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A column generation based distributed scheduling algorithm for multi-mode resource constrained project scheduling problem

Liu Changchun[a], Xiang Xi[a,b], Zhang Canrong[a,b], Wang Qiang[a], Zheng Li[a,*]

[a] Department of Industrial Engineering, Tsinghua University, Beijing 100084, China
[b] Logistics Engineering and Simulation Laboratory, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China

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ABSTRACT

This study develops a column generation-based distributed scheduling algorithm for multi-mode resource constrained project scheduling problem. The proposed distributed algorithm shares less information among independent decision makers compared with the traditional integrated approach. In this problem, many independent processors, which can produce different types of products, coordinate with a resource manager (or third-party logistic), who provides different types of vehicles to deliver products to the customers. The problem is decomposed into two parts: production planning for individual processors and vehicle scheduling for the resource manager. A total of 1200 instances are randomly generated to verify the effectiveness of the proposed distributed algorithm. Results of computational experiments verify that the proposed distributed algorithm has good solution quality and calculation efficiency compared with the integrated approach, i.e., CPLEX, hybrid Benders Decomposition, and Lagrangian Relaxation. Lastly, a general framework for the distributed algorithm is proposed to solve a generalized problem.

1. Introduction

Because of the current globalization trend, production has shifted from the single factory production to multi-factory production network. To become competitive in today's rapidly changing market requirements, many factories have shifted from a centralized to a more decentralized structure in many areas of decision making including scheduling (Behnamian & Ghomi, 2016). Researchers focused on determining an efficient schedule with limited available resources for several decades. Besides, the recent remarkable attention in distributed production management in both academia and the industry has demonstrated the significance of distributed scheduling (Jung & Jeong, 2005; Rached, Bahroun, & Campagne, 2016).

This paper examines a *multi-mode resource constrained project scheduling problem* (MRCPSP) in *manufacturing supply chain* (MSC), in which many independent processors can produce different types of products and coordinate with a *resource manager* (RM) or third-party logistic, who provides different types of vehicles to deliver products to meet the customers' demand. In such a problem, the customers provide orders to each processor and processors independently perform production planning, whereas RM conducts vehicle scheduling. Liu, Xiang, Zheng, and Ma (2017) proposed an integrated approach, i.e., *Lagrangian Relaxation* (LR), to solve this problem with the objective of minimizing the total system cost including inventory cost, shortage cost, and transport cost.

Some previous literature, i.e., Singh and Ernst (2011), Thomas, Singh, Krishnamoorthy, and Venkateswaran (2013), Thomas, Venkateswaran, Singh, and Krishnamoorthy (2014), Liu et al. (2017), formulated MRCPSP as an *integrated model* (IM) under certain assumptions. In the IM, the decisions of all decision makers, e.g., all processors and the RM, are represented as one objective function and are made simultaneously. However, such an integration is unrealistic and has the following limitations in practice.

- Nowadays, thanks to improvements in computers, solvers, and decomposition methods, e.g., LR and *Benders Decomposition* (BD), the IMs are desirable to be developed. However, an IM always makes the model highly complex, which cannot be solved efficiently. Besides, the collaboration among *supply chain* (SC) under the competitive environment makes the problem more and more complex. Solving IM is time-consuming, which is difficult to meet the requirements of the decision makers, especially that some decision makers need to make decisions in a very short time (Todd & Sen, 1999).

* Corresponding author.
E-mail addresses: 051908lcc@163.com (L. Changchun), xiangx16@mails.tsinghua.edu.cn (X. Xi), crzhang05@gmail.com (Z. Canrong), wq_tsinghuaie@163.com (W. Qiang), lzheng@mail.tsinghua.edu.cn (Z. Li).

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Abbreviations

B&B	branch and bound
BD	benders decomposition
CG	column generation
DM	distributed model
GA	genetic algorithm
HBD	Hybrid Benders Decomposition
IM	integrated model
LB	lower bound
LR	Lagrangian relaxation
MP	master problem
MRCPSP	multi-mode resource constrained project scheduling problem
MSC	manufacturing supply chain
PSO	particle swarm optimization algorithm
RCPSP	resource-constrained project scheduling problem
RM	resource manager
RMP	relaxed master problem
SA	simulated annealing
SC	supply chain
SP	sub-problem
UB	upper bound

- The objectives of all independent decision makers are combined into one global objective in the IM, which cannot efficiently handle different or conflicting objectives of independent decision makers, since the decision makers may have different objectives in reality (Elloumi, Fortemps, & Loukil, 2017). For example, one processor wants to improve inventory to improve customer satisfaction, while the other processor expects to reduce inventory to reduce costs. Their objectives are conflicting and cannot be met simultaneously in the IM.
- Information in the integrated approach needs to be completely shared among independent decision makers, which cannot protect information privacy of all the decision makers well. Actually, the decision makers are not able or willing to share complete information with others (Chen, Lan, & Zhao, 2018).

