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Research on Design Method of Dynamic Shop Floor Scheduling System Based on Human-computer Interaction

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Abstract

The shop floor dynamic scheduling system based on human-computer interaction is the use of computer-aided decision-making and human-computer interaction to solve the dynamic scheduling problem. A human-computer interaction interface based on Gantt chart is designed, which can not only comprehensively and quantitatively represent the scheduling process and scheduling scheme, but also have friendly human-computer interaction performance. The data transmission and interaction architecture is constructed to realize the rapid response to shop floor disturbance events. A priority calculation algorithm integrating priority rules and dispatcher preference is proposed, which realizes the automatic calculation of priority for the dispatcher's reference and reduces their burden. A man-machine interactive shop floor dynamic scheduling strategy is proposed. When solving the dynamic flexible job shop scheduling problem caused by machine tool breakdown and urgent order, the origin moments obtained by using this strategy are 0.4190 and 0.3703 respectively. As can be seen from the origin moment indicator, the dynamic shop floor scheduling system based on the human-computer interaction is efficient and reliable in solving dynamic scheduling problems, and related strategies of this system are also feasible and stable.

Keywords: *Human-computer interaction; Dynamic scheduling; Flexible shop floor scheduling; Perturbation events*

1 Introduction

With the continuous deep integration and application of information technology and advanced manufacturing technology, the relationship between human and manufacturing system is undergoing great changes, and the manufacturing industry has also entered the era of intelligent manufacturing characterized by Intelligent IoT, virtual-real integration and human-machine integration. Scientific and reasonable human-machine cooperation mode is a powerful guarantee for the effectiveness of intelligent human-machine system. The merits and disadvantages of human-machine integration cooperation mode will directly affect people's decision-making judgment and behavior efficiency, and determine the security of intelligent human-machine system and the feasibility and completion of major decision-making tasks. CPS (Cyber-Physical systems) are the basic framework of an intelligent manufacturing system. Its implementation is to build a virtual manufacturing system that is parallel to the physical manufacturing system, and to optimize the physical manufacturing system through intelligent decision, scheduling and control. People are both the participating subject and the service subject of the intelligent manufacturing system. Therefore, to realize the application of the intelligent manufacturing system, it is necessary to solve the human-computer interaction problems under the CPS architecture, such as the design of the human-computer interaction shop floor scheduling system, the design of the human-computer interaction shop floor system monitoring, and the design of the human-computer interaction shop floor system operation and maintenance system.

Scheduling is part of the fundamental aspects of intelligent manufacturing systems and is very important for modern companies. The main methods for solving scheduling problems are artificial intelligence scheduling [1] and automated forms of dealing with such as simulation-based [2]. Artificial intelligence methods can solve common scheduling problem, the core of which is to use the powerful data computing power of computers and artificial intelligence algorithms to solve

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mathematical models of scheduling problems. Meng Leilei et al [3] proposed a hybrid frog-hopping algorithm for the problem of minimizing the maximum completion time in a distributed flexible job shop. Shi Xiaoqiu et al [4] proposed an adaptive variable-level genetic weed algorithm for the flexible job shop scheduling problem with the objective of minimizing the maximum completion time. The artificial intelligence-based approach to scheduling decisions has a certain degree of intelligence and is particularly suitable for solving state exploding shop floor scheduling problems, but the reliability in solving complex scheduling problems is not ideal because the model usually needs to be simplified in the process of mathematical modelling. The simulation approach is very effective in designing and operating manufacturing systems, and it can be used as a support system for real-time scheduling of manufacturing systems. Jin Pengbo et al [5], in solving production rescheduling problems, proposed a decision model that incorporates data simulation, genetic optimization and BP neural networks for rescheduling methods. Cao Yuanchong et al [6] proposed a digital twin-based dynamic scheduling method for discrete assembly plants of complex products, which enable more accurate dynamic scheduling through data interaction between physical space and virtual space. However, there are some problems with the simulation-based real-time support system, for example, the simulation method takes too much time to run in some cases, and the simulation method built from one situation cannot be used in another, i.e. when the environment changes, the model needs to be rebuilt and re-tested to find the appropriate rule set according to the changed environment, which is not ideal for solving shop floor scheduling problems with many dynamic events The adaptability is not ideal when solving shop floor scheduling problems with many dynamic events.

Therefore, in order to give full play to the advantages of artificial intelligence algorithms in solving state explosion shop scheduling problems, as well as to bring into play the decision making ability, fast dynamic response ability and the ability to use knowledge and experience of schedulers, and also to improve the reliability and adaptability of the dynamic scheduling system of intelligent manufacturing shop, this paper focuses on the problem of designing the dynamic scheduling system of the shop based on human-computer interaction. The current research on HCI scheduling is still immature, mainly focusing on scheduling algorithms [7], HCI strategies [8] and HCI scheduling platform design [9]. In this paper, based on the existing domestic and foreign research, we further study the design method of HCI scheduling system and propose HCI scheduling strategies that can ensure efficient, safe and reliable operation of HCI scheduling system.

