Automation in Construction 48 (2014) 31–43

Contents lists available at ScienceDirect

Automation in Construction

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

Integrated scheduling of ready-mixed concrete production and delivery

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ARTICLE INFO

Article history:
Received 17 December 2012
Received in revised form 1 August 2014
Accepted 20 August 2014
Available online 14 September 2014

Keywords:
Ready-mixed concrete
Integrated scheduling
Production
Delivery
Genetic algorithm

ABSTRACT

This study presents an approach for improving the operations of production and delivery in ready-mixed concrete (RMC) plants. A network flow method is applied to formulate the integrated scheduling problem of ready-mixed concrete production and delivery with trucks and pumps, where the demands of construction sites are in certain time windows. A method is developed that applies a genetic algorithm in which the chromosome consists of three sequences (construction sites, delivery order and vehicle IDs); operators work on the sequences of construction sites. The approach is evaluated by simulation of real cases. Comparison with combinations of other priority rules for scheduling production and vehicles demonstrates the effectiveness of the genetic algorithm. Sensitivity analysis reveals the effects of the fleet size of an available vehicle, the cost rates and the time windows of construction sites. The model and algorithm may be helpful for practical integrated operations for operation management at RMC plants.

1. Introduction

Concrete is one of the principal materials used in the construction of buildings, bridges, railways, highways, dams and other infrastructures. The development of the construction industry has greatly influenced the concrete industry in some developing countries, especially in China, where the demand for concrete has grown at an increasing rate in recent years, and concrete markets are facing both the opportunities of great profit and the risks of competition. Greater attention has been given to achieving higher efficiency for more benefits to suppliers of ready-mixed concrete (RMC).

There are five main parts of the RMC supply process: production, loading, delivery, unloading/casting and vehicle return. When orders for concrete arrive at the RMC plant, managers cannot easily prepare a proper production and delivery schedule. First, the plant must arrange the production facilities and vehicle deliveries, trucks and pumps, for greater profit. However, construction sites require continuous concrete unloading and casting to ensure construction project quality and progress. Proper dispatch at RMC plants could greatly benefit the plant and construction sites in terms of both efficiency and effectiveness. However, in practice, dispatch is often accomplished individually for production and delivery. In this study, an integrated mode of production and delivery is proposed and discussed that will lead to lower operation costs for RMC plants.

The remainder of the paper is organized as follows. In Section 2, we give an overview of related literature. The basic operations of vehicles in plants are analyzed in Section 3. The factors that affect production and delivery are described in Section 4. A mixed-integer programming model is then presented in Section 5. Section 6 presents an improved genetic algorithm for solution of the model. Computational results are discussed in Section 7, including a comparison to the results that combines dispatch rules and sensitivity analysis of fleet size, cost rates and time windows of construction sites. The paper ends with some conclusions in Section 8.

2. Literature review

There have been relatively few studies of RMC production and delivery. Some related work can be found in the following studies, which are concerned with problems and methods in various situations. Tommelein and Li considered concrete delivery as a prototype case of the JIT (just-in-time) production process [1]. Wu and Low used case studies conducted in the RMC industry to support the advantage of the JIT purchasing threshold value models [2]. Feng mainly focused on the problem of one depot serving several construction sites with trucks of the same capacity to determine an arrangement of dispatched vehicles with minimal total waiting time for construction sites [3,4]. Sarker studied different planning methods and developed models for various aspects of the construction industry, including the scheduling and dispatching of RMC trucks [5]. Ko and Wang introduced a multi-

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http://dx.doi.org/10.1016/j.autcon.2014.08.004
0926-5805/

objective precast production scheduling model that considered production resources and buffer size between stations to enhance precast production scheduling [6]. Al-Araidah presented a model that considered the production and transportation costs of RMC and proposed a ground cost for improving the RMC production system using activity-based management to improve financial performance [7]. Matsatsinis studied a multi-plant, multi-vehicle routing problem with time windows and two types of vehicles (pumps and trucks) and analyzed the working modes of each. He also established a decision support system to schedule the vehicles [8]. Durbin developed a decision support tool to generate schedules for production, loading, unloading and vehicle return that could judge its own capability to receive new orders [9]. Li studied the relationships between pre-cast production operations and site construction activities and developed a pre-cast production planning model to meet the site construction demands for pre-cast elements, satisfy internal resource constraints, and optimize total production costs [10]. Lu and Lam introduced a simulation platform (HKCONSIM) to establish and solve the concrete delivery problem with a single plant, multiple construction sites, and trucks with two types of capacities [11]. They presented different test results and compared them to simultaneously optimize concrete delivery scheduling and resource provisions for RMC plants; TOI (total operation inefficiency) was applied to evaluate the results [12]. Naso addressed the problem of several plants serving multiple construction sites, all of which had a service time window. The vehicles were all trucks with homogeneous capacity [13]. Yan discussed both concrete production and vehicle dispatch under the condition of one depot, several construction sites and homogeneous vehicles [14,15]. Some possible emergency problems at plants were considered in another work [16]. Yan also considered the problem of RMC production and truck dispatch under stochastic travel times [17]. Schmid proposed a solution to solve the concrete delivery problem with multiple plants, multiple construction sites, and different types of vehicles, including trucks of different capacities and vehicles with specialized instruments like pumps [18,19]. In addition, Graham concentrated on modeling the problem using a neural network method with multiple nodes and network layers [20]. Lin established a model for vehicle scheduling based on the job shop problem in the case of demand postponement and weight limit regulation [21].

