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A dynamic reactive scheduling mechanism for responding to changes of production orders and manufacturing resources

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Abstract

This research introduces a dynamic reactive production scheduling mechanism for modifying the originally created schedules when these schedules cannot be completed due to changes of production orders and manufacturing resources. Production order changes include removal of an order that is canceled by a customer and insertion of an order that has to be completed within a short period of time. Manufacturing resource changes include breakdowns of machines and sudden sickness of workers. Match-up and agent-based collaboration approaches are employed to modify only part of the originally created schedules for improving the reactive scheduling efficiency, while maintaining the scheduling quality. The dynamic reactive production scheduling system was implemented using Smalltalk, an object oriented programming language.

Keywords: Reactive scheduling; Predictive scheduling; Match-up approach; Multi-agents; Artificial intelligence

1. Introduction

Production scheduling aims at allocating available manufacturing resources for the required manufacturing tasks and identifying the sequence and timing parameter values to accomplish these tasks. Typical manufacturing resources include facilities, persons, materials, and so on. Competitiveness of products can be improved by identifying the optimal production schedule that needs the minimum production efforts.

The research on production scheduling was started by developing algorithms for generating the optimal sequence to complete the required tasks considering either only one processor (machine) or multiple processors (machines) [1]. In each of these scheduling methods, an objective function, such as the minimum total make-span to complete all the selected tasks, or the minimum mean flow of these selected tasks, is selected for identifying the optimal schedule.

Most of the earlier developed scheduling methods have difficulty for solving actual industrial problems, due to the complexity of real-life manufacturing constraints. First, the industrial scheduling problems are dynamic in nature, i.e. new orders are received continuously during the production process. Second, the created schedule may be changed to reflect the changes of production orders and manufacturing conditions during production process. Production order changes include removal of an order that is canceled by a customer and insertion of an order that has to be completed within a short period of time. Manufacturing condition changes include disturbance events of resources such as breakdowns of machines and sickness of workers.

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With the advances in computer technologies, many new methods and systems considering industrial constraints were developed for two different types of production scheduling: predictive scheduling and reactive scheduling [2,3]. Predictive scheduling creates the optimal schedule based on given requirements and constraints prior to the production process. Most of the scheduling algorithms and systems were developed for predictive scheduling. Reactive scheduling, on the other hand, is a process to modify the created schedule during the manufacturing process to adapt changes in production environment. Reactive scheduling is also called rescheduling.

The intelligent system approaches have been proved effective for conducting both predictive scheduling and reactive scheduling [2,4,5]. For predictive scheduling, generally intelligent approaches aim at identifying the optimal schedule through iterative search process. For reactive scheduling, most approaches attempt to revise only part of the originally created schedule for responding to the production environment changes without rescheduling all the required tasks [6–9]. Because a large number of tasks are usually considered in predictive scheduling and reactive scheduling, the optimal schedules created using these developed methods are not the true global optimal schedules. Quality of scheduling result can be improved by employing stochastic computing methods, such as genetic algorithm and simulated annealing, to prevent the result from falling into the local optimal points [2].

Despite the progress, many problems have to be solved for predictive scheduling and reactive scheduling. These problems are summarized as follows.

1. In the presently developed scheduling systems, manufacturing requirements are usually modeled directly based upon customer requirements. The manufacturing requirements, together with manufacturing resource descriptions, are used as constraints for production scheduling. Product design descriptions and constraints, however, are not considered in these systems. Because many new designs are created using existing modules as their components, modeling of the manufacturing requirements of these component modules and identification of the manufacturing tasks of these designs by considering constraints among these components are required.
2. The production scheduling mechanisms in these systems were primarily developed based on centralized computing architecture, in which all the knowledge bases and databases were modeled at the same location. This control architecture has difficulty in handling complex manufacturing systems that require knowledge and data to be distributed at different locations. Therefore, development of distributed production scheduling systems is required.

In our previous research, an intelligent predictive scheduling system has been developed to solve these two problems [10,11]. In this system, product descriptions and design constraints are represented using a feature-based modeling approach. Manufacturing requirements for producing the products, including tasks and sequential constraints for accomplishing these tasks, are represented as part of the product feature descriptions. Manufacturing resources, including facilities and persons, are modeled as distributed agents that are coordinated by two mediators. The optimal production schedule and its timing parameter values are identified using constraint-based search and agent-based collaboration approaches. This project was initiated from the requirements of a building product manufacturing company — Gienow Building Products Ltd., where production tasks are created from customer orders.