2 Problem Formulation

As the automation of shop floor system increases and the scale of production elements expands, the frequency of disturbing events such as machine failure, rush order and order cancellation in the production process gradually increases. This puts higher demands on the dynamics, real-time, reliability and stability of shop floor scheduling. At the same time, each disturbance event will consume a lot of energy for schedulers to adapt and modify the existing scheduling plan.

Traditional static shop floor scheduling solves three problems: process start time, machine tool assignment, and machining duration. On the other hand, traditional dynamic shop floor scheduling has to solve two more problems: the problem of scheduling task changes and the problem of resource changes such as machine tools, i.e., dynamic shop floor scheduling is completed by adding processes, deleting defective machines, updating the start and end times of unprocessed processes, and updating machine tool assignments.

In the process of dynamic scheduling of HCI Shop floor, schedulers need to give full play to the role of human in state perception, solution decision and system operation and maintenance, and make full use of the computer-aided generated scheduling solution to complete the shop floor scheduling. Therefore, the key to solve the dynamic scheduling problem of HCI shop floor is the design of the dynamic scheduling system of HCI shop floor.

The design of a dynamic scheduling system for human-computer interaction on the shop floor focuses on the following 3 issues.

(1) Design issues of graphical human-computer interaction interface. The human-computer interaction interface is the foundation for realizing human-computer interaction. The basic problem to be resolved is how to display the scheduling process and results, and how to adapt this interface to the scheduling operation.

(2) Standardization of human-computer interaction. The essence of human-computer interaction is information interaction, and only by adding relevant constraints to the information, the rationality of the scheduling scheme can be ensured, for example the process constraints. In addition, in order to ensure the practicality of the scheduling system, the order of human-computer interaction must be standardized, such as how the preferences of the scheduler are reflected in the priority, and how to arrange the sequence between interactive operations and priority updates.

(3) Priority calculation problem. When calculating the process priority, it is necessary to take into account the equipment selection preference set by the decision maker, the load of the machine and the urgency of the process, etc. This is a key issue to be solved to ensure the safety and reliability of the scheduling system.

3 Human-Computer Interaction Scheduling System Design Method

The scheduling problem is the core problem of HCI scheduling systems. In solving the scheduling problem, it is necessary to consider selecting a graphical tool suitable for HCI first, which can not only represent the scheduling process and results comprehensively and quantitatively, but also have friendly HCI performance. Secondly, efficient and accurate information interaction needs to be designed for the purpose of rapid response to shop floor disturbance events and proactive response to reschedule problems. Finally, it is necessary to propose a calculation method that can calculate priority according to priority rules and preference priorities, which can automatically calculate priorities for schedulers' reference and reduce the burden of schedulers.

3.1 HCI scheduling tool selection

Gantt charts can graphically represent the temporal and spatial relationships between production elements in the shop, i.e., the machine tools, processing sequence and duration of processes are plotted in a certain order by bars of different colors and lengths in a coordinate system consisting of machine tools and time. Gantt charts can express complex production data in a comprehensive and quantitative way, and they can also facilitate schedulers to add, modify and delete processes in a graphical way. Therefore, Gantt charts were chosen as the graphical tool for human-machine interaction.

Gantt charts can be used to represent the before-and-after relationship between processes of a workpiece in a process queue, or to represent the sequential relationship between processes on a machine. Table 1 shows the optimal scheduling results for the shop floor example, and figure 1 shows the queue distribution, where the numbers before and after "/" in Table 1 indicates the candidate machine number and its theoretical machining duration, and "or" indicates the parallel candidate machine number and its theoretical machining duration.

Table 1 6×6 machine tool flexible job shop scheduling problems

	Seq1	Seq2	Seq3	Seq4	Seq5	Seq6
Job 1	1or3/5or4	5or3or2/3or5or1	3or6/4or2	6or2or1/5or6or1	3/1	6or3or4/6or6or3
Job 2	2/6	3/1	1/2	2or4/6or6	6or2or1/5or6or1	
Job 3	2/6	3or6/4or2	6or2or1/ 5or6or1	3or2or6/4or6or6	1or5/1or5	
Job 4	6or2or1/5or6or1	2/6	3/1	5or3or2/3or5or1	3or6/4or2	
Job 5	5or3or2/3or5or1	6or2or1/5or6or1	2/6	1or3/5or4	2or4/6or6	3or2or6/4or6or6
Job 6	3or6/4or2	1/2	3or2or6/4or6or6	2/6	6or2or1/5or6or1	1or4/3or2
Job 7	6/1	1or4/3or2	3or2or6/4or6or6	2or5or1/6or1or6	3/1	
Job 8	3or6/4or2	3or2or6/ 4or6or6	6or2or1/5or6or1	2/6	2or4/6or6	
Job 9	6/1	1or5/1or5	6or3or4/6or6or3	1/2	3or2or6/4or6or6	2or4/6or6
Job 10	3or6/4or2	3or2or6/ 4or6or6	5or3or2/3or5or1	6/1	2or4/6or6	1or4/3or2

