the total development time, and finally determine the optimal overlap start time coordination times according to the total time minimization principle.

The optimization results are shown in **Table 2**.

It can be seen from **Table 2** that the task overlap mode is shortened by 2.89 days on the basis of about 30% invalid workload compared to the sequential mode, so the mode fails to achieve better optimization results. If we further introduce coordination on this basis, it can effectively optimize the rework. The total working time is shortened by 19.32% (12.46 days) and 15.53% (9.57 days) respectively, which indicates the task-based overlap proposed in this paper. The coordination strategy has certain optimization effects, and the specific analysis is detailed below.

## 4.2. Impact of Overlap Start Time and the Times of Coordination on Total Working Time

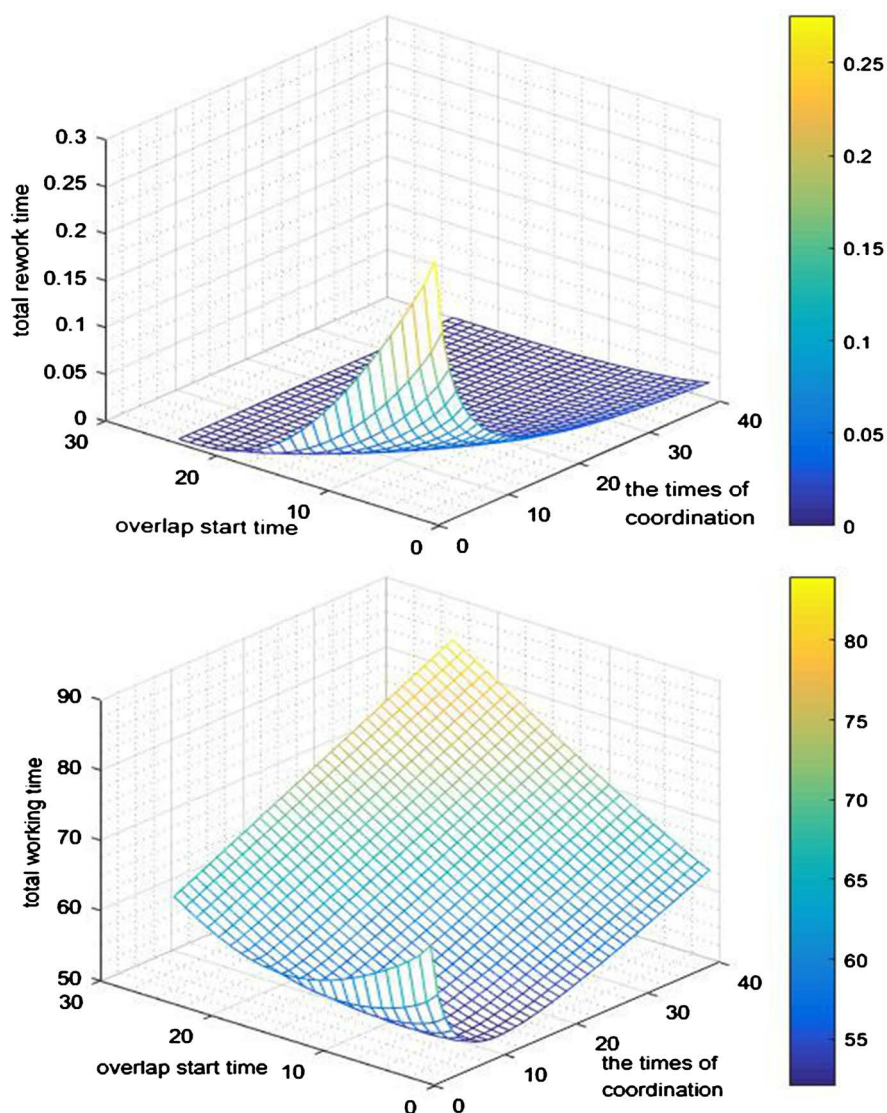
The optimization results are shown in **Figure 1**, the first day begins to overlap,

**Table 1.** Numerical analysis related parameters indispensable.

$T_u$	$T_d$	$\mu$	$K_u$	$K_d$	$\alpha_u$	$\alpha_d$	$T_t$	$m$
24	40	0.3	0.9	0.5	1.3	0.8	0.5	0.25

**Table 2.** Optimization results and comparative analysis.

	overlap start time	coordination times	coordination interval(day)	total rework	total working time(day)
sequential	24	1	—	0	64.50
task overlap	1	2	12.00	0.29	61.61
task overlap with coordination	1	11	2.18	0.06	52.04



**Figure 1.** Impact of overlap start time and the times of coordination on total working time.

and there are 11 times coordination (interval 2.18 days) is the optimal task overlap strategy.

