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Synchronizing production scheduling with resources allocation for precast components in a multi-agent system environment

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ABSTRACT

The performance of precast construction is highly dependent on the effectiveness of production planning for the precast components (PCs). However, existing studies focused primarily on the separate mathematical optimization of production scheduling or resource allocations using heuristic algorithms without considering the interactions between each other and the flexible production environment. This paper proposes a multi-agent based precast production planning model to synchronize the production scheduling and resource allocation. In this model, the on-time delivery, minimum waiting and extension time are achieved using a two-hierarchy resource constraints based production scheduling optimization method. Further, the heuristic algorithm is presented to integrate the optimization techniques with the competing goals shown in a multi-agent system. Finally, a real case is conducted to verify the performance of the proposed model. The results demonstrate that 9.1% and 27.4% cost savings can be achieved by comparison to the actual scheduling method in practice and the traditional scheduling methods without considering the resource constraints, respectively. This proposed methodology will support flexible and optimized decision makings on the precast production planning.

1. Introduction

Prefabrication is a form of industrialization that transfers construction activities from the field to off-site plants, which has become increasingly important in the entire construction industry including the public housing and transportation infrastructure projects. The China State Council, for example, announced that the proportion of precast construction should be increased to 30% in ten years, and all new buildings in the urban area of Shanghai must be prefabricated from 2016 onwards [1,2]. The precast construction can not only cut down the energy consumption, operation costs, wastes and labor demands, but also improve the construction quality as well as the safe operation of workers. Despite these well-documented benefits, the performance of this precast technology has often been hampered when the production of precast components (PCs) is not properly managed [3], such as prolonged waiting time for PCs' delivery and mass stock due to non-optimal production planning [4]. Generally, two essential decisions, namely, the production scheduling and resource allocations should be made during the precast production management. The optimization of these two tasks is currently considered independently from each other, whereas the planned schedule may be suboptimal if the assigned resources are not available at the planned time. Further, the optimization of scheduling and resources allocation is generally conducted using the traditional mathematical methods with multiple assumptions that are too restrictive for many practical applications [5–9]. These too complicated modeling will reduce its practical applicability and even invalidate the schedule in practice, potentially causing operation chaos, prolonged durations, and increased supply chain cost [10,11]. Therefore, these deficiencies indicate two critical research needs: (1) methods to synchronize the production scheduling and resource allocations to systematically optimize the decision makings during precast planning; and (2) methods for modeling the real-world production situations to automatically assign resources and simplify the mathematical optimization.

To-date, the existing studies on the precast production planning have concentrated only on single aspect of PC production scheduling [5,6,12] or resources allocation [13,14] as shown in Table 1. The table indicates these studies often lacked the consideration of overall mechanisms and relationships between different sections. The independent optimization under simplistic assumptions reduces the feasibility of applying these mathematical models in practice because the availability of resources impacts the beginning time of each operation during

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Table 1
Summaries of literature on precast production management.

Categories	Authors	Contributions	Methodologies	Limitations
Production scheduling	Ko and Wang [9]	Production scheduling considering the constraints of buffer sizes between production stations.	Genetic algorithm (GA)	1. The availability of resources was not considered; 2. The mathematical model lacked the flexibility in applications.
	Yang et al. [6]	Production scheduling with the practical consideration of multiple production lines	GA	
	Wang and Hu [12]	Production scheduling from the whole supply chain perspective considering the storage and transportation processes	GA	
	Nejad et al. [17]	A multi-agent architecture was developed for process planning and scheduling for multiple jobs	MAS	1. The availability of resources was not considered; 2. Solutions were sub-optimal due to the simplified or lack of optimization algorithms.
	Kouider and Bouzouia [18]	A direct multi-agent communication system was developed to solve static job shop scheduling problems	MAS	
Resource allocation	Li et al. [5]	Resources are optimized including molds, labors, inventory and workspace to minimize the production costs	GA and branch and bound methods	1. The production scheduling was not considered; 2. The mathematical model lacked the flexibility in applications.
	Khalili and Chua [13]	Resources utilization optimization by integrating the prefabrication configuration and component grouping	Mixed integer linear programming method	
	Zhang et al. [19]	An agent-based workflow management mechanism is proposed to facilitate interactions among RFID-enabled reconfigurable manufacturing resources	MAS	● Solutions were sub-optimal due to the simplified or lack of optimization algorithms
	Lim et al. [14]	Optimizing the resources utilization with integrating process planning and production scheduling across different facilities	MAS	

scheduling. Further, these theoretical optimization models have large decision variables, parameters and low reactivity and flexibility, which restrict its application only to the small-size problems. The multi-agent system (MAS) has been proved to enable the flexible and dynamic planning in the variable and complex manufacturing situations [15]. MAS is extensively applied in the industry domain, and its superiority could be summarized as (1) quick responding to tasks autonomously [11], (2) sensing disorders intelligently and facilitating the real-time production control [16], and (3) suitable for the large-size problems and frequently changing structures [15]. Whereas the distributed agent-based approaches in MAS cannot have a global view of the system, and it may not find the global optimal solutions compared with the classical mathematical optimization methods. Hence, the heuristic optimization algorithm is embedded within a MAS schema in this paper to synchronize the production scheduling and resource allocation using a multi-agent based precast production planning model (MAPM_PP). In this model, the two-hierarchy resource constraint based production scheduling optimization methodology is proposed to optimize the precast production planning in pursuit of the on-time delivery, minimum waiting time and extension time.

The remainder of this paper is organized as follows. Section 2 details the literature review. Section 3 proposes a multi-agent based precast production planning model. The resource constraint based production scheduling optimization method is presented in Section 4. An illustrative case is analyzed in Section 5. The conclusions are discussed in Section 6.

2. Literature review

Many efforts had been devoted to the research on the precast production management, and most focused on the production scheduling which was regarded as an NP-hard problem. The first paper was published by Johnson to solve the flow shop sequencing problem in pursuit of minimizing production makespan [20]. Afterward, a few studies had been conducted to optimize the production scheduling using the heuristic algorithms. Scholars modified the target of minimum completion time into the on-time delivery to meet the due date. For example, a flow shop sequencing model was proposed by Chan and Hu to minimize the tardiness and earliness penalty [21,8], further, the precast production processes were classified by their inherent characteristics. Ko and Wang analyzed the impacts of buffer sizes between different operation stations on the production scheduling [9], which integrated the consideration of single resource constraints. Whereas, all above studies did not consider the availability of resources during scheduling. On the other hand, Li et al. optimized the molds, labors, inventory and workspace resources to minimize the production costs [5]. Khalili and Chua maximized the utilization of mold resources based on the prefabricated component grouping [13]. However, all these studies employed the heuristic algorithms (such as genetic algorithm, Tabu search, and simulated annealing) with simplistic assumptions to pursue the optimal solutions. These simplified theoretical models were essentially centralized, that is, a central computing unit performed all computations. Due to its inherent limitations of structural rigidity and the lack of flexibility [10], the traditional methods were hard to be applied in real world, and its complexity restricted its applications only in the small-size problems.

Artificial intelligence was proved to be the right way to achieve the flexible management for the large-size problems. Of these, the multi-agent system represented one of the most promising approaches because of its distributed and adaptive nature of multiple agents [15]. The MAS model was extensively utilized to achieve dynamic scheduling in the manufacturing industry, while with limited application in construction industry. The similarity of the supply chain in these two industries makes MAS feasible in the domain of PC supply chain management. With respect to the applications of MAS in manufacturing industry, it could be classified into several categories including