Research Article

Collaborative Product Design for Tasks Sorting Based on Shortest Delivery

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The “people’s innovation” can promote development in enterprises in urgent need of innovative product design. Collaborative product design can be a powerful tool for enterprises wishing to improve their market competitiveness and customer satisfaction. To reduce decision costs, improve efficiency, and solve other issues, promoting “people’s innovation” can play a vital role. With this focus, this paper examines products produced through “people’s innovation.” A collaborative design task scheduling problem is presented. The design tasks are sorted based on a minimum delivery cost principle, which is determined using weighted shortest processing time (WSPT) rules and the shortest delivery time. The results show that distributed collaborative innovation can result in a reasonable arrangement for collaborative design tasks.

1. Introduction

With rapid societal, scientific, and technological development, modern manufacturing enterprises are facing new challenges daily. To strengthen the manufacturing sector, the Chinese government has proposed the “Made in China 2025” strategic framework, in which enterprises are seen not only as players in the main markets but also as drivers of innovation. Manufacturing enterprises are being encouraged to implement innovation-driven strategies to promote a “people’s innovation” to enhance their core competitiveness and brand building capability. To win market share and improve customer satisfaction based on the “people’s innovation,” it is necessary to improve the efficiency of the product design process, to reduce costs, and to improve quality. However, as the product design process involves multiple concurrent tasks, to carry out these multiple tasks, to reduce the cost of decision delivery, and to efficiently complete tasks have become a significant problem. If collaborative product design is organized efficiently, costs would be reduced, and enterprise competitiveness and collaborative product design efficiency improved.

In theoretical research on the study of collaborative intelligent product design methods and technology, domestic and foreign scholars have conducted a number of design-related studies, focused mainly on three main areas. Research in the first area has examined the complexity and dynamics of task sorting in collaborative product design and online ordering methods to minimize completion time. Song et al. [1] studied the optimization of three types of decision sorting at the ordering online point as well as task scheduling problem constraints, from which a collaborative design task rule was developed. Liang et al. [2] introduced coordination theory dependent concepts, a constraints graph analysis, and graph theory to describe collaborative design task logic based on a disjunctive constraint mathematical model for a collaborative design task scheduling problem. Lu et al. [3] simplified the simulation scheduling system using simplified discrete event simulation (SDESA) and particle swarm optimization (PSO) to automatically configure minimum completion time.

The second research area has examined complex product design process goals based on empirical analyses to study collaborative product design. Cui et al. [4] proposed Cooperating Correlative Map Based on Activity (CCM_A), which

was a process model based on a predigestion of a determined display expression conflict. The research was based on a large coupled task set degree of coordination using the tear planning method that fully accounted for the complexity of the information collaboration between the design tasks. Li et al. [5] used Lite-QFD software and combined it with an example of a car to achieve quality function deployment (QFD) conversion and a House of Quality view in collaborative product design. Arsenyan and Büyüközkan [6] proposed a fuzzy quality function deployment, a fuzzy integrated IT planning axiom design method, and a fuzzy rule system for collaborative product design verification to improve IT collaboration methods for enterprises. Joglekar and Ford [7] designed tasks according to priorities to build synergies aimed at improving product design efficiency and developed an optimal resource allocation model.

The third main research area has focused on production processes to complete tasks based on task sorting decomposition. Zhou et al. [8] assigned design tasks based on comprehensive abilities, interest, and time constraints and proposed a new collaborative design task time scheduling allocation policy based on the degree of parallelism and coupling in the collaborative design process. Meng et al. [9] adopted a function and structure approach by dividing the combination of machine tool products according to the breakdown of the collaborative design task. Through the implementation, it was found that a recursive structural design matrix was able to operate independently and complete a set when coupled with normalized operating plan design tasks. As can be seen from the previous research, collaborative product design task sequencing has tended to be limited to theoretical research and there have been few in-depth studies on manufacturing and management. Further, collaborative product design delivery costs and other factors have not been taken into account. Therefore, while a variety of production sorting tasks have been examined, there has been little focus on enterprise collaborative product design in China.