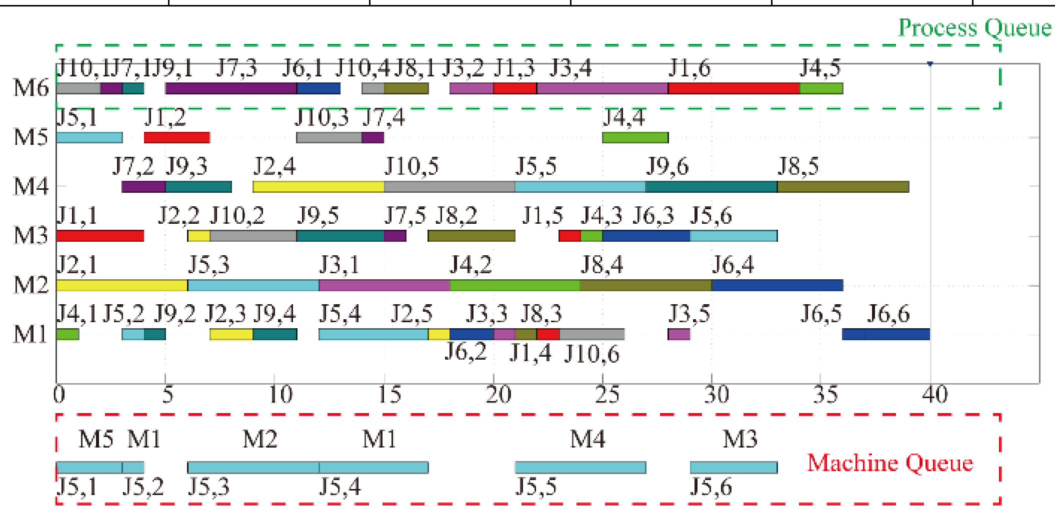


Figure 1 Scheduling results and queue representation

3.2 Data transfer and interaction function module

In the human-computer interaction shop floor dynamic scheduling system, the data transmission and interaction can be divided into 4 stages, as shown in Figure 2.

(1) When the scheduler encounters a disturbance event, he first interrupts the production process and obtains specific information about the disturbance time from the shop floor production monitoring module, as shown in ① and ② of Figure 2.

(2) The scheduler calculates and updates the priority of all unscheduled processes by setting preference coefficients in the process configuration area given the candidate machining machines for the process and their corresponding machining durations, as shown in③, ④, ⑤ and ⑥ of Figure 2.

(3) The scheduler refreshes the Gantt chart blocks of the processes in the priority queue and drags the Gantt chart process blocks in the priority queue area into the scheduling window, as shown in ⑦, ⑧, ⑨, and⑩ of Figure 2.

(4) After all processes are dragged into the scheduling window, the scheduler locks the scheduling results and downloads them to the shop floor controller to complete the scheduling, as shown in ⑪, ⑫, ⑬ and ⑭ of Figure 2.

