Automation in Construction 81 (2017) 34–43

Contents lists available at ScienceDirect

Automation in Construction

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

Optimal single-machine batch scheduling for the manufacture, transportation and JIT assembly of precast construction with changeover costs within due dates

Liulin Kong [a,b], Heng Li [b,*], Hanbin Luo [a,*], Lieyun Ding [a], Xiaochun Luo [b], Martin Skitmore [c]

[a] School of Civil Engineering & Mechanics, Huazhong University of Science & Technology, China
[b] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
[c] School of Civil Engineering and Built Environment, Queensland University of Technology (QUT), Australia

ARTICLE INFO

Article history:
Received 17 January 2017
Received in revised form 17 March 2017
Accepted 22 March 2017
Available online 23 May 2017

Keywords:
Precast construction
Just-In-Time (JIT) assembly
Single machine batch scheduling
Changeover cost

ABSTRACT

The manufacture, transportation and on-site assembly sectors of precast construction projects are often considered separately and managed by rule of thumb, causing an inefficient use of resources and postponed delivery. This study views these sectors as a whole from the perspective of a single machine batch-scheduling problem. A dynamic programming algorithm, which aims to search for solutions that entail maximum production efficiency, was developed accordingly with the constraints of changeover costs and production deadlines. We tested the method's ability by processing as many products as possible simultaneously using real data collected from a precast factory in a simulation and compared the effect with a previous study. We found that our method possesses great potential to improve the efficiency of precast production.

1. Introduction

Precast construction is one of the newer technologies that can reduce construction waste effectively and is gradually being recognized as a more ecological and sustainable approach in large cities [1]. However, the previous research efforts primarily focus on the study of production sector and the effects of considering the Manufacture, transportation and on-site Assembly (MtA) sectors simultaneously in the scheduling plan and batching and lot-sizing are not being investigated. One of the reasons is the substantial equipment adjustments and operation changes that frequently occur in production when switching from one product class to another [2]. The longer time required in the design and manufacturing phases and much shorter time in the assembly phase complicates the production scheduling of precast components-forcing schedulers into the use of an overly subjective 'rule of thumb' approach [3]. Thus, large storage spaces are occupied in waiting for the last of a batch of components to be delivered, causing an inefficient use of resources and delays in deliveries [4]. This has led to the inefficient use of resources and overstocking in the precast industry [3,5], which, according to Tam et al. [6], is restricting its development by creating an additional expense that contractors and developers can ill afford. As a result, it is mostly confined to repetitive public housing due to its high initial costs, time in the initial design development and lack of experience of contractors, resulting in a lack of demand for precast components [6]. Therefore, maximizing the precast production efficiency is the key to promote the development of precast construction projects.

Many studies focus on applying computerized scheduling techniques to provide more appropriate production plans to enhance effective resource utilization and minimize cost. Since the fabricator usually deals with the orders one by one, this leads to inefficient resource utilization and overstocking in the precast industry [3,5]. The precast factory cannot process all the orders at the same time due to the lack of such resources as machines, workers and storage areas. Thus, different orders from different contractors for hundreds of different precast components may await production. Importantly, the production of different types of precast components takes a different amount of time, and some may take longer than those requiring on-site assembly. What is needed is to find a sequence of precast components on the fabricators' production line that minimizes the total changeover and inventory holding costs by considering the MtA sectors simultaneously, subject to maintaining Just-In-Time (JIT) deliveries for all contractors.

Therefore, the scenario is investigated where the precast manufacturer accepts only some of the orders from the contractors due to limited storage space available, and the precast components of each order have to be manufactured in one factory, transported to the respective construction sites separately and then assembled. The problem of defining the optimal order sequencing is analytically modeled with the aim

* Corresponding author at: 410, 4/F, School of Civil Engineering & Mechanics, 430074 Wuhan, Hubei Province, China.
E-mail address: lhblhb1963@vip.sina.com (H. Li).

http://dx.doi.org/10.1016/j.autcon.2017.03.016
0926-5805/

of maximizing the production efficiency by reducing it to a single machine group-scheduling problem with deadlines by integrating the MtA sectors involved. An enhanced precast production scheduling method is developed to search for solutions with maximized production efficiency by coordinating production scheduling and delivery decisions with the JIT philosophy. This involves the development of an algorithm based on Cheng and Kovalyov [7] schema of dynamic programming algorithm. Finally, a simulated case based on a real-life Chinese precast factory is used to demonstrate and test the model's ability to improve the production efficiency by processing as many orders as possible.

The paper is organized as follows. In Section 2, the literature relating to scheduling problems for precast construction is briefly reviewed. Section 3 provides the notation and model formulation. Section 4 depicts the precast production process in mathematical form to maximum the production efficiency considering the changeover costs. In Section 5, a simulated case based on an actual Chinese precast concrete factory is used to demonstrate and validate the applicability of the model. Section 6 contains concluding remarks concerning the limitations of the study and prospects for future research.

