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A critical chains based distributed multi-project scheduling approach

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ABSTRACT

In this paper, we discuss the distributed resource constrained multi-project scheduling problem (DRCMPSP) and focus on handling resource conflicts. The resource conflicts among projects are originally caused by precedence constraints and resource constraints. To reflect the influences of both constraints, this paper incorporates the critical chain concept into the distributed problem and introduces a corresponding heuristic strategy. Besides, to deal with large scale instances, an elimination mechanism is proposed, which identifies a few conflict time slots in advance and allocates global resources in those time slots only. Depending upon the heuristics and elimination mechanism, we develop a distributed multi-agent system based algorithm called DMAS/EM. Experiments show that DMAS/EM algorithm can generate satisfactory solutions with low average project delay and significant time savings. Furthermore, we observe that our algorithm provides great scalability with respect to variations in the size of instances processed and the degree of conflicts.

1. Introduction

Traditional resource constrained project scheduling problem assumes perfect shared information in multi-project cases. Researchers in this field proposed many efficient approaches [1–3], in which Dorndorf et al. [4] introduce for the first time an efficient constraint programming approach. Unfortunately, due to the rapid growth of globalization and Internet technology, project environments are becoming more and more distributed [5]. Local project managers, *i.e.* autonomous decision makers, may not honestly disclose local resource information. It is likely that people have to deal with asymmetric distribution of information. As a result, in the recent decade, increasing attentions have been paid to investigations on the distributed resource constrained multi-project scheduling problem (DRCMPSP). The problem was formally introduced by Confessore et al. [6] as an extension of the Resource Constrained Project Scheduling Problem (RCPSP). In DRCMPSP, each project to be scheduled requires not only global resources (shared among all projects) but also local resources (only available to this project). Classical centralized models of RCPSP are no longer suitable to describe the new problem, since projects only utilize global resources in those models. Besides, the new problem is strongly NP-hard [6] and researchers in this field find difficulties in providing satisfactory solutions within reasonable times.

Currently, DRCMPSP is generally formulated as multi-agent system (MAS) based models, which are solved with various heuristic algorithms [5–13]. During the scheduling process, multiple agents have to compete with each other to obtain enough resources under the limitation of capacity of global resources. Then, the resource conflict is very likely to occur. An effective way to solve resource conflicts is to design reasonable coordination mechanisms. Related works mainly focus on two types of coordination mechanisms: auction mechanisms and negotiation mechanisms. In the first type, local agents calculate bids based on their own requirements. The global agent then allocates global resources according to the bids. In the second type, multiple agents make their own decisions and negotiate with each other to obtain the best solution. Both mechanisms can obtain satisfactory solutions for certain cases but there still remain issues to be explored for the following reasons. Firstly, precedence constraints have not been integrated effectively in most existing works. Current methods often seek to achieve a high global resource utilization rate while allocating resources. However, resource allocation strategies with relatively low global resource utilization rates yield substantially higher throughput than a full 100% allocation of the resources [14]. The performances of methods based on existing mechanisms may not stay good while solving cases with variant degrees of conflicts. Secondly, current approaches may find difficulties in providing satisfactory solutions

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for large-scale problems. The resource allocation process is carried out in every time slot, which actually cause unnecessary computational cost. Besides, the allocation process only concerns the information at each single time slot and usually ignores the impacts of allocation on the whole periods of projects. Hence, it is desirable and necessary to design new heuristics capable of describing both of the two constraints and reducing the computational cost.

To effectively solve DRCMPSP, we design a multi-agent system and embed critical chains into the solution algorithm to develop a conflict solution heuristic strategy. A critical chain is the longest resource and precedence feasible sequence of tasks that determines the overall duration of a project [15]. It is often used to monitor and adjust project schedules and resources providing constraints information [16,17]. In this paper, a critical chain based elimination mechanism is proposed to rank the tasks so that a relatively important task has greater chances to obtain resources. Based on the mechanism, we develop a distributed multi-agent system using elimination mechanism algorithm called DMAS/EM. By identifying the conflict time slots efficiently, the computational cost can be greatly decreased.

To test the proposed approach, we conduct computational experiments on the MPSPLIB problem library [8], a benchmark which is frequently used in the research on distributed project scheduling problems. We compare DMAS/EM with six existing algorithms to evaluate the quality of solutions, the applicability in various environments and the computational time. Experimental results show that: (a) for 85% of the instances, DMAS/EM performs better than any other compared methods with respect to average project delay. For other instances, the proposed algorithm can also obtain competitive solutions comparing with other methods. (b) DMAS/EM algorithm has high performance of providing satisfactory solutions for instances with different degrees of conflicts. (c) DMAS/EM algorithm successfully solves all problem instances from MPSPLIB problem library within 20 min.