To fill this gap, this article analyses the collaborative product design sorting task process in the context of the “people’s innovation.” In this analysis, we take the collaborative product design cost factors related to delivery into account. Using WSPT sorting rules to determine total minimum cost and minimum weighted completion time for the ordering scheme and the corresponding delivery, we determine the weight of the task based on the delivery. This operation provides production operating parameters, reduces design costs, improves design efficiency, and enhances enterprise competitiveness, all of which result in relatively good economic and social benefits as well as providing a reference for the next “people’s innovation” business background collaborative product design process.

2. Products under the “People’s Innovation” Collaborative Design Background

With the proposed “people’s innovation” concept, to enhance innovation capacity, enterprises need collaborative product

innovation process management, which is based on collaborative innovation processes and collaborative process management, as shown in Figure 1.

Collaborative product innovation process management is divided into a process level and management. Process level customer demand is the starting point followed by problem analysis, process identification, program generation, evaluation, testing, and improvement, until finally an innovative product is developed. The process management layer supports both the management and technology within the rules and constraints [10].

Collaborative information design, as well as understanding the needs of customers, clients, and designers, follows certain teamwork and consultation rules related to temporary team formation and a specific collaborative product design process which encompasses customer needs analysis, target breakdown, problem definition, case knowledge acquisition, problem representation, problem analysis, concept generation, program production, program evaluation, program output, and design completion. The coordination and management innovation platform supports the design process through the provision of product variety, negotiation rules, design constraints, and rules covering the complete collaborative design process, as shown in Figure 2 [10].

In collaborative product design, the designer assigns design tasks and, using queuing theory, task designers break these down to form a set of subtasks, each of which accomplishes a part of the task. Queuing theory is used to assign the task resources, which have been sorted in collaborative product design task order, to the machines. People rather than machines design the tasks, with the weight between the tasks being determined by delivery time. The design tasks are sorted according to the product case, the design constraints, and the innovative platform design rules. Task sorting based on delivery is affected by the length of delivery, which is influenced by many factors, such as personnel characteristics, task characteristics, human factor characteristics, environmental characteristics, and technical characteristics. Therefore, to accurately determine the collaborative product design task sort order for the shortest delivery, there is a need for additional theoretical analysis and research [10].

3. The Shortest Delivery Time for Products Based on the Sorting of the Collaborative Design Tasks

Based on the above collaborative product design process and according to the project management work breakdown structure (WBS), complex collaborative product design activity designers logically divide the activity into n subtasks, with a set denoted by $T = \{T_1, T_2, \dots, T_n\}$, where ① $T = \bigcup_{i=1}^n T_i$ indicates that all subtasks should be combined for collaborative task T , with the complete collaborative task T after being broken down being equal to the original set; ② $\bigcap_{i=1}^n T_i \neq \emptyset$ shows that the decomposed subtasks are independent [2]. This article discusses two types of single discussion group task scheduling problems, both of which are

FIGURE 1: Customer collaborative product innovation management.

FIGURE 2: Collaborative product design process.

based on a minimum cost of delivery and shortest scheduling time.

The first task scheduling problem is based on the cost of delivery for the smallest single main task.

Let collaborative design task delivery be k units and the set of tasks $T = \{T_1, T_2, \dots, T_n\}$, with $P_1, P_2, \dots, P_n$ representing the processing time for n collaborative product design tasks. There are three kinds of costs: the cost determined by the delivery of the collaborative design tasks, the cost for early task completion, and the penalty to be paid for late task completion.

A collaborative product design task consists of stages, and each stage has decision variables, state variables, an index function, available state transition equations, and a systems recurrence equation.

To determine the processing time required for the first stage of a task ($x_i = P_j$, $i, j = 1, 2, \dots, n$), D_i represents the first task completion point for the state variables.

