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An active learning genetic algorithm for integrated process planning and scheduling

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ABSTRACT

In traditional approaches, process planning and scheduling are carried out sequentially, where scheduling is done separately after the process plan has been generated. However, the functions of these two systems are usually complementary. The traditional approach has become an obstacle to improve the productivity and responsiveness of the manufacturing system. If the two systems can be integrated more tightly, greater performance and higher productivity of a manufacturing system can be achieved. Therefore, the research on the integrated process planning and scheduling (IPPS) problem is necessary. In this paper, a new active learning genetic algorithm based method has been developed to facilitate the integration and optimization of these two systems. Experimental studies have been used to test the approach, and the comparisons have been made between this approach and some previous approaches to indicate the adaptability and superiority of the proposed approach. The experimental results show that the proposed approach is a promising and very effective method on the research of the IPPS problem.

1. Introduction

Process planning and scheduling are two of the most important sub-systems in the manufacturing system. A process plan specifies raw materials or components what are 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. Process planning is the bridge of the product design and manufacturing. With the process plans of jobs as inputs, a scheduling task is to scheduling the operations of all 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, 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, where scheduling was conducted separately after the process plans had been generated. Those approaches have become an obstacle to improve the productivity and responsiveness of the manufacturing systems. Because of the development of the modern manufacturing system, the process planning system can generate more than one process plans for each job. In this case, the process planning and scheduling have to be integrated to meet the requirements (including flexibility and real-time requirements) from the modern manufacturing enterprises. Therefore, there is an increasing need for deep research and application of the integrated process planning and scheduling (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 & 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.

However, the IPPS problem is very different from the separate process planning problem and the scheduling problem. Because, the objectives, the constraints and the solution space between them are very different. The IPPS problem has more constraints, and it is more complicated than the process planning problem and the scheduling problem. The previous methods for the scheduling cannot be used to solve the IPPS problem. And the traditional intelligent algorithms also have to be modified and improved to solve this new problem effectively. Therefore, in this research, a new active learning genetic algorithm (ALGA) 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.

The remainder of this paper is organized as follows: Section 2 introduces the related works. Problem formulation is discussed in Section 3. ALGA-based optimization approach for IPPS is proposed in Section 4. Experimental studies and discussions are reported in Section 5. Section 6 is conclusion.

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2. Related works

In the early studies of CIMS, it had been identified that IPPS is very important to the development of CIMS (Tan & Khoshnevis, 2000). The preliminary idea of IPPS was first introduced by Chryssolouris, Chan, and Cobb (1984), Chryssolouris and Chan (1985). 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 Zhang (1993) and Larsen (1993) extended the conceptions of alternative process plans and dynamic feedback and defined an expression to the methodology of hierarchical approach. Some earlier works of the integration strategy had been summarized in (Tan & Khoshnevis, 2000; Wang, Shen, & Hao, 2006). In the recent years, in the area of IPPS, several models have been reported, and they can be classified into three basic models based on IPPS (Li, Gao, Zhang, & Shao, 2010a): nonlinear process planning (NLPP), closed loop process planning (CLPP) and distributed process planning (DPP) (Usher & Fernandes, 1996).

The methodology of NLPP is to give every alternative plan for each part with a rank according to the 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 to the scheduling system.

NLPP is the most basic model of IPPS. Because the integration 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. Lee and Kim (2001) presented the NLPP model based on the genetic algorithm. Kim, Song, and Wang (1997) gave a scheduling system which was supported by flexible process plans and based on negotiation. Li and McMahon (2007) used a simulated annealing-based approach for flexible process plans. Yang, Parsaei, and Leep (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, Park, and Ko (2003) used a symbiotic evolutionary algorithm for the IPPS. Shao, Li, Gao, and Zhang (2009), Li, Gao, Shao, Zhang, & Wang (2010b) used the evolutionary algorithm based approaches to solve this problem. Li, Shao, Gao, and Qian (2010c) proposed a hybrid algorithm to solve the IPPS problem effectively. However, through a number of experimental computations, Usher (2003) concluded that the advantages gained by increasing the number of alternative process plans for a scheduling system diminishes rapidly when the number of the plans reaches to a certain level.

The methodology of CLPP is using a dynamic process planning system with a feedback mechanism. CLPP can be used to generate real-time process plans by means of a dynamic feedback from scheduling system. The process planning mechanism generates process plans based on available resources. Scheduling system provides the information about which machines are available on the shop floor for an incoming job to the process planning system, so that every plan is feasible in respect to the current availability of production facilities. This dynamic simulation system can improve the real-time, intuition and manipulability of process planning system, and 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.

The methodology of DPP is to perform both the process planning and 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.

Wu, Fuh, and Nee (2002) gave the integration model of IPPS in the distributed virtual manufacturing environment. Zhang, Gao, and Chan (2003) presented the framework of concurrent process planning based on Holon. Kempenaers, Pinte, and Detand (1996) demonstrated the three modules of the collaborative process planning system. Wang, Song, and Shen (2005) presented the framework of collaborative process planning system supported by a real-time monitoring system. Li, Zhang, Gao, Li, and Shao (2010d) presented an agent-based approach to solve the IPPS problem.

In this research, a new ALGA-based approach has been developed to facilitate the integration and optimization of the IPPS problem. The experimental studies show that the proposed approach can solve the IPPS problem effectively.

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.*"

In this paper, scheduling is often assumed as job shop scheduling, and the mathematical model of the IPPS problem is based on the mixed integer programming model of the job shop scheduling problem (Fattahi, Mehrabad, & Jolai, 2007). The optimization objective of this integration model is to minimize the makespan.

In order to solve this problem, the following assumptions are made (Li et al., 2010b):

(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.
(5) Setup time for the operations on the machines is independent of the operation sequence and is included in the processing time.

Based on these assumptions, the mathematical model of the IPPS is described as follows: (Li et al., 2010b).

The notations used to explain the model are described below:

N	the total number of jobs;
M	the total number of machines;
G_i	the total number of alternative process plans of the ith job;
o_{ijl}	the jth operation in the lth alternative process plan of the ith job;
P_{il}	the number of operations in the lth alternative process