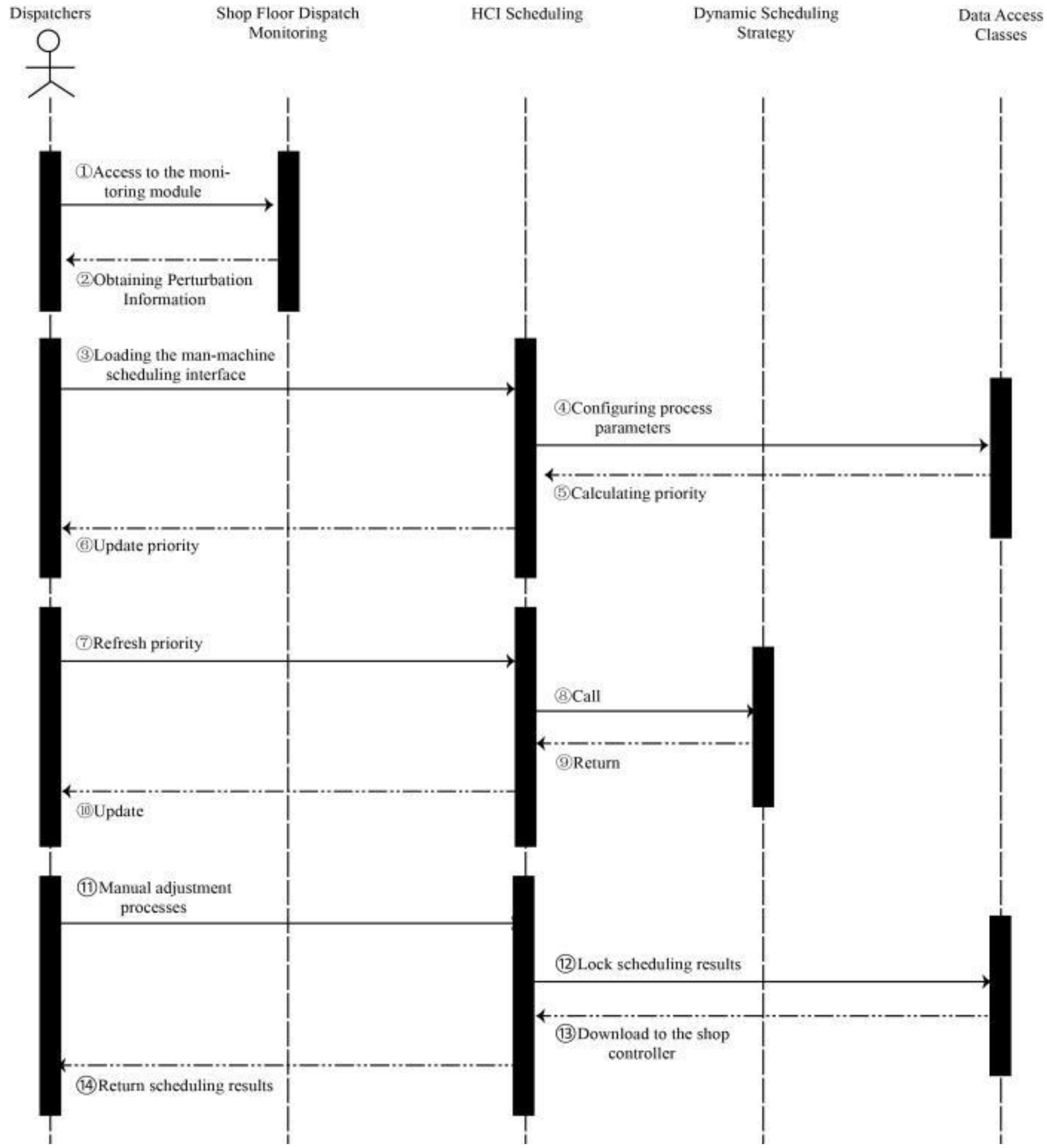


Figure 2 Data transmission and interaction process

3.3 Work order priority algorithm

The priority rule scheduling method is a traditional method for solving shop floor scheduling problems. Due to its simplicity, it is especially suitable for solving dynamic shop scheduling problems and real-time reproducible shop scheduling problems. The priority rule scheduling strategy is actually a greedy strategy, which mainly targets local or short-term objectives with high computational efficiency. Because of the large uncertainty of the HCI shop floor, it is the preferred strategy in many dynamic and real-time scheduling systems because of its feature of seeking relatively more desirable scheduling results with lower computational cost, although it cannot find the global optimal solution.

Shop floor scheduling needs not only to determine the process sequence problem of the process, but also to solve the problem of selecting processing equipment for the process. The priority rule scheduling strategy usually has the ability to solve both of these problems, and common shop scheduling priority rules are shown in Table 2.

Table 2 Workshop scheduling priority rules.

Rule	Full Name
SPT	The machine with the shortest processing time is preferred for the process
ECP	Priority is given to the machine that can complete the process at the earliest
MWR	Priority is given to workpieces with more remaining processes
LWR	Priority is given to workpieces with fewer remaining processes
MPR	Priority is given to workpieces with more processing time remaining
LPR	Priority is given to workpieces with little remaining machining time

Usually, it is difficult to satisfy the requirements of the shop floor scheduling with one scheduling rule. Therefore, priority rules can often be combined when solving shop floor scheduling problems. In the previous research results of this paper, a heuristic algorithm based on the combination of ECP and MWR rules was proposed, and the performance of the solution was better [10]. Therefore, the heuristic algorithm built on the combination of ECP and MWR rules is chosen as the basis of the process prior calculation algorithm in this paper.

In solving the actual dynamic scheduling problem, in order to give full play to the role of human in state sensing, solution decision making and system operation and maintenance, the balance between the decision maker's equipment selection preference and task completion needs to be considered. In order to weigh the two factors, the weights of them need to be given to the calculation of the integrated priority, and the formula for the priority.

$$S = \omega_1 \times S_S + \omega_2 \times S_P \tag{1}$$

Where S is the composite priority value, SS and SP are the priority rule score and personal preference score, respectively, ω1, ω2 are the priority rule score weight and personal preference score weight, respectively, and all are subject to normalization.