The research presented in this paper is a further development of this intelligent production scheduling system by introducing a reactive scheduling mechanism for responding to changes of production orders and manufacturing resources. Changes of production orders include cancellation of previously scheduled orders and insertion of urgent orders. Changes of manufacturing resource conditions include breakdowns of machines and sickness of persons. Match-up and agent-based collaboration approaches are employed for rescheduling the tasks and identifying the optimal timing parameter values of these tasks, for improving the scheduling efficiency while maintaining the scheduling quality.

The remaining of this paper is organized as follows. Section 2 introduces the previously developed predictive scheduling mechanism. Section 3 proposes the architecture of the intelligent production scheduling system that supports both the predictive scheduling function and the reactive scheduling function. Section 4 presents the reactive scheduling algorithms and examples for responding to changes of orders and resources. Section 5 gives a number of case study examples to show the effectiveness of the introduced approach. Section 6 summarizes this research.

2. Review of a previously developed predictive scheduling mechanism

The previously developed predictive scheduling mechanism is composed of three sub-systems: product modeling sub-system, resource management sub-system, and scheduling sub-system.

2.1. Product modeling sub-system

In the product modeling sub-system, a product is modeled by primitives called features [12,13]. Features are described at two different levels, class level and instance level, corresponding to standard product libraries and special product data, respectively. Instance features are generated using class features as their templates. A feature is composed of element features, attributes, qualitative relations among features, and quantitative relations among attributes. For instance, Fig. 1 shows a product modeled by three instance features. The top-level instance feature, `c`, is generated from a class feature `WindowCenter` that is composed of two element features: `?Left` and `?Right`. When the class feature, `Window-Center`, is used to generate its instance feature, `c`, the two element features are also generated as instance features, `cl` and `cr`, respectively.

The manufacturing requirements for producing each feature are defined by a graph of tasks, representing the sequential constraints to accomplish these tasks. For instance, the right component, `cr`, shown in Fig. 1 can be produced by six tasks, including cutting, `C`, framing, `F`, assemblies, `A1`, `A2`, and `A3`, and glazing, `G`. A task in an instance feature is carried out in production only when all the tasks in this feature's element features have been completed. Each task is defined by its type, requirements of resources including facilities and persons, and time period to carry out this process.

2.2. Resource management sub-system

In the resource management sub-system, the facility resources and person resources are modeled as

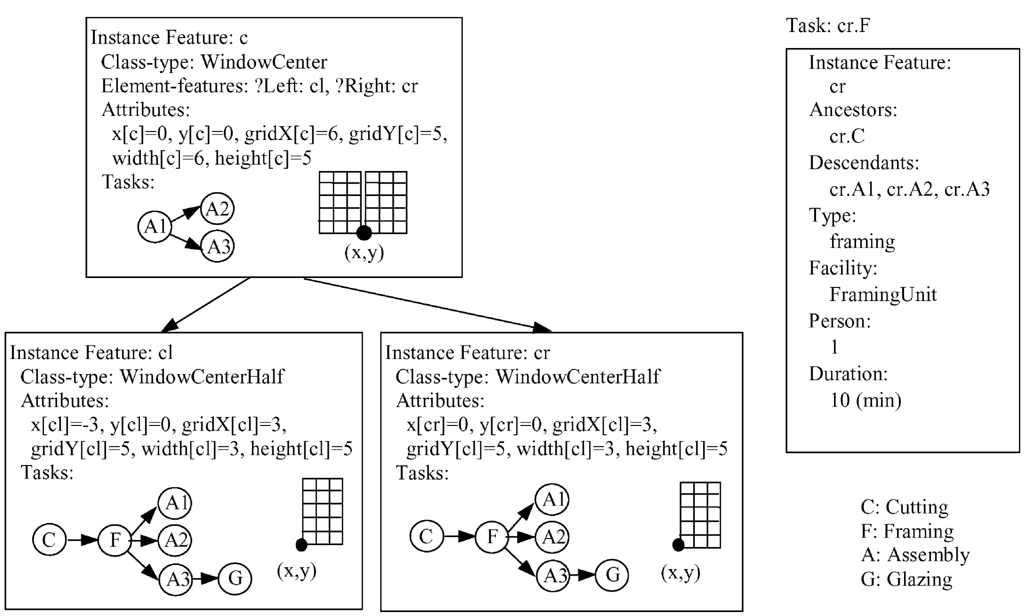

Fig. 1. Feature-based product and manufacturing requirement representation.

