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## An Approach to Measuring Coupled Tasks Strength and Sequencing of Coupled Tasks in New Product Development

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**Abstract:** To manage a new product development process is difficult because of the coupled tasks. Design structure matrix (DSM) is an effective tool to resolve this problem. The early research on DSM describes the tasks' relationships by Boolean sign, and the focus of further research is how to measure the coupled strength and how to sequence the coupled tasks module. Based on the existent research, we construct a new method to measure the coupled strength and to calculate the first iteration's gross workload of a different sequence of coupled tasks, thereby ascertaining the best sequence of coupled tasks. The method is illuminated by an example of a mechanical product design process, whose result suggests that the method can be manipulated in the real development process of a new product easily, and it overcomes the disadvantage of the existent research on measuring coupled strength subjectively.

**Key Words:** new product development, coupled tasks strength, coupled tasks sequence.

### 1. Introduction

New product development usually has the character of more coupled designed activity, especially in the design process of large and complex product development systems. The complex interdependent relationships induce more difficulties in the management of the design process, which consequently becomes more important and a focus in the cycle of engineering and science.

Many of the traditional project management techniques (e.g., Gantt, critical path method (CPM), program evaluation and review (PERT), and integrated definition (IDEF) models) only express the sequential and parallel relationships, not the interdependent relationships in tasks [1]. Moreover, these techniques assume that all task durations in a process are predictable, which is not true for new product design where the tasks duration are often delayed by the iterations. The DSM model can express the interdependent relationships as well as the iterations induced by the relationships. It is useful in concurrent engineering management and implementation [2,3].

In contrast with the traditional project management techniques, the DSM model presents the iterations and feedback loops in a new product design process, 'Iteration cycles can delay projects by being more in number, longer in the distance which information must

travel, slower in traversing that distance, and occurring later than possible' [4], then measuring the coupled strength and getting the best sequence of coupled tasks module becomes the key to DSM research. It is known to all that most of the existent literatures usually focus on other aspects based on coupling strength, but only a few literatures consider how to measure coupling strength. This calls for the intention of this research to measure coupling strength. The goals of this research are to construct a new method of using parameter information in tasks to measure the coupled strength and to get the principle of ascertaining the best sequence of coupled tasks module.

The rest of the article proceeds as follows. In the next section, we survey the existent literatures on a design structure matrix (DSM) model, in particular, the research on measuring coupled tasks strength. Section 3 introduces the concept of task output influence ratio and expectant task change ratio, which is the basis to measure coupled tasks strength and ascertain the best sequence of coupled tasks module. Therefore, a new method of measuring coupled tasks strength, according to the concept, is constructed. In Section 4, the method is illuminated by an example of a machine design. Finally, Section 5 presents our concluding remarks and potential extensions of this research.

### 2. Related Works

A design structure matrix is a useful tool to manage a new product development process. Since Steward [5]

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Figures 1 and 2 appear in color online: <http://cer.sagepub.com>

first introduced the notion of DSM, many researchers have demonstrated its effectiveness in the past decade. Most researchers studied DSM in different aspects. For example, the decomposition of large engineering projects and the interdependency relationships (uncoupled relationship, coupled relationship, and decoupled relationship) in design activities [6,7]; iterations and the ordering of tasks to minimize expected duration [8–12]; project scheduling [13–15], and so on. Because coupled relationships and iterations are the main characters of new product development, and the key to DSM model is distinguished from other traditional project management theories and techniques, the relationships, especially the coupled ones in tasks become the focus of research and the basis of other developments on DSM.

The interdependent relationships in tasks are different. Thus, coupled tasks strengths in an interdependent task group should not be simply treated as neither 0 nor 1 as in binary DSM. Steward suggested the use of level numbers instead of simple 'X' marks in DSM. He developed a tearing algorithm, using a 1–9 numerical scale for interfaces where the less important elements within an interdependent task group are temporarily removed, or he 'tore' one at each time followed by a repartitioning process in order to find a suitable ordering for the coupled tasks. The numbers reflect the order in which the feedback marks should be torn.