The state transition equation is

$$\begin{aligned} D_i &= D_{i-1} + x_i \quad i = 1, 2, \dots, n, \\ D_1 &= x_i, \end{aligned} \quad (1)$$

where $A_{(k)}$ is delivery costs of the decision; $B_i(\max\{0, k - D_i\})$ is the personnel costs wasted if early task completion occurs, a nondecreasing function; $E_i(g(\max\{0, D_i - k\}))$ is the delay fine, a nondrop function:

$$g(\max\{0, D_i - k\}) = \begin{cases} 0 & \max\{0, D_i - k\} = 0 \\ 1 & \max\{0, D_i - k\} > 0. \end{cases} \quad (2)$$

Remember

$$C_i = B_i(\max\{0, k - D_i\}) + E_i(g(\max\{0, D_i - k\})). \quad (3)$$

Then $f_i(D_i)$ represents the minimum cost from state 1 to state i in state D_i ; the recurrence equation is

$$\begin{aligned} f_i(D_i) &= \min \{C_i + f_{i-1}(D_{i-1})\} \quad i = 2, 3, \dots, n, \\ f_1 &= \min_{x_1=D_1} C_1. \end{aligned} \quad (4)$$

The total cost f is

$$f = A_{(k)} + f_n(D_n). \quad (5)$$

In this paper, design task delivery is uncertain. Based on the collaborative design task sort order, the calculation steps for the shortest delivery time are as follows.

Step 1. Determine the possible values:

- ① Determine different combinations.
- ② For each combination calculate the elements and assign a number $2^n - 1$, according to the sort appreciation, that, is $a_1, a_2, \dots, a_{2^n-1}$, if it involves the same number, only one.

Step 2. Let $k_j = a_i$; solve k_j dynamic programming problems (4) and (5) using the formula to determine the corresponding optimal ordering $\{x_1^*, x_2^*, \dots, x_n^*\}$, with no minimum total cost $f_j = A_{(k_j)} + f_n(D_n)$, $j = 1, 2, \dots, 2^n - 1$.

Step 3. $2^n - 1 f_j$: remember $f_a = \min\{f_j\}$, so A_a is the optimal delivery, $\{x_1^*, x_2^*, \dots, x_n^*\}_a$ is the optimal sort, and f_a is the minimum cost [11].

The second task scheduling problem is the total flow for the shortest single main task.

Schedule the collaborative product design tasks using the quad $\alpha \mid \beta \mid \gamma \mid \sigma$, where α indicates that there is only single item, β is the implementation task constraints, for which there may be none or many, γ is the minimization objective, and σ indicates that it is a heavy task. Let the collaborative single main task be $\text{TASK} = (p_j, d_j, \gamma_j, \sigma_j, S_{jk}, n)$, in which p_j is the time required to complete task j , d_j is the promised task completion time for j , γ_j is main start time for task j , σ_j is the weight of the task, and S_{jk} is the sequence determined in the preparation time between task j and the task execution order; that is, if task is the first task, S_{0k} is the preparation time for the task and if task j is the last task, then S_{j0} is adjusted after task j and n is the number of tasks.

The model is then $(1 \mid r_j, \sigma_j, S_{jk} \mid \sum_{j=1}^n C_j)$. To achieve the optimization goal, the total flow for the shortest single group task scheduling problem needs to be considered which includes all tasks associated with the task sort. The optimization target is $\sum_{j=1}^n C_j$ [12].

4. Applications

F enterprise manufactures digital electronic products. To retain and increase market share, the company needs to design new products every year. Therefore, suppose F enterprise needs to design a new R model computer. However, F enterprises have limited technology, resources, and staff. To improve design efficiency, they need to have a “people’s innovation” response, so there is a need to involve several companies in the collaborative design to fully understand customer needs and collaboratively design the R model basic computer products. Based on the WBS principle, the R model computer main chassis design tasks can be decomposed into five separate design subtasks: “BIOS Basic Input Output System,” “CPU,” “Memory,” “bus expansion slot,” and “Chipset” design; the processing time for the five design tasks is, respectively, 20, 50, 10, 30, and 40 days; however, the collaborative design task delivery is unknown. The scheduling problem of five design tasks about R model computer’s chassis is based on the following two aspects.