4 Dynamic Scheduling Strategy for Human-Computer Interaction Shop Floor

The operational state of shop floor can be modeled by two virtual queues. One is the process queue, which is generally generated by priority rules; the other is the machine queue, which is generally generated based on the part machining process flow. The process queue is used to simulate the processes of each workpiece, which are arranged in order of priority in the cache of the respective assigned machine, with the process with the highest priority at the top of the queue and the first to be processed, called the head of the queue. And the machine queue is used to simulate the machine tools assigned to each process of a workpiece arranged in accordance with the process flow on the processing line of the workpiece, thus forming a queue. Therefore, the essence of smooth shop operation is that the two virtual queues are executed according to the established arrangement, the essence of shop operation status monitoring is whether the execution is the same as the established arrangement, and when the shop encounters an abnormal event disturbance, the members of the whole queue and its order can be adjusted to ensure that the shop operation can be restored to another steady state.

The basic principle of using virtual queues to achieve dynamic scheduling of HMIs is illustrated in figure 3. ①The scheduler identifies the processes affected by abnormal events and rearranges the process and machine queues according to the automatically calculated priority values.② The scheduler arranges the process at the head of the queue at the earliest of the scheduling reference time, the completion time of the previous process on the same workpiece, and the completion time of the aforementioned process on the same machine. ③ The scheduler drags the process at the head of the queue into the scheduling window and removes the process from the process queue, and the process with the highest priority in the process queue is automatically added as the process at the head of the queue. ④ After all processes have been foreseen, the scheduling plan is locked and downloaded to the shop floor system controller.

Take the case shown in figure 3 as an example, according to the base time of the scheduling window, at the current moment when the workpiece 9 is transferred to the workpiece's next process machine 3, according to the shop machine queue information machine 3 is in a fault state, at this time the workpiece 9 is in a waiting state at machine 3; when the workpiece 8 is transferred to the workpiece's next process machine 6, according to the machine queue information machine 3 is in a fault state, at this time the workpiece 8 is in a processing state at machine 6; when the workpiece 4 is transferred to the workpiece's next process machine 2, according to the machine queue information machine 2 is in a processing state, at this time the workpiece 4 is in a waiting state at machine 2.

A demonstration of the process of implementing a dynamic strategy for human-machine interaction is illustrated in figure 4.