Eppinger et al. [8] presented sequential iteration and parallel iteration in a new product development process and extended the binary DSM to a numerical DSM. In order to minimize the expected duration, they obtained an initial ordering of the coupled design tasks by the model. Moreover, they analyzed the convergence of iteration in a coupled tasks module. All these researches above assume that the probabilities of iterations are given without an explanation of how to get the probabilities of iterations.

Yassine [16] proposed a methodology that allowed practical estimation and assessment of rework probabilities. Activity rework is related with the probability of a change in inputs and the impact of that change, then the concepts of information variability and task sensitivity are defined. Information variability (IV) describes the likelihood that information provided by an input task would change after being initially released. Task sensitivity (TS) describes how sensitive the completion of a dependent task is to changes or modifications of information from an input task. The parameters of IV and TS are categorized by 1, 2, 3 respectively. In this way, task volatilities (TV), the product of IV and TS, replaces the interdependent marks in the binary DSM. In contrast with previous researches, this one gains a deeper understanding of task interdependencies and iteration in the engineer design process. However, the method still deviates obviously

from the real engineer design process because of the subjective estimate of IV and TS.

Shi-Ji Chen et al. [17] measured the coupled strength in DSM by the analytic hierarchy process (AHP) and proposed a two-way comparison scheme. This two-way comparison scheme contains two phases: phase one performs pairwise comparisons in one way for tasks in rows; phase two performs pairwise comparisons in another way for tasks in columns. The comparison scale ranges from equal importance to extreme importance using 1, 3, 5, 7, and 9 and their intermediate values, i.e., 2, 4, 6, and 8. At last, the evaluated information in rows and columns are combined to measure the tasks coupled strengths.

The research above measured coupled tasks strengths or probability of iterations. In order to get the coupled tasks strengths, more system information is used to estimate whether the task receives more information output from other tasks or the task supplies more information to other tasks. It is necessary to estimate coupled tasks strengths in view of system information if there is no more other information. However, the difference of expert evaluation influences the final result and restricts the application in new product development. This calls for the intention of this research to construct a new model to measure coupling strength. Based on the research above, the article here deeply discusses how to measure the tasks coupled strengths by using parameters information, and construct a new method to get the minimum expected duration of coupled tasks module.

### 3. Measure and Sequence on Coupled Tasks

With AHP, the numerical DSM models have been designed usually to compare the task's importance, and then the task's dependent strength can be ascertained by using fuzzy theory to discern the information flow. Accordingly, these models have some effect in new product design process, but it is difficult to apply the model in the new product design process because of the difference of expert's judgments. Besides, the existent literature always assumes that the coupled strength is given. The numerical DSM models have been designed to put more attention to the optimization and ordering of dependent relationship, independent relationship, and coupled relationship of tasks, while the research on how to ascertain the coupled strength is relatively limited. Therefore, the article here designs a new method to measure coupled strength. That is, applying interface parameters in tasks to discuss the information's flow strength and scaling the task's interdependent strength, and forming the principle of how to sequence the task in the coupled tasks module in the end.

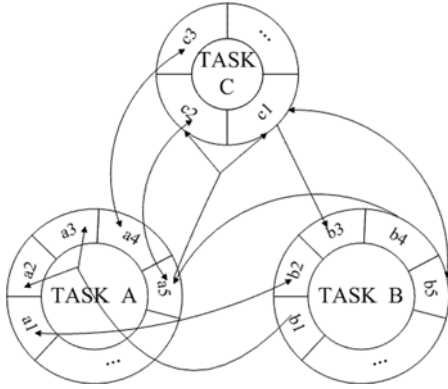


Figure 1. Coupled tasks module parameters relationship.

It can be seen from the coupled relationships of three tasks in Figure 1, that task A, B, C have complex coupled relationships. There are some simple relationships such as parameter b1 in task B influences parameter a2 and a3 in task A, and also there are some complex relationships such as parameter b4 in task B which influences parameter a5 in task A, then a5 influences parameter c1 and c2 in task C. Meanwhile, there are some interdependent relationships such as parameter a4 in task A and parameter c3 in task C. Because the influence of every parameter in the tasks to other task is different, the importance of every parameter is different. It induces the task's influence on other tasks in the coupled tasks module to be different. Considering these things, this article scales the strength of information flow in tasks by using the interdependent relationship in parameter, and designs a new method.

