Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

A multi-agent system for decentralized multi-project scheduling with resource transfers

Sunil Adhau *,[1], M.L. Mittal, Abhinav Mittal

Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur-302017, Rajasthan, India

ARTICLE INFO

Article history:
Received 3 May 2012
Accepted 8 July 2013

Keywords:
Decentralized multi-project scheduling
Multi-agent system
Resource transfer time
Combinatorial bidding and auction
Distributed negotiations
Heuristic algorithms

ABSTRACT

The companies dealing with multiple projects are geographically distributed at different locations. These projects require local (always available to the concerned project) and global (shared among the projects) resources that are available in limited quantity. The global resources are generally required to be transferred physically among the projects, consuming significant amounts of both time and cost. The existing multi-agent systems for decentralized resource constrained multi-project scheduling problem (DRCMPSP) do not consider the resource transfer time and related cost for execution and control. We introduce DRCMPSP-RT that explicitly considers the transfer of shared global resources. This paper proposes a novel distributed multi-agent system using auctions based negotiation (DMAS/RIA) approach for the resource intervals and allocating multiple different types of shared resources amongst multiple competing projects.

To incorporate this feature the resources are planned to transfer in advance for the eligible successor activities to schedule within the current time. The proposed approach can solve complex large-sized multi-project instances without any limiting assumptions regarding the number of activities, shared resources or the number of projects. The DMAS/RIA is tested on standard set of 140 problem instances. Computational experiments compare the presented managerial approach with two transfer time neglecting approaches. The result found the relative GAP with an average of 33.43% with respect to average project delay (APD). Whereas, the percentage gap of total makespan (TMS) is obtained with an average of 16.52%. The result proves the impact of resource transfer time on project delay and increase in multi-project duration that can be minimized by project managers considering it in planning phase.

1. Introduction

With the increase in globalization and internet technology, companies are now dealing with multiple projects at the geographically different locations. These projects require local (always available to the concerned project) and global (shared among the projects) resources that are available in limited quantity. Multiple projects running parallel often follow a resource allocation scheme that allows informational and a managerial decentralization. These projects use the same global resources (e.g. heavy equipment, specialized man power) at different times and thus needs to be transferred between projects frequently, giving rise to their optimized use at different sites when idle at the home site. A large amount of time is spent on transferring or adjusting resources to new tasks on different projects. These transfer times – as well as the related cost need to be considered earlier in the planning phase in order to ensure efficient utilization of scarce company resources (Kruger and Scholl, 2010, 2009)

The consideration of resource transfer time is rarely found in the literature of resource constrained multi-project scheduling environment. A very few studies address this important aspect in centralized decision making up to now. Yang and Sum (1993) were the first who especially consider positive resource transfer times in multi-project scheduling. The authors assume positive and equal times for transfers of resources from the resource pool to all the projects and zero time for the transfers from projects to the pool. Further, they prioritized projects based on resource allocation rule. These assumptions are limiting in practice. Moreover, the procedure was found to be incapable of providing solutions to many of the problems with tighter resource constraints. In consideration to these limitations, Mittal and Kanda (2009) extended the work of Yang and Sum (1993). The authors developed a heuristic procedure in which they assumed the resources not only transferred from/to the projects but also between the pool and the projects based on maximum and minimum demand for a pre-decided

* Corresponding author. Tel.: +91 9922370325; fax: +91 020 25656217.
E-mail addresses: suniladhau@gmail.com (S. Adhau), mlmittal.mnit@gmail.com (M.L. Mittal), abhinav.krishan.mittal@gmail.com (A. Mittal).

[1] Department of Mechanical Engineering., Government Polytechnic, Pune, University Road, Pune (M.S)-411016, India.

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http://dx.doi.org/10.1016/j.ijpe.2013.08.013

period of time in future. From the extensive experimentation, they concluded that while making resource transfer decisions, demand for longer period should be considered when the objective is to minimize the cost of resource transfers.

A managerial framework presented by Kruger and Scholl (2010, 2009) for handling resource transfers is based on a classification of resource transfers and resource roles in those transfers. Further they introduced the resource constrained multi-project scheduling problem with transfer times, cost (RCMPSPTTC), and developed a heuristic framework based on the priority rule for the both single and multi-project environment.

All these centralized procedures used a resource allocation rule for prioritizing the projects for allocation of resources where transfers were not allowed from high to low priority project. Hence the resources allocated to a higher priority project that are neither sufficient to start activities at the project nor transferred to another project lead to increase in resource idleness at large size project with high resource overload.

We must also then realize the possibility of economy in capital project equipment due to this expanded use, alternatively, increased project capacity with acme equipment. This paper proposes the advance work in this direction considering managerial and informational decentralization that warrants improving the utilization of project equipment and planning them to receive just in time and minimizes the number of resource transfers. This is a well-known important problem from an industrial engineering point of view for which the standard method of centralized control has significant drawbacks.