Because of the above reasons, a distributed approach is also necessary to be developed to solve MRCPSP. Distributed scheduling is an approach that enables local decision makers to create schedules that consider local objectives and constraints within the boundaries of the overall system objectives. Distributed scheduling has attracted the interest of many researchers, i.e., Lu and Yih (2001), Lau, Huang, Mak, and Liang (2005), Lau, Huang, Mak, and Liang (2006), Martins (2006), Confessore, Giordani, and Rismondo (2007), Homberger (2007), Aysegul and Ihsan (2010), Cao, Yu, Ren, and Chen (2012), and Behnamian and Ghomi (2016). Compared with the traditional integrated approach, the distributed approach has the following advantages:

- *Distributed decision making*. In MRCPSP, many independent decision makers, e.g., processors, RM and customers, in different geographical locations, are naturally distributed. Thus, the distributed approach is closer to reality. Each of the processors and the RM make their operating decisions independently and autonomously. No single decision maker can control the decision making of the others (Lau et al., 2005; Todd & Sen, 1999).
- *Easily solvable*. The distributed approach may not provide globally optimal solutions, but may provide acceptable solutions within a reasonable amount of time (Lau et al., 2006). In this paper, the biggest relative gap is no more than 10% in about 90% of the instances. It is easily solvable, less complex, and convenient for sensitivity analysis and partial execution. A huge advantage of the proposed algorithm in this paper is that a feasible solution can be generated in each iteration. While the integrated approach often generates a feasible solution until the whole program is terminated.
- *Information privacy*. There is no single enterprise that has global information about the whole system. An asymmetric distribution of information is assumed, i.e., the decision makers are not able or willing to exchange complete information they have. Compared with the integrated approach, a distributed approach has less information sharing and no central coordinator (Agnetis, Mirchandani, Pacciarelli, & Pacifici, 2004; Lau et al., 2006; Thomas, Krishnamoorthy, Singh, & Venkateswaran, 2015). For example, a processor does not know about the capacity and current operations of the RM.
- *Multiobjectives*. Decision makers in the MRCPSP have different objectives. The objectives of processors are to minimize the total cost, which includes the cost of inventory cost, the demurrage cost and the resource requesting cost. The objective of RM is to obtain a feasible solution to satisfy the request of all the processors. The solutions obtained using a distributed approach are more acceptable

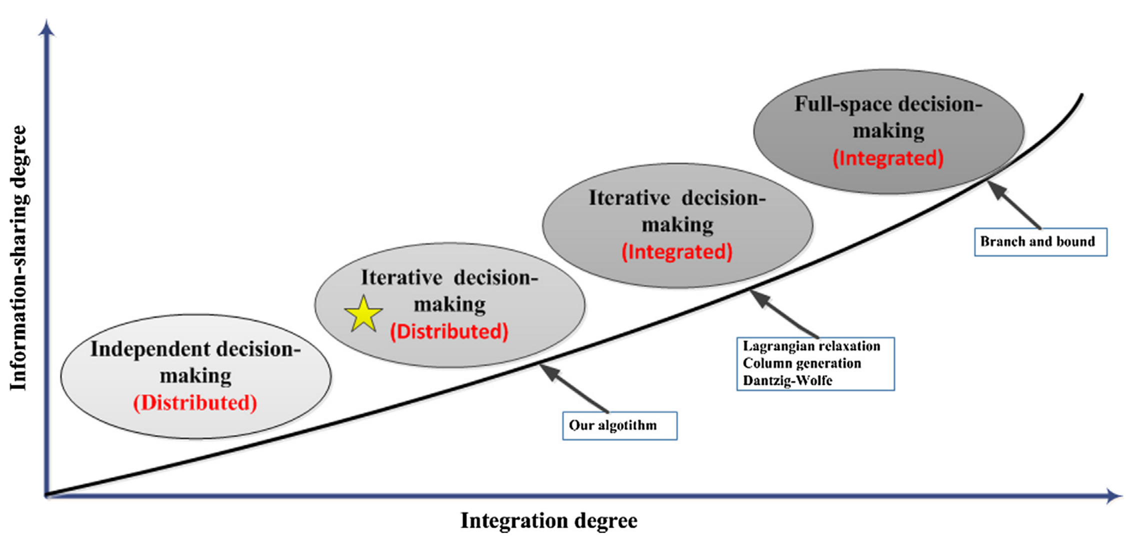

Fig. 1. Different decision-making modes with different degree of information-sharing.