This article assumes that the tasks' relationships are only influenced by the interface parameters, and the workload induced by the first iteration is the greatest in all iterations' workload. These suppositions are reasonable in the real product design process, and these suppositions reduce the problem.

The definition is given as follows:

**Definition 1** (Task output influence ratio): Assuming that the number of task A's interface parameter is  $n$ , and task B's interface parameter is  $m$ , and task A influences  $t$  parameters in task B, then task output influence ratio of A to B is defined by  $\eta^{ab} = (t/m)$ .

**Definition 2** (Parameter change influence ratio): Assuming that the change of parameter  $a_i$  in task A influences task A's rework, then the proportion of A's rework  $\lambda_i$  ( $i=1, 2, \dots, n$ ) is defined as parameter  $a_i$ 's parameter change influence ratio.

Engineers usually thoroughly learn the influence of interface parameters on the task, so they are required to give parameter  $\lambda$  before calculating the following parameters.

**Definition 3** (Parameter feedback change ratio): Assuming that parameter  $b_j$  in task B influences task A's  $p$  parameters, then parameter feedback change ratio of  $b_j$  is defined by  $\gamma_i = \sum_{i=1}^p \lambda_i$ ,  $i = 1, 2, \dots, p$ .

**Definition 4** (Expectant task change ratio): Assuming that the number of task A's interface parameter is  $n$ , and task B's interface parameter is  $m$ . And the change of parameters in task B is generally unknown, so the probability of every parameter's change is assumed to be equal by  $P_i = 1/m$ ,  $i = 1, 2, \dots, m$ . Then the expectant task change ratio of B to A is defined by  $\delta^{ba} = \sum_{i=1}^m \gamma_i P_i$ ,  $i = 1, 2, \dots, m$ .

The fundamental strategy of sorting the task in coupled tasks module is to ascertain the sequence by calculating the first iteration's gross workload when A, B, C compose the coupled tasks module. The strategy also has effect on the coupled tasks module in which the task's number is more than three.

The formula to calculate the first iteration's gross workload is given as follows:

Assuming the coupled tasks module consists of  $R_i$ ,  $i = 1, 2, \dots, n$ , and every task's workload executed individually is  $W_i$ ,  $i = 1, 2, \dots, n$ , and the executed sequence is  $R_1, R_2, \dots, R_n$ , the execution of downstream tasks induces an iteration of upstream tasks, then the first iteration's gross workload is defined as:

$$W_1 = \sum_{i=1}^n W_i + \sum_{i=1}^n \sum_{j=i+1}^n \eta^{ji} \delta^{ij} W_j, \quad (1)$$

$$i = 1, 2, \dots, n; \quad j = i + 1, i + 2, \dots, n.$$

The formula is illuminated by a coupled tasks module including task A and task B. Assuming every task's workload executed individually is  $W_a, W_b$ , and the executed sequence is A, B. It is clear that the more influence of A on B, the more information of A to B, and the more feedback information of B to A. With consideration of the first iteration of task A induced by execution of task B, the first iteration's gross workload is defined as:

$$W_1 = W_a + W_b + \eta^{ab} \delta^{ba} W_a.$$

The procedure to measure and sequence coupled tasks module consists of five steps as follows:

**Step 1.** The engineers list the interdependent parameters and the values of parameter change influence ratio  $\lambda$ .

**Step 2.** Calculate the task output influence ratios  $\eta$  according to the list.

**Step 3.** Calculate the parameter feedback change ratios  $\gamma$  and the expectant task change ratios  $\delta$  according to the list.



**Step 4.** Calculate the first iteration's gross workload  $W$  of different sequences of the coupled tasks module according to the task output influence ratios  $\eta$  and the expectant task change ratios  $\delta$ .