In terms of solution methods, in 1995, Dawood applied job shop scheduling theory to build a simulation model and provide decision support for operators. Priority rules of construction sites, concrete production and delivery were also applied in the simulation [22]. Feng developed a simulation platform called “RMC Dispatching Schedule Optimizer” (RMCDiSO) using a genetic algorithm to obtain a better solution [3]. In 2006, Feng applied fast messy genetic algorithms (fmGA) and CYCLONE to solve the problem [4]. Lu and Lam employed combined discrete-event simulation and genetic algorithms in HKCONSIM [11,12]. Naso demonstrated the specific restrictions of the ready-mixed concrete supply process and proposed a new hybrid heuristic algorithm that combined constructive heuristic and genetic algorithms [13]. Yan integrated the concrete production and delivery problem and built a model with time and space network technology [14,15]. Similarly, Durbin considered a time and space network model and applied network flow optimization and tabu search methods to minimize total cost [9]. Asbach proposed a special local search algorithm to optimize the problem whose result was better than that of the exact MIP model with CPLEX [23]. Park suggested a dynamic simulation model using system dynamics to consider the tradeoff between truck mixer dispatching interval and queuing time on-site [24]. In addition, some combinatorial algorithms have been mentioned, such as the combination of variable neighborhood search and exact methods presented by Schmid [18,19]. Hyper-heuristics, as proposed by Misir, provided hybridization by performing a search on multiple low-level heuristics to generate efficient solutions in real instances of the RMC delivery problem [25]. Silva utilized a hybrid heuristic algorithm for ant colony optimization and a genetic algorithm [26]. Hertz proposed a two-phase solution method to divide the problem into two integer linear programming problems for cement delivery [27].

Scheduling studies for ready-mixed concrete production and delivery have been conducted for several years. Most of these studies consider some of the restrictions that are involved in real situations, and few have considered the integrated scheduling of both production and delivery. Compared to these prior studies, this paper, however, focuses more on the integrated scheduling of production and delivery of pumps and trucks and considers more practical elements, such as waiting time between vehicles and construction sites and continuity of work in construction sites, to provide an effective method for improving efficiency as well as saving costs.

3. Basic operations of vehicles

In practical situations, trucks and pumps should be dispatched together; trucks are used to transport concrete to the corresponding construction site, and pumps with specialized instruments are used for RMC unloading and casting work.

3.1. Pumps

An example of pump operations is presented in Fig. 1, where C.S.1–C.S.6 represent six different construction sites and P1–P3 are three different pumps. Pumps should work during the time window of the RMC plant. At the end of each work day, all pumps must return to the plant. Pumps could leave for the next construction site after the entire concrete casting work of one site has been completed.

The time flow of a pump is shown in Fig. 2. Each pump leaves the plant at the departing time. After traveling for a period (*traveling duration* 1), the pump should arrive at C.S.1 at *arriving time* 1 before the arrival of the first truck. The time spent on RMC casting is denoted as *casting duration* 1. The pump departs at *leaving time* 1 when all demanded deliveries of C.S.1 are completed. The pump does not need to return to the plant but instead can leave directly for the next construction site. When all tasks are completed for a given day, the pump must return to the plant.

3.2. Trucks

An example of truck operations is shown in Fig. 3, where C.S.1–C.S.5 represent five different construction sites and T1–T5 are five different trucks. Similar to pumps, trucks should work during the time window of the RMC plant, and, at the end of each work day, all trucks must return to the plant. In contrast to pumps, however, trucks must return to the plant after each delivery.

The time flow of a truck is shown in Fig. 4. The plant begins RMC production at or after its starting time. After the plant finishes production, RMC is loaded into the truck, which departs the plant at the *departing time* after being sufficiently filled. Each truck should arrive at the construction site within the time window of the site. After unloading RMC

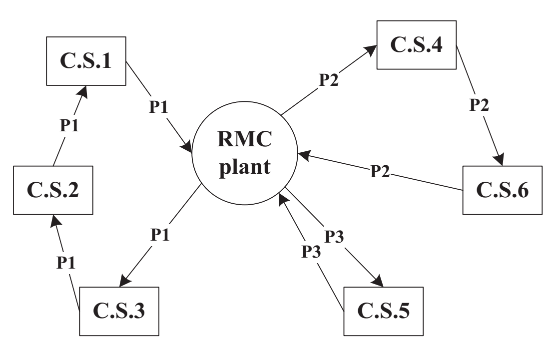

Fig. 1. Operations of pumps.