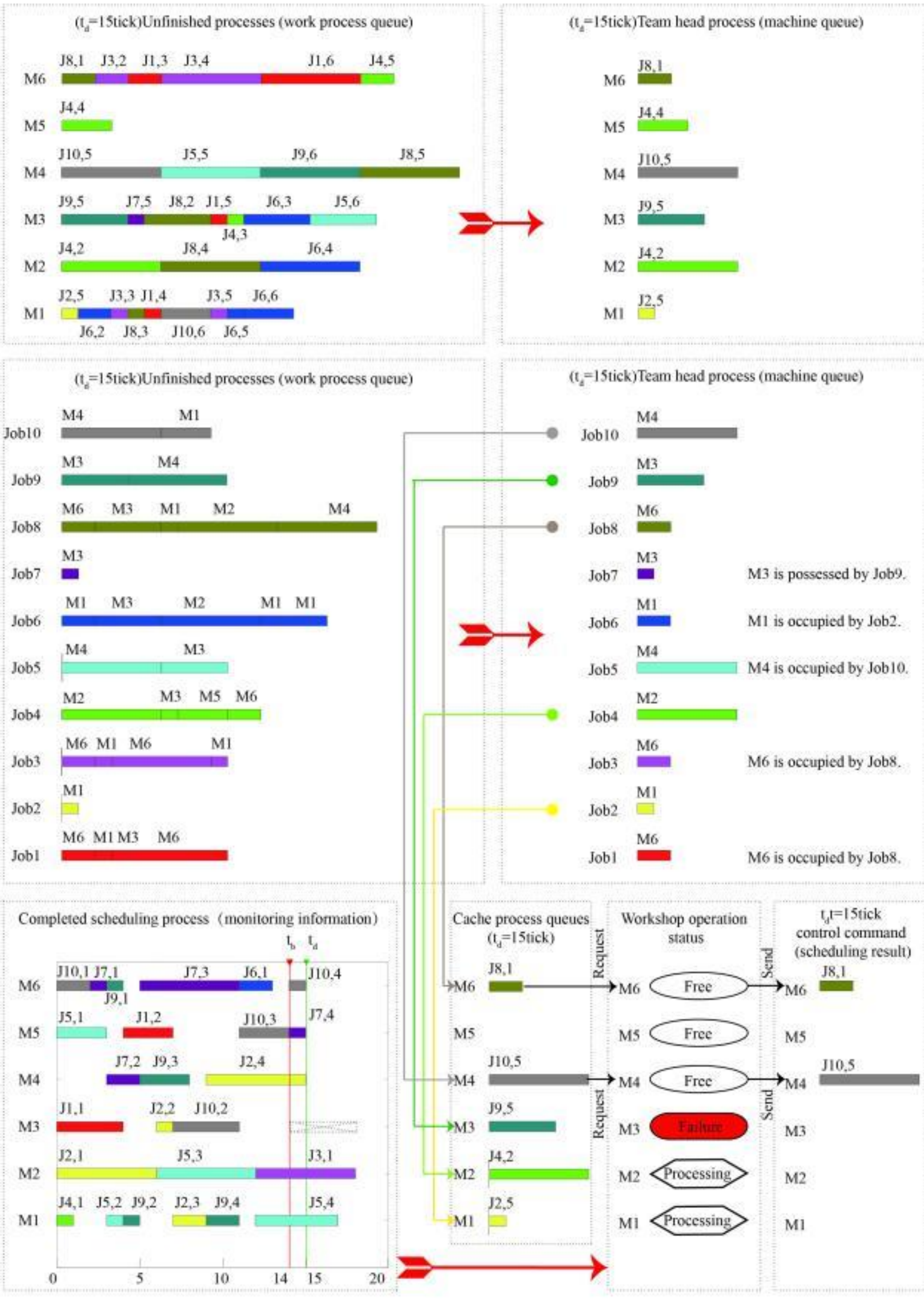
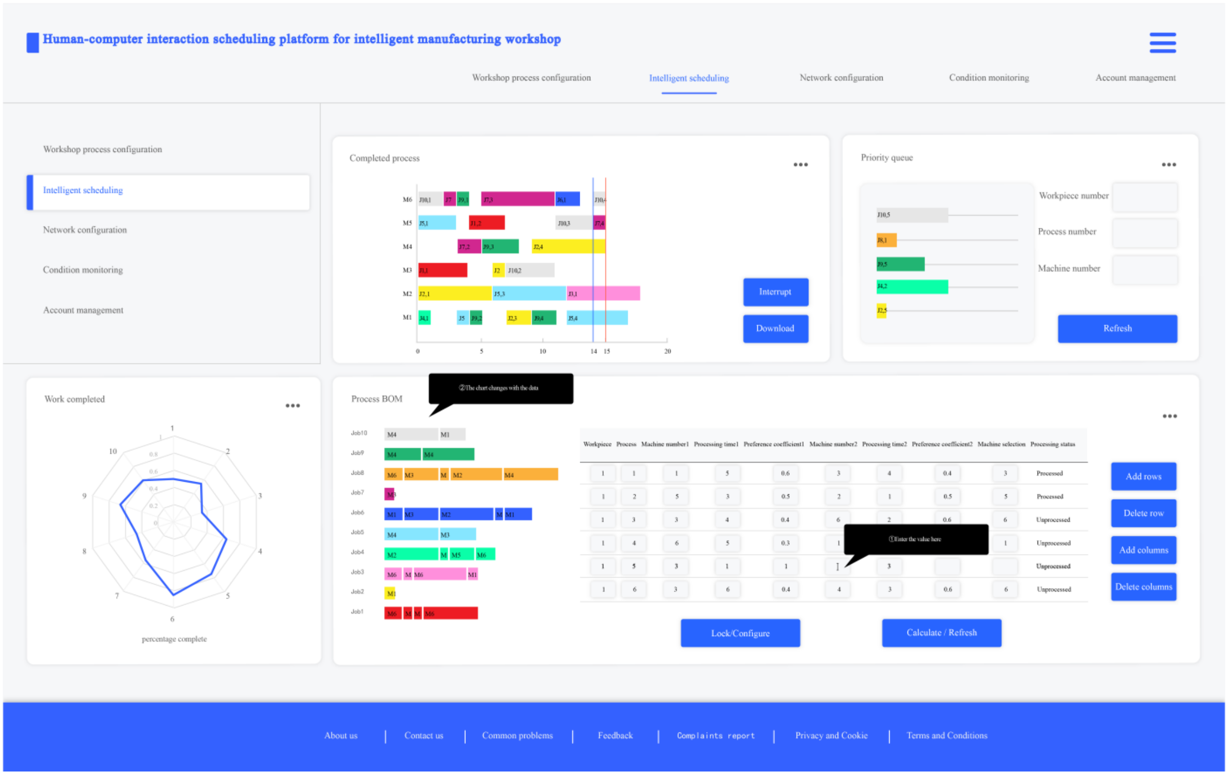
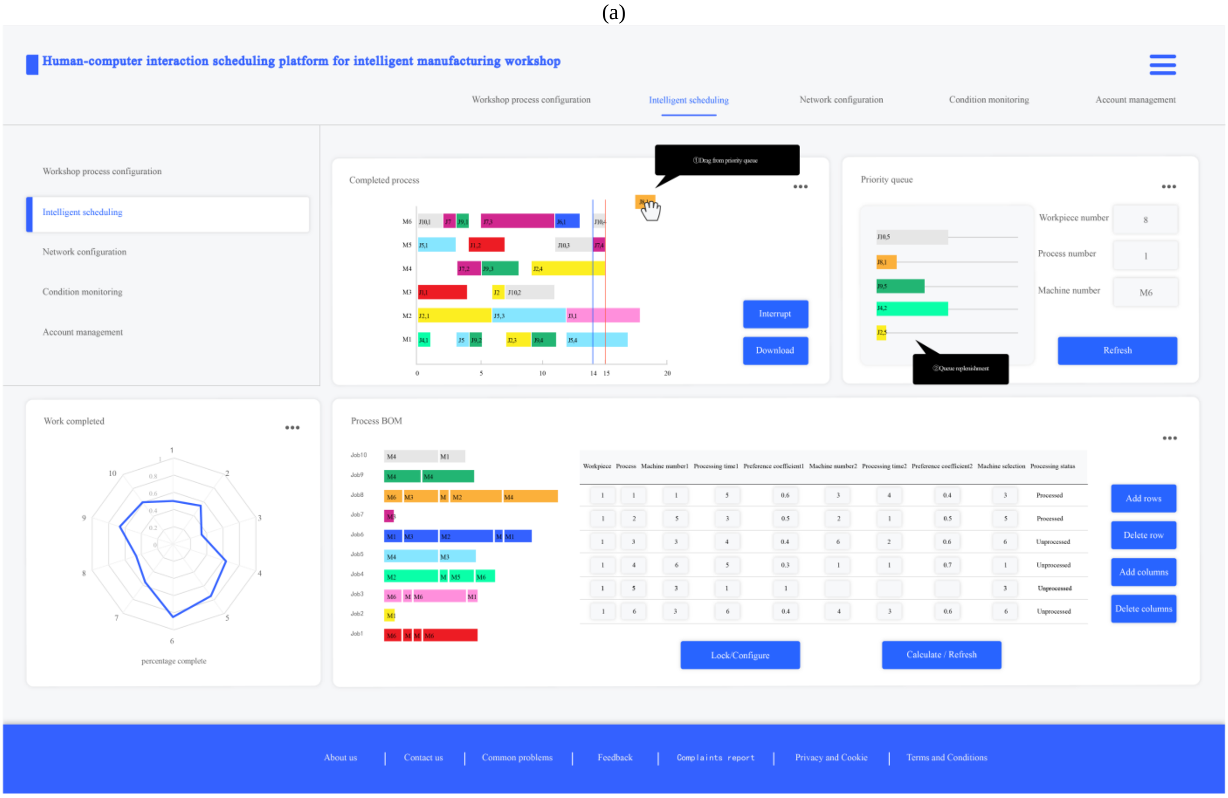