**Figure 1** shows that  $Q_r$  decreases with the increase of  $t_0$  and  $n$ , and the decreasing trend becomes more gradual, and finally stabilizes at the minimum value of 0;  $Z$  has an inverted U-shaped trend with the increase of  $t_0$  and  $n$  respectively, and the optimal value appears in the region. The optimization results of  $t_0$  and  $n$  values which are larger or smaller on both sides; it can be seen that  $t_0$  and  $n$  are direct causes of influence of  $Q_r$  and  $Z$ , and the direction of influence is the same. However, the reason why  $Q_r$  and  $Z$  trend are different is that the larger  $t_0$  improves the ability level of the initial coordination in the upstream, and reduces the intensity and frequency of understanding modify during the overlap period. Several times coordination transfers the upstream understanding modify to the downstream in time. Both measures are beneficial to the decline of  $Q_r(T_r)$ , but there is also a corresponding cost and

there is a limit to the optimization. In addition to  $T_r$ ,  $Z$  also includes normal working time and coordination time. When  $t_0$  is increased, the advantage of task overlap for working time savings is compressed, and the increase of  $n$  directly increases the coordination times. When  $t_0$  and  $n$  are smaller than the optimal value and gradually increase,  $Z$  will gradually decrease but the trend becomes more gradual; when  $t_0$  and  $n$  exceed the optimal value,  $Z$  will gradually increase and the trend becomes more apparent. In both cases,  $Z$  is greater than  $Z^*$  and may even exceed the total working time of the sequential mode (64.5 days).

Since the model index part is more complicated, it is impossible to obtain the analytical solution based on the characteristics of the task in the retained model. The following propositions ignore the different characteristics of the ability level growth path, namely  $\alpha_u, \alpha_u = 1, V_r = \alpha_d \cdot K_d / T_d$ .

**Proposition 1:** Deferring the overlap start time can reduce the rework time of the task

Proof:  $Q_r = \sum_{i=0}^{n-1} \frac{(T_u - t_0)}{n} \cdot \left[ 1 - (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u} \right]$ , and let  $p = \frac{(T_u - t_0)}{n}, q = 1 - (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u}$ . Since  $K_u, T_u, n, \mu > 0$  and  $i < n$  (regardless of sequential mode) and  $(1-m) \in (0,1)$ , so  $p, q > 0$ . For every part in the equation,  $\frac{\partial p}{\partial t_0} = -\frac{1}{n} < 0$ ,

$$\frac{\partial q}{\partial t_0} = \frac{2K_u \cdot (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u} \cdot (2n-2i-1) \cdot (T_u - t_0) \cdot \ln(1-m)}{n^2 \cdot T_u}$$
. When

$t_0 \in (0, T_u)$ ,  $\frac{\partial q}{\partial n} < 0$ , so  $\frac{\partial Q_r}{\partial t_0} = \sum_{i=0}^{n-1} \left( \frac{\partial p}{\partial t_0} \cdot q + p \cdot \frac{\partial q}{\partial t_0} \right) < 0$ . It can be seen that as

$t_0$  increases, the number of upstream understanding modify is gradually reduced when  $\Delta T$  is the same, thereby causing a decrease in the influence of the modify on the downstream task, and it is proved that the rework time is marginally decreased by the increase of the overlap start time.

**Proposition 2:** Increasing the times of coordination can reduce the rework time of the task.

Proof:  $Q_r = \sum_{i=0}^{n-1} \frac{(T_u - t_0)}{n} \cdot \left[ 1 - (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u} \right]$ , and let  $p = \frac{(T_u - t_0)}{n}, q = 1 - (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u}$ . Since  $K_u, T_u, n, \mu > 0$  and  $i < n$  (regardless of sequential mode),  $(1-m) \in (0,1)$ , so  $p, q > 0$ . For every part in the equation,  $\frac{\partial p}{\partial n} = -\frac{(T_u - t_0)}{n^2} < 0$ ,

$$\frac{\partial q}{\partial n} = \frac{2K_u \cdot (1-m) \frac{\mu K_u \cdot (2n-2i-1)(T_u - t_0)^2}{n^2 \cdot T_u} \cdot (2n-2i-1) \cdot (T_u - t_0)^2 \cdot \ln(1-m)}{n^3 \cdot T_u}$$
. When

$n \in N^*$ ,  $\frac{\partial q}{\partial n} < 0$ , so  $\frac{\partial Q_r}{\partial n} = \sum_{i=0}^{n-1} \left( \frac{\partial p}{\partial n} \cdot q + p \cdot \frac{\partial q}{\partial n} \right) < 0$ . It can be seen that with the increase of  $n$ ,  $\Delta T$  decreases when  $t_0$  is the same, which leads to a decrease in the amount of downstream ability growth and the times of upstream understanding modify during the overlap, which proves the proposition.

Through the above two propositions, we can find that: deferring the overlap start time or increase the times of coordination both are effective to reduce downstream's rework; However, when considering total development task time, these two methods will lead to the extension of actual working time and coordination time, respectively. In extreme cases, too late start of downstream task and too many times of coordination will completely offset or even exceed the time savings caused by overlap.

## 5. Conclusions

Based on the task characteristics of product development, this paper refines and characterizes the development process. It also researched the causes and mechanism of task overlap and rework, then quantitatively analyzed the optimization effect of task coordination. The joint strategy proposed in the paper, including overlap start time, the times of coordination and time intervals, is an important supplement and improvement to the coordinated research of existing product development teams. Through case optimization and numerical model, the following main conclusions are drawn:

1) The overlap start time and the times of coordination are the main factors affecting the amount of downstream rework. They generate different function on upstream understanding modify and downstream rework through different ability levels. The amount of growth determines the total amount of downstream rework during the overlap period.

2) Upstream and downstream's coordination during overlap helps to reduce total downstream rework. There is an optimal overlap start time and the times of coordination to minimize the total working time, and thus determine the coordination time interval, and the joint optimization of this two helps to reduce the total rework amount and the total working time.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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