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An agent-based approach for integrated process planning and scheduling

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ABSTRACT

Traditionally, process planning and scheduling were performed sequentially, where scheduling was done after process plans had been generated. Considering the fact that these two functions are usually complementary, it is necessary to integrate them more tightly so that the performance of a manufacturing system can be improved greatly. In this paper, an agent-based approach has been developed to facilitate the integration of these two functions. In the approach, the two functions are carried out simultaneously, and an optimization agent based on an evolutionary algorithm is used to manage the interactions and communications between agents to enable proper decisions to be made. To verify the feasibility and performance of the proposed approach, experimental studies have been conducted and comparisons have been made between this approach and some previous works. The experimental results show the proposed approach has achieved significant improvement.

1. Introduction

Process planning and scheduling used to link product design and manufacturing are two of the most important functions in a manufacturing system. A process plan specifies what manufacturing resources and technical operations/routes are needed to produce a product (a job). The outcome of process planning includes the identification of machines, tools and fixtures suitable for a job, and the arrangement of operations and processes for the job. Typically, a job may have one or more alternative process plans. With the process plans of jobs as input, a scheduling task is to schedule the operations of all the jobs on machines while precedence relationships in the process plans are satisfied. Although as mentioned above, there is a close relationship between process planning and scheduling, the integration of them is still a challenge in both research and applications (Sugimura, Hino, & Moriwaki, 2001).

In traditional approaches, process planning and scheduling were carried out in a sequential way. Scheduling was conducted after the process plan had been generated. Those approaches have become an obstacle to improve the productivity and responsiveness of manufacturing systems and to cause the following problems in particular (Kumar & Rajotia, 2003; Saygin & Kilic, 1999):

(1) In manufacturing practice, process planner plans jobs individually. For each job, manufacturing resources on the shop floor are usually assigned on it without considering the competition for the resources from other jobs (Usher & Fernandes, 1996). This may lead to the process planners favoring to select the desirable machines for each job repeatedly. Therefore, the generated process plans are somewhat unrealistic and cannot be readily executed on the shop floor for a group of jobs (Lee & Kim, 2001). Accordingly, the resulting optimal process plans often become infeasible when they are carried out in practice at the later stage.
(2) Scheduling plans are often determined after process plans. Fixed process plans may drive scheduling plans to end up with severely unbalanced resource load and create superfluous bottlenecks.
(3) Even though process planners consider the restriction of the current resources on the shop floor, the constraints in the process planning phase may have already changed due to the time delay between the planning phase and execution phase. This may lead to the infeasibility of the optimized process plan. Investigations have shown that 20–30% of the total process plans in a given period have to be modified to adapt to the dynamic change in a production environment (Kumar & Rajotia, 2003).
(4) In most cases, both for process planning and scheduling, a single criterion optimization technique is used to determine the best solution. However, the real production environment is best represented by considering more than one criterion simultaneously (Kumar & Rajotia, 2003). Furthermore, the process planning and scheduling may have conflicting objectives. Process planning emphasizes the technological requirements of a job, while scheduling involves the timing aspects and resource sharing of all jobs. If there is no appropriate coordination, it may create conflicting problems.

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To overcome these problems, there is an increasing need for an Integrated Process Planning and Scheduling (IPPS) system. The IPPS introduces significant improvements to the efficiency of manufacturing resources through eliminating or reducing scheduling conflicts, reducing flow-time and work-in-process, improving production resources utilizing and adapting to irregular shop floor disturbances (Lee & Kim, 2001). Without IPPS, a true Computer Integrated Manufacturing System (CIMS), which strives to integrate the various phases of manufacturing in a single comprehensive system, may not be effectively realized.

The remainder of this paper is organized as follows. Section 2 introduces a literature survey of the problem. Problem formulation is discussed in Section 3. The proposed agent-based approach for IPPS is given in Section 4. Experimental studies and discussion are reported in Section 5. Section 6 is the conclusion.

2. Literature survey

In the early studies of CIMS, it has been identified that IPPS is very important to the development of CIMS (Kumar & Rajotia, 2005; Tan & Khoshnevis, 2000). The preliminary idea of IPPS was first introduced by Chryssolouris and Chan (1985) and Chryssolouris et al. (1984). Beckendorff, Kreutzfeldt, and Ullmann (1991) used alternative process plans to improve the flexibility of manufacturing systems. Khoshnevis and Chen (1989) introduced the concept of dynamic feedback into IPPS. The integration model proposed by Larsen (1993) and Zhang (1993) extended the concepts of alternative process plans and dynamic feedback and defined an expression to the methodology of hierarchical approach. Some earlier works of IPPS had been summarized in Tan and Khoshnevis (2000). In recent years, in the area of IPPS, the agent-based approach has captured the interest of a number of researchers.