Based on this background the scheduling problem considered in this paper consists of multiple distributed projects. In recent years Multi Agent Systems (MAS), a branch of distributed artificial intelligence (DAI) have gained tremendous popularity in providing solution to the distributed decision making problems in different domains of industrial life. Some of the applications are in supply chain event management (Lorena et al., 2012); routing and dispatching of multiple mobile agents in integrated enterprises (Elalouf et al., 2013) etc. A MAS is a distributed system consisting of a set of self-interested, interacting problem solving entities, called agents (Jennings and Wooldridge, 1995; Sandholm, 2001). There are as many decision makers (project agents) as there are projects. Every individual project is autonomous, requires its own limited local resources, and shared global resources within which the activities are scheduled to minimize makespan. Each project is managed decentrally by a self-interested project agent on behalf of a project manager and a self-interested resource agent on behalf of a resource manager collectively manages all global resource types. All different types of agents try to achieve their goals and make scheduling decisions based on a given objective function.

Recently many researchers have studied such kind of environment and recommended multi-agent based system (MAS) for decentralized multi-project scheduling (Lee et al., 2003; Confessore et al., 2007; Lau et al., 2005a, 2006; Homberger 2007, 2009; Kim, 2001; Arauzo et al., 2010; Wauters et al., 2010; Mao, 2011; Adhau and Mittal, 2011; Adhau et al., 2012). However, none of them explicitly considers resource transfer times and thus is not applicable when the resource transfer times are significant. In this paper, the DRCMPSP is considered with explicit consideration of resource transfer times and is termed as DRCMPSP-RT. Hence, this research is concerned with developing a real time distributed multi-project scheduling system which embodies the economic-based approach, flexible enough to handle dynamic situations and capable of solving highly complex large sized multi-project instances decentrally without any limitation on the number of activities, shared resources or the number of projects.

Coordination framework for distributed multi agent system embedded with resource interval with auction based negotiation, denoted as DMAS/RIA, is developed to resolve resource conflict and transfers of shared global resources between the projects. The DMAS/RIA scheduling system has been implemented in Java on the JADE Agent Development platform. The proposed multi agent system is tested on standard set of 140 problem instances from the literature. Additionally transfer time data was randomly generated in original data set. The results are compared with decentralized procedure of Adhau et al., 2012, distributed multi agent system using auction based negotiation (DMAS/ABN) and variant of DMAS/RIA with zero transfer time to find the relative gap and impact of resource transfer time on performance measure, average project delay (APD) and average total makespan (TMS). In this paper, aspects of resource transfers in decentralized resource constrained multi-project scheduling problem (DRCMPSP) are considered for the first time. Thus, the results obtained by our DMAS/RIA can be suggested as benchmark in state-of-the-art literature.

The remainder of this paper is organized as follows: Section 2 provides formal definition of the problem. Section 3 provides a resource transfer mechanism. The multi-agent system DMAS/RIA is described in Section 4. Section 5 presents the proposed combinatorial auction and scheduling algorithms. An illustrative problem is taken up in Section 6. Computational experimentation and analysis of results are presented in Section 7. The last Section 8 is devoted to conclusions and summary of this paper.

2. Problem description

There is a set of M $\{i=1,\ldots,M\}$ projects that are to be scheduled. Project i has a release time $t_{ri} \geq 0$ at which it can be started. In extension to Homberger (2007, 2009), the first project in multi-project instance may arrive at $t_{ri} \geq 0$, while the other projects have various arrival times after the first project. Each project i consists of n_i non-preemptable activities with activity a_{ij} being the jth activity of project i. Two dummy activities a_{i0} and $a_{i(ni+1)}$ are added to each project i to represent the 'start' and the 'end' of the project i respectively. Without loss of generality, it is assumed that the dummy activities do not require any resource and can be completed instantaneously. PC_{ij} is a set of direct predecessors of activity j of project i. For project i, pair (a_{ij}, a_{ik}) means a_{ij} precedes a_{ik} ($a_{ij} < a_{ik}$). The precedence constraints exist only between activities of the same project. SC_{ij} is a set of direct successors of activity j of project i. There is a set of K ($k=1,\ldots,K$) types of local renewable resources assigned to each project i. Resource k is available in constant amount $R_{k\tau}$ in each time slot τ ($\tau=1,\ldots,T$). Where, T is the planning horizon. There is a set of G ($g=1,\ldots,G$) types of global renewable resources shared by all the projects. Resource g is available in constant amount $R_{g\tau}$ in each period τ ($\tau=1,\ldots,T$). Activity a_{ij} requires r_{ij}^{k} units of local resource k and r_{ij}^{g} units of global resource g. Activity a_{ij} takes p_{ij} units of time (fixed) for its completion. The global resources g may be transferred between the central resource pool of resource manager and the pool of project managers and also between the one or many resource provider projects h (source) to a resource receiver (destination) project i. Non-negative resource transfer times are assumed known for all possible routes (Mittal and Kanda, 2009). We assumed equal transfer time for all type of global resource $g \in G$.

The objective of the decentralized resource constrained multi-project scheduling problem with transfer times (DRCMPSPTT) is to determine the schedules such that, in each time slot τ ($\tau=1,\ldots,T$), the total resource demand by all the projects is less than or equal to the resource availability for each local and each global resources. The problem is to determine: (i) the start/finish times for the activities in the project and (ii) corresponding schedule for each of the resource transfers, which essentially means the determination of the source and destination, starting time, and number of units being transferred such that the precedence and shared resource constrained are fulfilled (Kruger and Scholl, 2009).

Please cite this article as: Adhau, S., et al., A multi-agent system for decentralized multi-project scheduling with resource transfers. International Journal of Production Economics (2013), http://dx.doi.org/10.1016/j.ijpe.2013.08.013