agents, which are coordinated by a facility mediator and a personnel mediator during the predictive scheduling process. The idea to model resources using agents comes from the distributed modeling approach for improving flexibility of manufacturing systems [14–19]. A facility resource agent is defined by its type, manufacturing functions, and time constraints including available periods and unavailable periods. A person resource agent is defined by the facilities that the person is responsible for, and time constraints including available periods, regular schedule, and unavailable periods.

2.3. Scheduling sub-system

The scheduling sub-system aims at identifying the optimal schedule for the orders received from customers. When an order is received, an order agent is then created to represent the customer requirements. The order agents negotiate with the resource agents using the corresponding design constraints and manufacturing requirements, which are preserved in the instance features, to identify the optimal production schedule. Constraint-based search and agent-based collaboration approaches are employed for identifying the optimal schedule, as shown in Fig. 2.

2.3.1. Constraint-based search

The optimal sequence of tasks for a customer order is identified using best-first search [20], as shown in Fig. 2. Each node in the search tree represents a partial schedule developed so far. A start node describes an empty schedule, while a goal node describes the schedule in which all the tasks of the customer order have been allocated with required resources and timing parameter values. In predictive scheduling, each time the best node is selected for generating its sub-nodes. When a sub-node is generated, an unscheduled task is then selected for resource allocation and timing parameter value instantiation through collaboration among relevant agents. Evaluation to this node is conducted using a heuristic function. This process is conducted continuously until the selected best-node is the goal node. The scheduling results are described

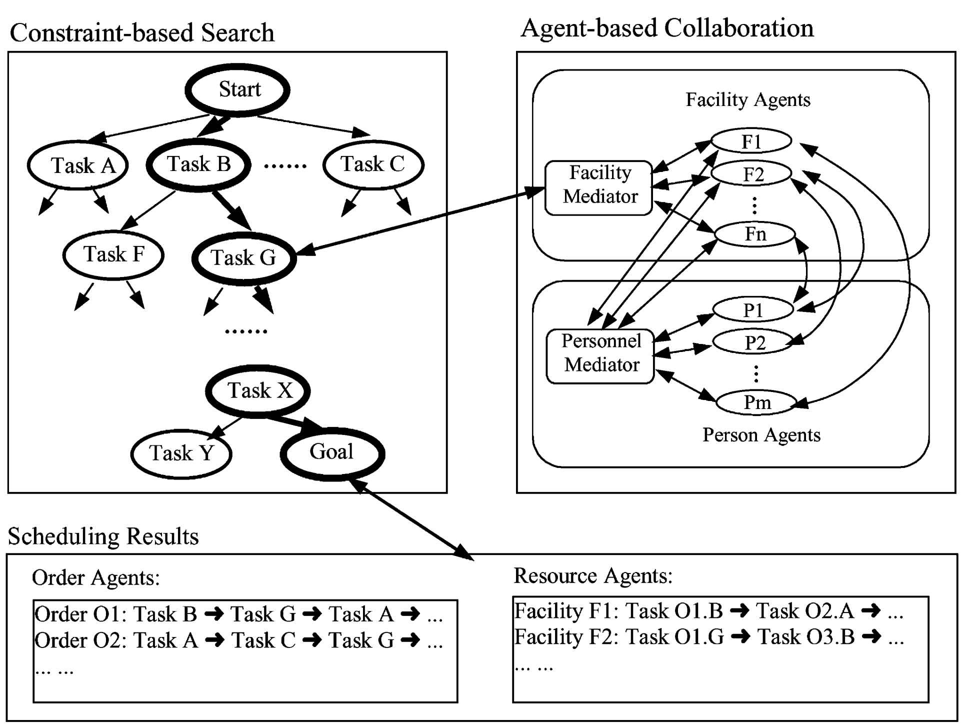

Fig. 2. Predictive scheduling using constraint-based search and agent-based collaboration.

by sequences of tasks that are preserved in order agents and resource agents, as shown in Fig. 2. In predictive scheduling, the created schedule should satisfy the following temporal constraints: (1) a task in an instance feature can be carried out in production only when all the tasks in this feature's element features have been completed. (2) A task can be carried out only when all its ancestor tasks have been completed.