Figure 3 Shop floor information interaction



(a)



(b)

Figure 4 The process of implementing dynamic human-computer interaction

The scheduler first interrupts the production process when a disturbance event is raised. Candidate machines for the process and their corresponding processing duration are given in the process configuration area, and the priorities of all unscheduled processes are calculated and updated by setting preference factors, as showed in figure 4(a). Then the Gantt chart processes blocks of the processes in the priority queue are refreshed. Next, the scheduler drags the Gantt process blocks in the priority queue into the scheduling window, as showed in figure 4(b). Finally, after all processes are dragged into the scheduling window, the scheduling results are locked and downloaded to the shop floor controller to complete scheduling.

5 Case and Application Analysis

In order to verify the feasibility of the dynamic scheduling strategy of the HCI shop floor and to test the performance of the HCI shop floor dynamic scheduling system in solving scheduling problems, the computer CPU main frequency is 2GHz and memory is 2.0GB under Windows 7 environment, and MATLAB programming is used to choose to simulate machine failure and expediting order on the standard flexible job shop scheduling arithmetic MK06 [11] scenarios. The origin scheduling scheme is shown in figure 5, and the meaning of the elements in the graph is the same as in Section 2.1.

To measure the results of scheduling, the origin moment metric is chosen. By examining the origin moments for robustness and stability metrics, values closer to zero indicate ideal results for dynamic scheduling [12]. The origin moment is calculated as following:

$$MID = \sqrt{Robustness^2 + Stability^2} \tag{2}$$

In the formula, Robustness and Stability denote robustness and stability, respectively.

The robustness metric is the relative robustness metric proposed by Kouvelis and Yu [13]:

$$RM = \frac{|MS\_R - MS\_P|}{MS\_P} \times 100\% \tag{3}$$

The stability indexes proposed by Al-Hinai and Elmekkawy [14] were used:

$$SM = \frac{\sum_{i=1}^{n}\sum_{j=1}^{q_i}|CO_{ijP} - CO_{ijR}|}{(\sum_{i=1}^{n}O_i) \times MS\_P} \times 100\% \tag{4}$$

Where MS_P is the planned completion time for pre-scheduling, qi is the total number of processes for workpiece i, COijP is the planned machining completion time for the jth process of workpiece i, COijP is the actual machining completion time for the jth process of workpiece i, and Oi is the number of all processes that do not change machining machines (excluding faulty machines).

