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An effective hybrid algorithm for integrated process planning and scheduling

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A B S T R A C T

Process planning and scheduling are two of the most important functions in the manufacturing system. Traditionally, process planning and scheduling were regarded as separate tasks performed sequentially, where scheduling was implemented after process plans had been generated. However, their functions are usually complementary. If the two systems can be integrated more tightly, greater performance and higher productivity of manufacturing system can be achieved. In this paper, a new hybrid algorithm (HA) based approach has been developed to facilitate the integration and optimization of these two systems. To improve the optimization performance of the approach, an efficient genetic representation, operator and local search strategy have been developed. Experimental studies have been used to test the performance of the proposed approach and to make comparisons between this approach and some previous works. The results show that the research on integrated process planning and scheduling (IPPS) is necessary and the proposed approach is a promising and very effective method on the research of IPPS.

1. Introduction

Process planning and scheduling are two of the most important sub-systems in a manufacturing system. A process plan specifies raw materials or components needed to produce a product, processes and operations, which are necessary to transform those raw materials into the final product. The outcome of process planning includes the identification of machines, tools and fixtures suitable for a job and the arrangement of operations for a job. And, a job may have one or more alternative process plans. Process planning is the bridge of the product design and manufacturing. With the process plans of jobs as inputs, a scheduling task is to schedule the operations of all the jobs on machines while precedence relationships in the process plans are satisfied. Scheduling is the link of the two production steps, which are the preparing processes and putting them into action. Although there is a close relationship between process planning and scheduling, their integration is still a challenge in both research and applications (Sugimura et al., 2001).

In traditional approaches, process planning and scheduling were carried out in a sequential way, where scheduling was conducted separately after the process plans had been generated. Those approaches have become the obstacles to improve the productivity and responsiveness of the manufacturing systems and to cause the following problems (Kumar and Rajotia, 2002, 2003):

- Traditionally, in a manufacturing organization, the process planning function works in static. Process planner plans jobs separately. 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 and Fernandes, 1996). This may lead to the process planners favoring to select the desirable resources for each job repeatedly. Therefore, the resulting optimum process plans often become infeasible when they are carried out in practice at the later stage (Lee and Kim, 2001).
- Even though process planners consider the restriction of the current resources on the shop floor, because of the time delay between planning phase and execution phase, the constraints considered in the planning phase may have already changed greatly, which may lead to the optimum process plans being infeasible (Kuhnle et al., 1994). Investigations have shown that 20–30% of the total production plans in a given period have to be rescheduled to adapt to dynamic changes in a production environment (Kumar and Rajotia, 2003).
- Traditionally, scheduling plans are often determined after process plans. In the scheduling phase, scheduling planners have to consider the determined process plans. Fixed process plans may drive scheduling plans to end up with severely unbalanced resource load and create superfluous bottlenecks.
- 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 and Rajotia, 2003). And, process planning emphasizes the technological requirements of a job,

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while scheduling attaches importance to the timing aspects and resource sharing of all jobs. If there is no appropriate coordination, it may create conflicting problems.

To overcome these problems, there is an increasing need for deep research and application of the IPPS system. The IPPS can introduce significant improvements to the efficiency of manufacturing 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 and 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 review. Problem formulation is discussed in Section 3. Hybrid algorithm for IPPS is proposed in Section 4. Experimental studies and discussions are reported in Section 5. Section 6 is conclusion.

2. Literature review

In the beginning research of CIMS, some researchers have found that the IPPS is very important to the development of CIMS (Tan and Khoshnevis, 2000). The preliminary idea of IPPS was introduced by Chryssolouris et al. (1984) and Chryssolouris and Chan (1985). Beckendorff et al. (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 Zhang (1993) and Larsen (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) and Wang et al. (2006). In recent years, in the area of IPPS, several models have been reported, and they can be classified into three basic models based on IPPS: nonlinear process planning (NLPP), closed loop process planning (CLPP) and distributed process planning (DPP) (Li et al., 2010a).

2.1. Nonlinear process planning

The methodology of NLPP is to provide all alternative plans for each job with a rank according to process planning optimization criteria. The plan with highest priority is always ready for submission when the job is required. If the first-priority plan is not suitable for the current shop floor status, the second-priority plan will be provided into the scheduling system.

NLPP is the most basic model of IPPS. Because the methodology of this model is very simple, most of the current researches on the integration model focus on the implementation and improvement of this model. Kim et al. (1997) gave a scheduling system that was supported by flexible process plans. Lee and Kim (2001) presented the NLPP model, which was based on the genetic algorithm (GA). Yang et al. (2001) presented a prototype of a feature-based multi-alternative process planning system. Thomalla (2001) investigated an optimization methodology for job shop scheduling with alternative process plans. Kim et al. (2003) used a symbiotic evolutionary algorithm for the IPPS problem. Li and McMahon (2007) used a simulated annealing-based approach for the IPPS problem. Shao et al. (2009) used a modified GA to solve the IPPS problem. Baykasoglu and Ozbakir (2009) analyzed the effect of dispatching rules on the scheduling performance of flexible job shop with different flexibility levels. However, through a number of experimental computations, Usher (2003) concluded that the advantages obtained by increasing the number of alternative process plans for a scheduling system diminishes rapidly when the number of plans reaches a certain level.

2.2. Closed loop process planning

The methodology of CLPP is a feedback mechanism. CLPP is a dynamic process planning system that faces the shop floor. CLPP generates real-process plans by means of a dynamic feedback from scheduling system. The process planning mechanism generates process plans based on available resources. Scheduling provides the information about the current shop floor status to process planning system, so that every plan is feasible and respects the current availability of production facilities. This dynamic simulation system can enhance the real-time, intuition and manipulability of process planning system and it also can enhance the utilization of alternative process plans.

Usher and Fernandes (1996) divided the dynamic process planning to the static phase and the dynamic phase. Seethaler and Yellowley (2000) presented a dynamic process planning system, which can give the process plans based on the feedback of scheduling system. Anosike and Zhang (2009) proposed an agent-based approach for integrating manufacturing operations.

2.3. Distributed process planning

The methodology of DPP is to perform both the process planning and the scheduling simultaneously with a hierarchical approach. It divides the process planning and scheduling tasks into two phases. The first phase is the initial planning phase. In this phase, the characteristics of parts and the relationship between the parts are analyzed, and the primary process plans are determined at this stage as well. The process resources are also evaluated simultaneously. The second phase is the detailed planning phase. In this phase, the process plans are adjusted to the current status of shop floor. The detailed process plans and scheduling plans are obtained simultaneously.

Kempenaers et al. (1996) demonstrated the three modules of the collaborative process planning system. Wu et al. (2002) gave the integration model of IPPS in the distributed virtual manufacturing environment. Zhang et al. (2003) presented the framework of concurrent process planning based on Holon. Wang et al. (2005) presented the framework of collaborative process planning system supported by a real-time monitoring system.

In this research, a new HA-based approach has been developed to facilitate the integration and optimization of the IPPS problem. Through experimental studies, the merits of the proposed approach can be shown clearly.

3. Problem formulation

3.1. Problem definition

The IPPS problem can be defined as follows (Guo et al., 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.

In the manufacturing systems considered in this study, a set of process plans of each part is designed and maintained. The