2. Precast production scheduling

A great amount of research into precast production scheduling has been published to date in academic journals worldwide [8]. Leu and Hwang [9], for example, propose a flowshop scheduling model for resource-constrained mixed production of precast components and a Genetic Algorithm (GA)-based scheduling approach correspondingly to minimize the makespan. Benjaoran and Dawood [10] formulate a six step precast component production as a flowshop scheduling model with six machines in conjunction with GA-based optimization to minimize total flowtime, which provides statistically better schedules than from the traditional Earliest Due Date (EDD) of around 25% (total flowtime reduction). Zhai et al. [11] consider a scheduling model for make-to-order precast production based on a simulation technique and GA to minimize total costs. Ko and Wang [3] develop a multi-objective GA to solve the precast production scheduling model with minimum makespan and delay penalties, allowing for production resources and buffer size between workstations to store the work-in-processes. Tharmmaphornphilas and Sareinpithak [12] develop a heuristic approach to select concrete formulae and schedule jobs to minimize total product cost. Yang et al. [2] propose their Flowshop Scheduling Model of Multiple production lines for Precast production (MP-FSM) and apply GA optimization to minimize the changes in types of precast components during production. Another approach, by Arashpour et al. [13], models the problem of off-site construction producing multiple classes of products with multi-skilled resources to minimize changeover time in production when switching from one product class to another using the optimization-based metaheuristics-tabu search to find the optimal sequence in off-site production of *n*building elements. Their results indicate customer demand to be the most sensitive factor in obtaining the optimal sequence of multiple classes of products and the earliest due dates within product classes.

Although the MtA sectors of precast components are strongly linked and should be treated as a unified system [14], the few existing models that do this are either special cases of, or have a different structure to, our problem. For instance, Anvari et al. [14] use a GA-based optimization approach to a holistic MtA problem while sharing resources and the sequencing and timing of operations for a special case where the assembly area is also the manufacturing area, so that resources can be shared. In our research, the factory is in an inexpensive area far from the on-site assembly areas to save manufacturing costs [15] and therefore no resources can be shared between the two sectors. This is closer to the real problems of precast construction, where the MtA sectors need to be considered simultaneously.

Secondly, the prefabrication planning models of previous research consider precast components to be separate jobs with the same individually produced operations, with the GA being used widely to optimize the sequence of job operations to minimize total cost or reduce resource wastage. Hence, most studies do not take changeover cost into account. In reality, precast components can be generally grouped into several types, such as precast wall panels, beams, columns, slabs, balconies and staircases. Different orders of the same type of precast units may be produced with the same mold group with slight variations [16] or with different mold group. However, frequent production changes from one type of precast component to another can lead to substantial equipment adjustments and operation changes, which reduce production efficiency and increase costs [12]. Khalili and Chua [16], for example, establish a scheduling model for precast modular units that enables several building elements to be produced, transported and installed as units, and propose a mixed integer linear programming method to solve the scheduling problem involved. The difference in our research is that the scheduling of precast construction incorporates batching and lot-sizing. Precast components of the same type are classed as a group type as they are identical items with the same due date, with the changeover cost being minimized because the same concrete mix or formwork can be used. This is called the grouping concept [17]. On the other hand, a group type of precast components cannot be processed in one production batch, as the inventory holding cost is very high and other group types have to wait too long to be delivered. Therefore, a lot-sizing decision is made to split a production lot of the same type of components into sub-lots [18].

We model the MtA sectors as a whole from the perspective of a single machine batch-scheduling problem applying the batching and lot-sizing concepts. In our method, the deadline of each part type is rescheduled into many different sub-deadlines for each sub-lot, which considers the corresponding transportation times and assembly times. Thus, instead of producing a single large batch of each part type within its deadline, our method shows it's preferable to produce smaller batches of part type within their sub-deadlines so that the inventory storage areas can be released timely. We found that our method possesses great potential to improve the efficiency of precast production.

3. Model formulation

3.1. Problem description

The fabricator usually deals with the contractors' orders serially because frequently changing the type of precast components during production involves substantial equipment adjustments and operation changes [2]. Large quantities of precast components are piled orderly in a precast factory waiting for delivery, as it takes a long time to produce one order of components. Moreover, the precast components produced are usually bulky, large and heavy and need large storage areas; therefore, different orders from different contractors have to wait to be produced due to limited storage areas available prior to delivery to the construction site for direct assembly, where JIT delivery is advocated to improve customer service level. This involves the manufacturer incurring a storage cost that depends on inventory size and storage time. Thus, the cost of producing precast components can be very high if the manufacturing factory is located in an urban area. On the other hand, transportation costs will be much higher if it is located in a less expensive region outside the urban area. These are two of the main factors that make the direct cost of precast construction much higher than traditional construction and clearly a trade-off is needed. However, in reality, most precast factories are located where the costs of production are low irrespective of the transportation involved [15].

Here, we consider the scheduling problems of precast construction in which both changeover/delay-penalty costs of component manufacture and JIT deliveries apply. The orders of all the precast components are divided into several part types according to the types of components involved. Scheduling the resource of production orders allows fabricators to assess the effectiveness of resource utilization, reduce costs and