**Step 5.** Ascertain the best sequence according to the  $W$  in step 4.

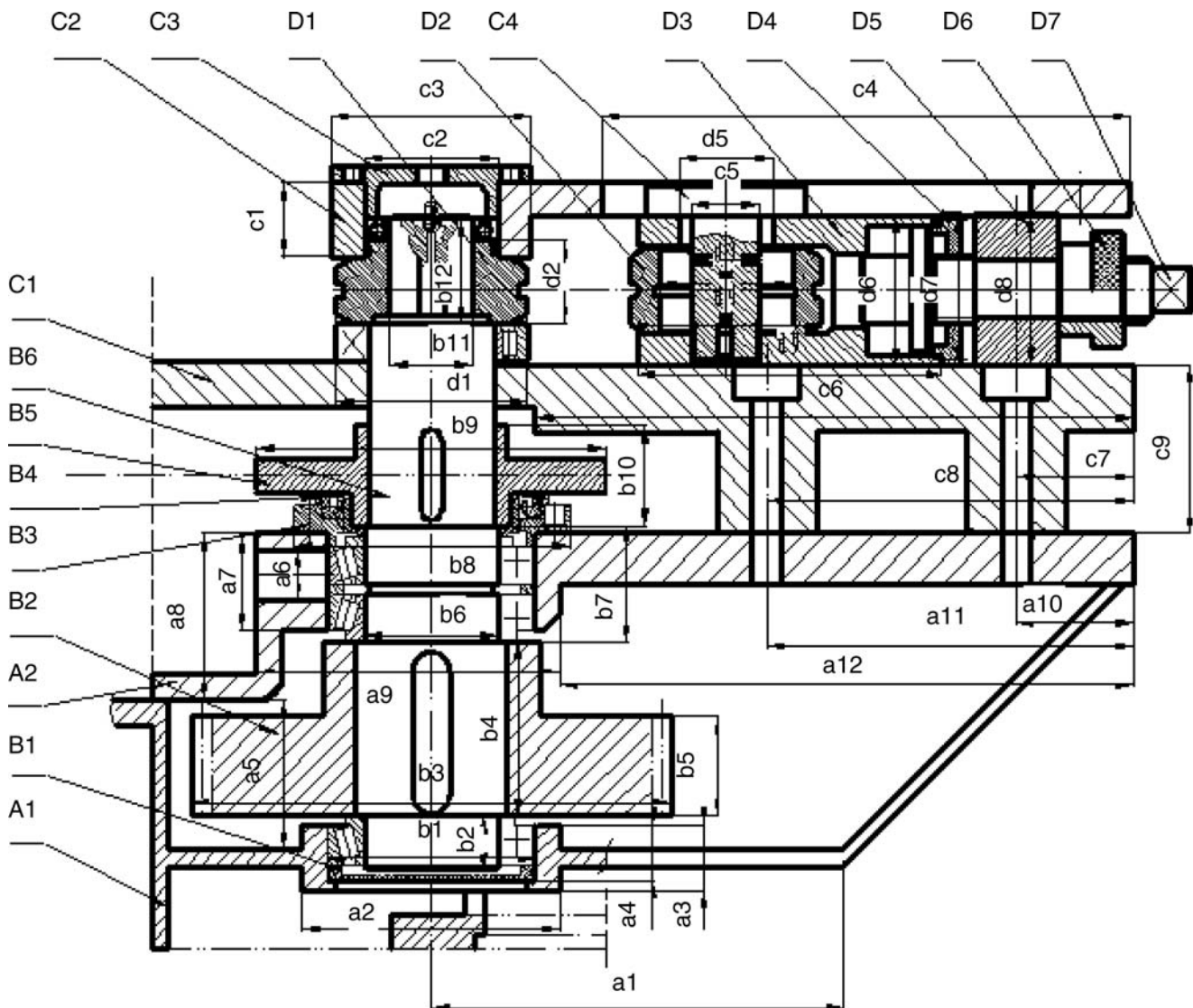
According to the procedure, the interface parameters in the coupled task should be ascertained firstly in order to ascertain the inter-influence of coupled tasks. And  $\lambda$ , which denotes the task change strength by its interface parameter change, should be ascertained by the engineer to execute the task. Then the upstream task's influence strength to downstream task  $\eta$  and the downstream task feedback strength to upstream task  $\delta$  can be calculated.

It is objective to ascertain coupled task strength by using interface parameters information. And the method overcomes the disadvantage of the old one which used system information only and made it difficult to get accordant result when experts' estimation differed.