Two heuristic functions have been developed in this research: (1) F_{max} — the latest task finish time considering all the scheduled tasks of an order and (2) S_{min} — the earliest task start time considering all the scheduled tasks of an order. Two search strategies for predictive scheduling have also been developed based upon the two heuristic functions: (1) earliest-delivery-time-based scheduling strategy — to provide the product to the customer as early as possible by selecting the node with the minimum value of the F_{max} as the best node, and (2) due-time-based scheduling strategy — to start the product manufacturing as late as possible to reduce the space for storing the produced product by selecting the node with the maximum value of the S_{min} as the best node.

2.3.2. Agent-based collaboration

Allocation of resources and instantiation of timing parameter values for the required tasks are conducted based upon agent-based collaboration using the contract net protocol [21]. Two timing parameters of tasks, *start time* and *finish time*, are considered in scheduling. The agent-based collaboration in predictive scheduling is conducted at two different levels: order-facility collaboration level and facility-person collaboration level, as shown in Fig. 2. When the facility mediator receives a to-be-scheduled task from the order agent, this mediator sends messages to all the relevant facility agents it knows. Each facility agent then starts negotiation with the relevant person agents through the personnel mediator and sends a bid (with the proposed start time, finish time, and person) to the facility mediator. The facility mediator selects the facility that provides the best bid, such as the one with the earliest product manufacturing completion time for the earliest-delivery-time-based scheduling, or the one with the latest product manufacturing releasing time for the due-time-based scheduling.

3. Architecture of an intelligent production scheduling system

The dynamic reactive scheduling mechanism introduced in this research was developed as a

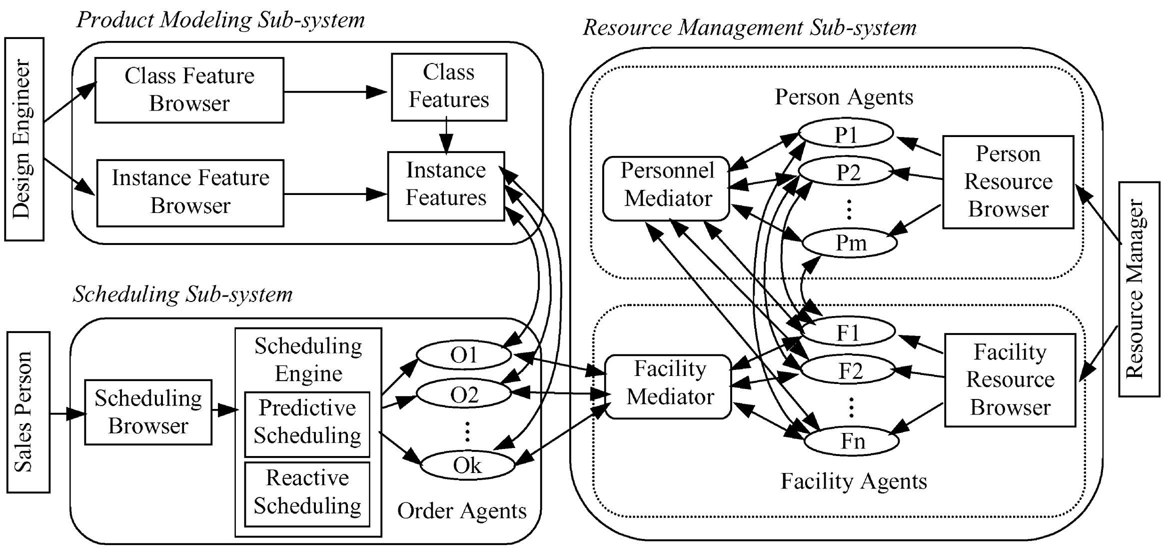

Fig. 3. Architecture of the intelligent production scheduling system.

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