The remainder of this paper is organized as follows: the related work about DRCMPSP and critical chain scheduling is introduced in Section 2. Section 3 presents a description of the main problem discussed in this paper. Section 4 explores critical chains and presents an elimination mechanism. DMAS/EM algorithm is proposed in Section 5. Section 6 shows the experimental analysis. The conclusion of this paper is presented in Section 7.

2. Literature review

The distributed resource constrained multi-project scheduling problem (DRCMPSP) is an extension of RCPSP. It discusses scheduling problems in distributed environments and has received wide attention during the last decade. Due to the informational decentralization, traditional central coordination approaches, such as multi-criteria combinatorial optimization procedures [18,19], are no longer suitable for the problem. Thus, researchers in this field seek to develop new models and algorithms. A common way is to formulate the distributed problem as a Multi-Agent System (MAS) model and solve it with coordination mechanisms. According to different mechanisms, existing MAS based methods can be divided into the following two types.

The first one is auction mechanism based methods. Lee et al. [5] propose a dynamic economy multi-agent system model and a market based mechanism. Resource agents and task agents are built to allocate the resources while only global resource information is considered during this process. Confessore et al. [6] introduce the classification of local resources and global resources, while developing a marked-based MAS model. The results show that the distributed method performs almost the same as, or even better than the classical centralized method. However, the resource conflicts among projects are still thought to be associated with global resources only. Besides, above methods are all tested on small multi-project instances with up to 5 projects and up to 18 tasks for each project.

The second type is negotiation mechanism based methods, which has become a hot issue related to DRCMPSP recently. Lau et al. [11,12] present a negotiation-based multi-agent system. Each agent exchanges information to get candidate solutions from which a final schedule is voted. The method is tested on small instances (with up to 8 projects and up to 12 tasks). Homberger [7] extends the DRCMPSP by considering multiple global resources and proposes a multi-agent system based on a restart evolution strategy. In a succeeding work [8], the author generates MPSPLIB problem library and successfully solves the problem on large instances (with up to 20 projects and up to 120 tasks). Adhau et al. [9] introduce an auctions-based negotiation method. Three kinds of costs are considered to build the bids, which ensure a low average project delay but usually overestimate the effect of local resources when allocating global resources. Based on the work, Adhau et al. [10] considers the transfer of shared global resources in a multi-agent system. Wauters et al. [13] use a game theoretic approach, in which projects coordinate through learning a simple sequence game, which is managed by a trusted third party or mediator agent.

From above literature review, it is obvious that successful attempts have been made to solve DRCMPSP by applying multi-agent systems and coordination mechanisms. However, there still remain shortages among current MAS based methods. Specifically, most of them could hardly maintain low average project delays of solutions for cases with respect to variations in the size of instances processed and the degrees of conflicts. Usually, researchers only use resource information when designing conflict-solving heuristics. Actually, in real-world project management, resource conflicts are determined by precedence constraints as well as resource constraints. Thus, it is necessary to develop efficient coordination mechanisms that integrate both types of constraints. To realize this idea, this paper incorporates critical chains into the distributed problem.

A critical chain is a set of tasks which determines the overall project duration, taking into account both precedence and resource dependencies [20]. It has received considerable attention in the project management literature as a direct application of the Theory of Constraints [21]. As an inherent characteristic of a project, the critical chain is often utilized to improve the robustness of projects [22–24]. Generally speaking, critical chain tasks of a project are different under variant degrees of conflicts [25]. Thus, the critical chain can be used to identify the degrees of conflicts among tasks. Unfortunately, to the best of our knowledge, few researchers have tried to combine critical chain scheduling with the conflict-solving strategy towards DRCMPSP. In other words, there is a research gap when considering resource allocation in multi-project environments regarding critical chain approaches. To fill this gap, we propose a critical chain based conflict elimination mechanism and a distributed multi-agent system based algorithm for DRCMPSP in this paper.

3. Problem description

In DRCMPSP, a group of distributed projects, sharing a set of global resources, have to be planned simultaneously by a group of local decision makers or agents. The basic information and description about DRCMPSP are stated as follows.