#### 4. The Application in a Machine Design Process

As an example, Figure 2 describes the complex machine design process. The whole design process includes task A, task B, task C, and task D. Task A consists of two parts whose numbers are A1 and A2. Task B consists of six parts whose numbers are B1, B2, B3, B4, B5, and B6. Task C consists of four parts whose numbers are C1, C2, C3, and C4. Task D consists of seven parts whose numbers are D1, D2, D3, D4, D5, D6, and D7. The durations of task A, task B, task C, and task D are 15, 81, 21, and 50 h, respectively. The relationships of parameters in tasks got from engineers are shown in Table 1, and the tasks' changes induced by the parameters' change that received from engineers are shown in Table 2.

The first, third, and fifth columns in Table 1 express interface parameters; and the second, fourth, and sixth columns express parameters in other tasks influenced by



**Figure 2.** Complex machine product design drawing.

the parameter in the anterior column. The first, third, and fifth columns in Table 2 express interface parameters, and the second, fourth, and sixth columns express the task's change ratio induced by the interface parameter's change of the task in the anterior column.

According to definition 1 and definition 4, task output influencing ratio  $\eta$  and expectant task change ratio  $\delta$  can be calculated, which is shown in Table 3. The first column expresses the preceding task's influence on the subsequent task. For example,  $A \rightarrow B$  denotes the sequence is from A to B, and task B can get information from task A after task A is being finished. The second column expresses the calculated outcome of task output influencing ratio  $\eta$ . The third column expresses the subsequent task's feedback to the preceding task, for example,  $A \leftarrow B$  denotes the sequence is from B to A, and task A has to change after task B had finished on account of task B's feedback information. The fourth column expresses the calculated outcome of expectant task change ratio  $\delta$ .

According to formula 1, the first iteration gross workload of different sequences of coupled tasks module can be calculated. The process of A, B, C, and D's first iteration gross workload is shown as follows:

$$\begin{aligned}
 W_1^{ABCD} &= \sum_{i=A,B,C,D} W_i W_A + \sum_{j=B,C,D} \eta^{Aj} \delta^{jA} W_A \\
 &+ \sum_{k=C,D} \eta^{Bk} \delta^{kB} W_B + \eta^{CD} \delta^{DC} W_C \\
 &= 15 + 81 + 21 + 50 + (0.83 \times 0.07 \\
 &+ 0.44 \times 0.04 + 0) \times 15 \\
 &+ (0.44 \times 0.06 + 0.22 \times 0.03) \\
 &\times 81 + 1 \times 0.09 \times 21 \\
 &= 172.7.
 \end{aligned}$$

Table 1. Relationship of parameters in tasks.

Interface parameter	Parameters influenced	Interface parameter	Parameters influenced	Interface parameter	Parameters influenced
a1	b3	b3	a1	c5	d3,d4,d5
a2	b1	b4	a5	c6	d9,a12
a3	b2	b5	a5	c7	a10
a4	b2	b6	a9	c8	b9,a11
a5	b4,b5,c9	b7	a6,a7,a8	c9	a5,a8,b10,d2,d6,d7,d8
a6	b7	b8	a9	d1	b11,c3,c4
a7	b7	b9	a11,c8	d2	b12,c1,c9
a8	b5,b7,b10,c9	b10	a8,a9	d3	c4,c5
a9	b6,b8	b11	c2,d1	d4	c4,c5
a10	c7	b12	c1,d2	d5	c4,c5
a11	b9,c8	c1	b12,d2	d6	c9
a12	c6	c2	b11	d7	c9
b1	a2	c3	d1,d4	d8	c9
b2	a3,a4	c4	d3,d4,d5,d9	d9	c4,c6

Table 2. Parameter change influence ratio  $\lambda$ .