The solution obtained for the dynamic scheduling problem caused by machine fault disturbance is shown in figure 6. By comparing the schemes of figure 5 and figure 6, the RM index is calculated to be 0.1167, the SM index is calculated to be 0.4025, and the origin moment is calculated to be 0.4190 using Eq. (2).

For the dynamic scheduling problem caused by the expedited single disturbance, the solution obtained is shown in figure 7. By comparing the schemes in figure 5 and figure 7, the RM index is calculated to be 0.1167, the SM index is calculated to be 0.3514, and the origin moment is calculated to be 0.3703 using Eq. (2).

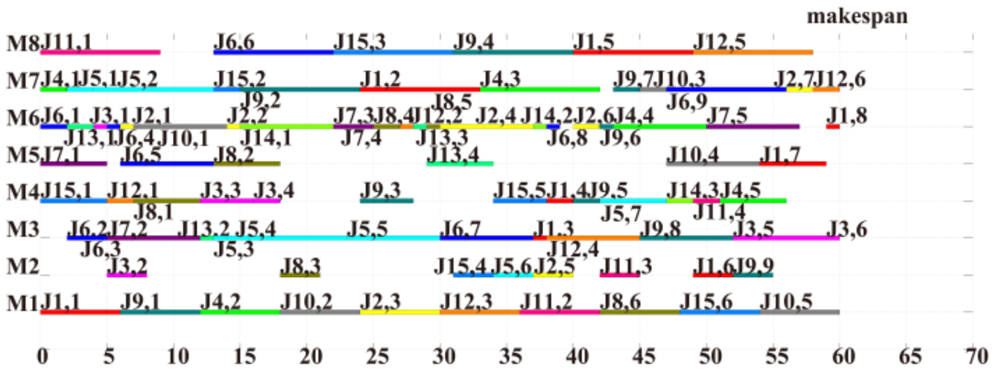


Figure 5 Original scheduling scheme

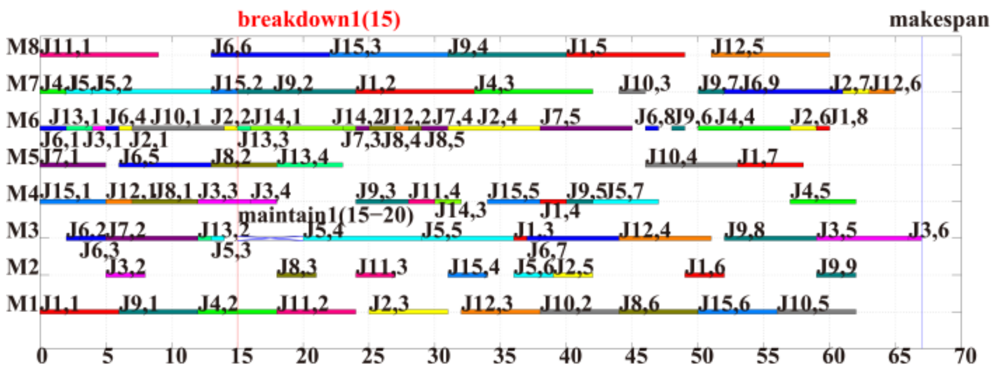


Figure 6 Scheduling scheme for dynamic scheduling problems caused by machine fault disturbances

Figure 7 Scheduling scheme for dynamic scheduling problems caused by expedited order disturbances

Therefore, it is clear from the origin moment index that the HMI-based shop floor dynamic scheduling system is efficient and reliable in solving dynamic scheduling problems, and its related strategies are feasible and stable.

6 Conclusions

The shop floor dynamic scheduling system with human-computer interaction implements the shop floor dynamic scheduling through computer-aided decision making and human-computer interaction. In order to solve the design problem of graphical human-computer interaction interface, the standardization problem of human-computer interaction and the priority calculation problem in the system design, a human-computer interaction interface based on Gantt chart is designed, a data transmission and interaction architecture is constructed, and a priority algorithm that integrates priority rules and scheduler preferences is proposed. The human-computer interaction shop floor dynamic scheduling strategy is proposed, and the origin moments obtained by using it in solving the flexible dynamic operation shop floor scheduling problem caused by machine failure and expediting order are 0.4190 and 0.3703, respectively. From the origin moment index, it can be seen that the human-computer interaction-based shop floor dynamic scheduling system is efficient and reliable in solving the dynamic scheduling problem, and its related strategy is feasible and stable.

Further research will continue to focus on the integration of reality and information interconnection in the process of human-computer interaction scheduling.

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