Zhang and Xie (2007) reviewed the agent technology for collaborative process planning. The focus of the research was on how the agent technology can be further developed in support of collaborative process planning as well as its future research issues and directions in process planning. Wang, Shen, and Hao (2006) provided a literature review on IPPS, particularly on the agent-based approaches for the problem. The advantages of the agent-based approach for scheduling were discussed. Shen, Wang, and Hao (2006) reviewed the research on manufacturing process planning, scheduling as well as their integration.

Gu, Balasubramanian, and Norrie (1997) proposed a multi-agent system where process routes and schedules of a part are accomplished through the contract net bids. IDCPPS (Chan, Zhang, & Li, 2001) is an integrated, distributed and cooperative process planning system. The process planning tasks are separated into three levels, namely, initial planning, decision-making, and detail planning. The results of these three steps are general process plans, a ranked list of near-optimal alternative plans and the final detailed linear process plans, respectively. The integration with scheduling is considered at each stage with process planning. Wu, Fuh, and Nee (2002) presented a computerized model that can integrate the manufacturing functions and resolve some of the critical problems in distributed virtual manufacturing. This integration model is realized through a multi-agent approach that provides a practical approach for software integration in a distributed environment.

Lim and Zhang (2003, 2004) introduced a multi-agent based framework for the IPPS problem. This framework can also be used to optimize the utilization of manufacturing resources dynamically as well as provide a platform on which alternative configurations of manufacturing systems can be assessed. Wang and Shen (2003) proposed a new methodology of distributed process planning. It focused on the architecture of the new approach, using multi-agent negotiation and cooperation, and on the other supporting technologies such as machining feature-based planning and function block-based control. Wong, Leung, Mak, and Fung (2006a, 2006b) developed an online hybrid agent-based negotiation Multi-agent System (MAS) to integrate process planning with scheduling/rescheduling. With the introduction of the supervisory control into the decentralized negotiations, this approach is able to provide solutions with a better global performance. Shukla, Tiwari, and Son (2008) presented a bidding-based multi-agent system for solving IPPS. The proposed architecture consists of various autonomous agents capable of communicating (bidding) with each other and making decisions based on their knowledge. Fuji, Inoue, and Ueda (2008) proposed a new method in IPPS. A multi-agent learning based integration method was devised in the study to solve the conflict between the optimality of the process plan and the production schedule. In the method, each machine makes decisions about process planning and scheduling simultaneously, and it has been modeled as a learning agent using evolutionary artificial neural networks to realize proper decisions resulting from interactions between other machines. Nejad, Sugimura, Iwamura, and Tanimizu (2008) proposed an agent-based architecture of an IPPS system for multi jobs in flexible manufacturing systems.

In the literature of agent-based manufacturing applications, much research applied simple algorithms such as dispatching rules which are applicable for real time decision making (Shen et al., 2006). These methods are simple and applicable, but they do not guarantee the effectiveness for complex problem in the manufacturing systems. As the efficiency becomes more important in the agent-based manufacturing, the recent research works are trying to combine the agent-based approach with other techniques such as genetic algorithm, neural network and some mathematical modeling methods (Shen et al., 2006). In this research, an agent-based approach with optimization agent was introduced for improving the generated process plans and scheduling plans.

3. Problem formulation

The IPPS problem can be defined as follows (Guo, Li, Mileham, & Owen, 2009):

> *"Given a set of n parts which are to be processed on machines with operations including alternative manufacturing resources, select suitable manufacturing resources and sequence the operations so as to determine a schedule in which the precedence constraints among operations can be satisfied and the corresponding objectives can be achieved."*

The mathematical model of IPPS is defined here. The most popular criteria for scheduling include makespan, job tardiness and the balanced level of machine utilization, while manufacturing cost is the major criterion for process planning (Li, Gao, Li, & Guo, 2008a). In this paper, scheduling is often assumed as job shop scheduling, and the mathematical model of IPPS is based on the mixed integer programming model of the job shop scheduling problem (JSP).

In order to solve this problem, the following assumptions are made:

(1) Jobs are independent. Job preemption is not allowed and each machine can handle only one job at a time.
(2) The different operations of one job cannot be processed simultaneously.
(3) All jobs and machines are available at time zero simultaneously.
(4) After a job is processed on a machine, it is immediately transported to the next machine on its process, and the transmission time is assumed to be negligible.