Interface parameter	Parameter change influence ratio	Interface parameter	Parameter change influence ratio	Interface parameter	Parameter change influence ratio
a1	0.05	b3	0.12	c5	0.05
a2	0.11	b4	0.32	c6	0.23
a3	0.07	b5	0.1	c7	0.15
a4	0.07	b6	0.08	c8	0.15
a5	0.1	b7	0.37	c9	0.2
a6	0.1	b8	0.1	d1	0.18
a7	0.1	b9	0.1	d2	0.41
a8	0.1	b10	0.17	d3	0.17
a9	0.12	b11	0.11	d4	0.17
a10	0.05	b12	0.12	d5	0.12
a11	0.05	c1	0.1	d6	0.42
a12	0.1	c2	0.1	d7	0.42
b1	0.1	c3	0.1	d8	0.42
b2	0.1	c4	0.1	d9	0.43

**Table 3. Task output influencing ratio and expectant task change ratio.**

Preceding task's influence to subsequent task	Task output influencing ratio	Subsequent task feedback to preceding task	Expectant task change ratio
A→B	0.83	A←B	0.07
A→C	0.44	A←C	0.04
A→D	0	A←D	0
B→A	0.83	B←A	0.13
B→C	0.44	B←C	0.06
B→D	0.22	B←D	0.03
C→A	0.42	C←A	0.05
C→B	0.33	C←B	0.05
C→D	1	C←D	0.09
D→A	0	D←A	0
D→B	0.17	D←B	0.05
D→C	0.67	D←C	0.31

All the outcomes are shown as follows:

$$\begin{array}{lll}
 W_1^{ABCD} = 172.7 & W_1^{ABDC} = 181.19 & W_1^{ACBD} = 170.91 \\
 W_1^{ACDB} = 170.8 & W_1^{ADBC} = 181.08 & W_1^{ADCB} = 179.29 \\
 W_1^{BACD} = 180.57 & W_1^{BADC} = 189.06 & W_1^{BCAD} = 180.74 \\
 W_1^{BCDA} = 180.74 & W_1^{BDAC} = 189.06 & W_1^{BDCA} = 189.24 \\
 W_1^{CABD} = 171.08 & W_1^{CADB} = 171.24 & W_1^{CBAD} = 178.95 \\
 W_1^{CBDA} = 178.95 & W_1^{CDAB} = 170.97 & W_1^{CDBA} = 178.84 \\
 W_1^{DABC} = 181.08 & W_1^{DACB} = 179.29 & W_1^{DBAC} = 188.95 \\
 W_1^{DBCA} = 189.13 & W_1^{DCAB} = 179.47 & W_1^{DCBA} = 187.34
 \end{array}$$

It can be seen from the calculated outcome that the longest duration is B, D, C, A, which takes 189.24 h to complete the coupled tasks module, and the shortest duration is A, C, D, B, which takes 170.8 h to complete the coupled tasks module. Then the best sequence of the coupled tasks module is A, C, D, B.

Although the example is simplified, it illuminates the thought to measure coupled tasks strength and find the optimized sequences of coupled tasks module. According to formula 1, the result is subject to the number of coupled tasks module, task output influencing ratio  $\eta$  and expectant task change ratio  $\delta$ . When the strength of upstream tasks impacts downstream tasks ( $\eta$ ) and the feedback strength of downstream tasks to upstream tasks ( $\delta$ ) becomes greater, upstream tasks' workload produced by the first iteration will become larger. When the difference of tasks' parameters is greater, the gap of the first iteration gross workload of different sequences will be greater, and it is more valuable to find the optimized sequences.

### 5. Conclusions

The article gives a method for measuring coupled strength and ascertaining the best sequence of coupled

tasks module. After comparing with the existing research of measuring coupled strength, the article takes a further step, and the coupled strength is calculated by parameter relationship in tasks in this article, whereas the AHP and other methods got the parameters by experts matching the tasks' importance. Therefore, the method in this study is more objective, and it has the advantage of being easily operated and applied in an engineering design process. Furthermore, based on measuring the information flow's strength by calculating parameter relationship in tasks, the study gets the principle of ascertaining the task sequence in coupled tasks module by the outcome of first iteration's gross workload.

Due to the complex relationship in coupled tasks module, interdependence of the parameters would induce the task's reiteration inevitably. So one iteration model in the article did not exactly accord with the real new product development process, and how to establish multi-reiterations model is the future direction. The model in this article only discusses the parameters' interdependence, ignoring the restriction of change space and design cost. How to establish an advanced algorithm to sequence-coupled tasks module based on various restrictions is another future direction.

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