The first calculation is based on the cost of delivery of the decision task’s smallest single main task schedule.

Set A , B_i , and E_i as the linear variable functions,

$$\begin{aligned} A_{(k)} &= \lambda_1 \cdot k, \\ B_i(\max\{0, k - D_i\}) &= \lambda_2 \max\{0, k - D_i\}, \\ E_i(g(\max\{0, D_i - k\})) &= \lambda_3 g(\max\{0, D_i - k\}). \end{aligned} \quad (6)$$

TABLE 1: Calculation table.

Delivery date k	Sorting task $\{x_1^*, x_2^*, \dots, x_n^*\}_a$	Minimum cost f
10	{10, 20, 30, 40, 50} ... {10, 20, 30, 50, 40}	410
20	{20, 10, 30, 40, 50} ... {20, 10, 30, 50, 40}	420
30	{20, 10, 30, 40, 50} ... {20, 10, 30, 50, 40}	340
40	{30, 10, 20, 40, 50} ... {30, 10, 20, 50, 40}	350
50	{40, 10, 20, 40, 50} ... {40, 10, 20, 50, 40}	360
60	{30, 20, 10, 40, 50}, {30, 20, 10, 50, 40}	330
70	{40, 20, 10, 30, 50}, {40, 20, 10, 50, 30}	350
80	{40, 30, 10, 20, 50}, {40, 30, 10, 50, 20}	370
90	{40, 30, 20, 10, 50}, {40, 30, 20, 50, 10}	400
100	{50, 30, 20, 10, 40}, {50, 30, 20, 50, 40}	420
110	{50, 30, 20, 10, 40}	440
120	{50, 40, 20, 10, 30}	470
130	{50, 40, 30, 10, 20}	500
140	{50, 40, 30, 20, 10}	540
150	{50, 40, 30, 20, 10}	610

λ_1, λ_2 , and λ_3 , indicate the unit costs of delivering on schedule, the unit cost for early task completion, and the unit penalty cost for late task completion. C_i of i stage is

$$C_i = \lambda_2 \max\{0, k - D_i\} + \lambda_3 g(\max\{0, D_i - k\}) \quad (7)$$

with total cost

$$f = \lambda_1 \times K + f_n(D_n),$$

$$\lambda_1 = 1,$$

$$\lambda_2 = 2,$$

$$\lambda_3 = 100,$$

$$P_1 = 20, \quad (8)$$

$$P_2 = 50,$$

$$P_3 = 30,$$

$$P_4 = 10,$$

$$P_5 = 40.$$

① Possible point values for the common species are $2^n - 1 = 25 - 1 = 31$.

② There are 31 combinations for {20, 50, 30, 10, 40}, which are {20}, {50}, {30}, {10}, {40}, {20, 50}, {20, 30}, {20, 40}, {20, 10}, {50, 30}, {50, 10}, {50, 40}, {30, 10}, {30, 40}, {10, 40}, {20, 50, 30}, {20, 50, 10}, {20, 50, 40}, {20, 30, 10}, {20, 30, 40}, {20, 10, 40}, {50, 30, 10}, {50, 30, 40}, {50, 10, 40}, {30, 10, 40}, {20, 50, 30, 10}, {20, 50, 30, 40}, {20, 50, 10, 40}, {20, 30, 10, 40}, {50, 30, 10, 40}, and {20, 50, 30, 10, 40}.

