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Integrated process planning and scheduling by an agent-based ant colony optimization ☆

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Abstract

This paper presents an ant colony optimization (ACO) algorithm in an agent-based system to integrate process planning and shopfloor scheduling (IPPS). The search-based algorithm which aims to obtain optimal solutions by an autocatalytic process is incorporated into an established multi-agent system (MAS) platform, with advantages of flexible system architectures and responsive fault tolerance. Artificial ants are implemented as software agents. A graph-based solution method is proposed with the objective of minimizing makespan. Simulation studies have been established to evaluate the performance of the ant approach. The experimental results indicate that the ACO algorithm can effectively solve the IPPS problems and the agent-based implementation can provide a distributive computation of the algorithm.

Keywords: Process planning and scheduling; Ant colony optimization; Multi-agent system

1. Introduction

Process planning and scheduling are two important manufacturing planning activities which can greatly affect the performance of manufacturing systems. While process planning determines how a product is to be manufactured in accordance with its design specifications, scheduling is to assign manufacturing resources and schedule operations so that some relevant criteria, such as due dates, are satisfied. Traditionally, these two functions are performed sequentially. To establish the manufacturing requirements of a product, the process plan has to be prepared first, scheduling will then be performed to allocate manufacturing resources according to the process plan. Since the real-time status of the production facilities is not considered in either process planning or scheduling, in actual production, process plans and schedules may become deficient or infeasible due to dynamic changes in production.

The merit of integrated process planning and scheduling (IPPS) is to increase the production feasibility and optimality by combining both the process planning and scheduling problems. Making use of alternative

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process plans as inputs of scheduling, it is then possible to select the routings and to sequence the operations for producing the parts according to the availability of the manufacturing resources and the current state of the manufacturing system. Since the actual process plan and the schedule are determined dynamically in accordance with the order details and the status of the shop, IPPS provides an essential solution on dynamic scheduling in a practical production environment. However, due to the combination of the two optimization problems and the flexibilities in the manufacturing systems, IPPS is a very complex problem. In most of the IPPS approaches, process selection and sequencing are still required to be predefined first, and the integrated approach is mainly to handle the choice of alternative routings in considering the scheduling constraints.

This paper presents the application of the ant colony optimization (ACO) algorithm in an agent-based system to integrate process planning and shopfloor scheduling. Recently, collaborating advanced heuristics with multi-agent systems (MAS) has received significant attention in the agent community. While the distributive and autonomous features of the agent-based platform are maintained, the search-based heuristic is able to enhance the computational ability of the system. To evaluate the suitability and effectiveness of incorporating the heuristic search in MAS for solving the IPPS problem, a novel approach of integrating the ACO algorithm with the MAS-based IPPS system is proposed in this paper. The integration is important to demonstrate the extensibility of the agent-based system for the complex IPPS problems.

With respect to the manufacturing order to produce N-parts with M-machines in a jobshop or similar kind of flexible manufacturing systems, a full set of processing flexibilities which includes alternative routings and alternative machines will be considered in the proposed IPPS model. The proposed ant algorithm takes advantage of distributed computation in the multi-agent platform. Each artificial ant is implemented as a software agent who runs separately and simultaneously, with a supervisory agent controlling the flow of the algorithm.

2. Related work

Some researchers have attempted to solve the IPPS problem with exact optimization methods and advanced search techniques. Advanced metaheuristics such as tabu search (Weintraub et al., 1999), genetic algorithm (Lee & Kim, 2001) and other evolutionary algorithms (Kis, 2003) are found to be more effective and efficient for larger IPPS problems, with the objective to find near-optimal solutions in a reasonable time. The authors have engaged in the development of agent-based IPPS systems (Wong, Leung, Mak, & Fung, 2006a, 2006b, 2006c). A MAS-based decentralized negotiation has been established for solving the IPPS problems, with advantages of flexible system architectures and responsive fault tolerance. In consideration of the scheduling requirements and availability of manufacturing resources, the actual process plan and schedule for producing a particular product are determined through negotiation between part agents and machine agents representing parts and machines respectively. Two types of negotiation-based IPPS approaches – MAN (multi-agent negotiation) and HAN (hybrid-based agent negotiation) were developed. They are featured with two different MAS architectures to solve the IPPS problems (Fig. 1). MAN has a fully distributive architecture and HAN has hybrid MAS architecture with an addition of a supervisory agent. A negotiation protocol was introduced to coordinate the interaction amongst the agents. It is an extension of the well-known Contract Net Protocol (CNP) which is able to handle multiple-task and many-to-many negotiation. Besides, a fictitious currency function, which incorporates the important IPPS parameters – processing time and due date, has been adopted to facilitate the negotiation processes such as the preparation and evaluation of bid.

Recently, the ACO technique (Dorigo, Maniezzo, & Colorni, 1996) has been widely applied to combinatorial optimization problems like travelling salesman problem (TSP), quadratic assignment problem (QAP), and jobshop scheduling problem (JSP). The ACO algorithm or ant system is inspired by the capability of a colony of real ants to find the shortest path between their nest and a food source. The path-finding ability refers to the behaviour that the ants leave a pheromone trail while travelling. This pheromone is favourable to the succeeding ants which are intended to follow it. When the ants are given with several possible paths, each ant initially chooses one path randomly, consequentially some ants picking the shortest route will return faster. So immediately after their completion of one tour, there will be more pheromone on the shortest path, influencing other later ants to follow this path. After some time, this results in the whole colony travelling on the shortest path.