③ The elements of each combination are 20, 50, 30, 10, 40, 70, 50, 60, 30, 80, 60, 90, 40, 70, 50, 100, 80, 110, 60, 90, 70, 90, 120, 100, 80, 110, 140, 120, 100, 130, and 150; remove same 50, 30, 60, 40, 70, 80, 90, 100, 110, and 120; get results 20, 50, 30, 10, 40, 70, 60, 80, 90, 100, 110, 120, 140, 120, 130, and 150.

④ Appreciating the sort, then get 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150.

⑤ For 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150, step two is calculated according to the model. The results are shown in Table 1.

Comparison in Table 1 shows that the minimum cost of 330 when $k = 60$ is the optimal delivery point. At this time, the optimal scheduling task processing time is {30, 20, 10, 40, 50} and {30, 20, 10, 50, 40} and the best task sort is $T_3-T_1-T_4-T_5-T_2$ or $T_3-T_1-T_4-T_2-T_5$.

The second application is based on a total flow dependency shortest single main task scheduling problem. Reference [12] demonstrated that, with WSPT rules, single issues can be optimally scheduled; the rule for WSPT is to work according to the descending order $\bar{w}/p_i$, where $\bar{w}$ represents the weight of heavy task j and p_i represents the task processing time.

The design process is divided into five independent tasks. Each task has a job number, a job submission time, a task processing time, a task completion time, and a task weight. The task sequence is TASK = (ID, ST, PT, FT, DL) in which ID is the task number, ST is the task submission time, PT is the task processing time, FT is task completion time, and DL is the weight.

$|r_j, S_{jk}| \sum_{j=1}^n C_j$; the weighted task matrix corresponding to the expression is

$$\text{TASK} = \begin{bmatrix} 1 & 0 & 20 & 30 & 1 \\ 2 & 0 & 50 & 80 & 3 \\ 3 & 0 & 30 & 60 & 2 \\ 4 & 0 & 10 & 50 & 1 \\ 5 & 0 & 40 & 70 & 2 \end{bmatrix}. \quad (9)$$

Prepare a zero matrix.

In the above 31 possible delivery values, frequencies of 20 to 1, 50 to 3, 30 to 2, 10 to 1 and 40 to 2 are given which are related to delivery frequency. Weights are assigned to the tasks to align processing time with delivery. Therefore, the weights for the five design tasks are {1, 3, 2, 1, 2}.

FIGURE 3: Lekin Sort.

From the data for the five manual design tasks corresponding to the Lekin Scheduler input system and the WSPT sorting principle, the order for the five tasks is shown in a Gantt chart (Figure 3). The program is $T_4-T_3-T_2-T_1-T_5$ for the weighted completion time, with a minimum target value of 770. This scenario corresponds to the shortest delivery time $k = 10$ and a minimum total cost of 410.

For the shortest delivery time $k = 10$, the R computer model ordering scheme for the five main chassis design task ($T_4-T_3-T_2-T_1-T_5$) costs is determined by the minimum delivery weighted completion time and minimal cost. The order for the R model main computer chassis design for the five subtasks is “bus expansion slots”, “Memory”, “CPU”, “BIOS Basic Input Output System”, and “chipset.”

5. Conclusion

In this article, based on a WBS collaborative task analysis, the complex business product design process was divided into n subtasks. First, according to the minimum cost of delivery principle decision to sort the tasks for different delivery solutions, WSPT rules were used to determine a reasonable sort order to achieve a total minimum cost and a minimum weighted completion time, all of which reduced costs, improved efficiency, and enhanced core competitiveness.

In this article, the shortest delivery time was determined by sorting the collaborative product design tasks based on delivery to determine the task weight. Using the WSPT sort rules, the ordering scheme was derived to achieve total minimum cost and minimum weighted completion time. This method allows for the identification of the actual product design process parameters, which is in line with the “Made in China 2025” and “people’s innovation” aims for an effective distributed collaborative design task ordering scheme. This innovation could be useful for China future industrial policies.

Competing Interests

The authors declare that they have no competing interests.

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