Automation in Construction 84 (2017) 1–13

Contents lists available at ScienceDirect

Automation in Construction

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

Heuristic algorithm for ready-mixed concrete plant scheduling with multiple mixers

Zhenyuan Liu[a,b,*], Yakun Zhang[a], Minghui Yu[a,b], Xiaolu Zhou[a]

[a] School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Key Laboratory of Education, Ministry for Image Processing and Intelligent Control, Wuhan 430074, China

ARTICLE INFO

Keywords:
Ready-mixed concrete
Multiple mixers
Production scheduling
Vehicle dispatching
Conjoint-rule based heuristic algorithm

ABSTRACT

In this study, the problem of integration of ready-mixed concrete (RMC) production scheduling and truck and pump dispatching in an RMC plant with multiple mixers is focused upon. A time-space network model, which combines RMC production and vehicle dispatching, is proposed. A heuristic algorithm with eight sets of conjoint priority rules for production scheduling, truck and pump dispatching, and mixer scheduling is developed to solve the problem. Computational experiments are conducted on actual cases collected from an RMC company; these cases are classified into four types based on the quantity of orders from construction sites and the discrete degree of construction sites. The advantages and disadvantages of adopting various conjoint-rules in the various types of cases are determined. The experimental results demonstrate that this heuristic solution is capable of enabling managers of RMC plants to develop more suitable schedules in various types of practical cases.

1. Introduction

Ready-mixed concrete (RMC) is widely used in the construction industry. At present, RMC is generally supplied to construction sites from offsite plants. Production and delivery of RMC are of high significance in the daily operations of RMC plants. Production scheduling and vehicle (trucks and pumps) dispatching are generally developed by experts by utilizing their experience. In practice, there are few effective methods and tools in support of these operations. A few scheduling models and algorithms have been developed and reported in literature, and majority of these are studies of cases of RMC plants with one mixer. However, more than one mixer is likely in practical cases. Orders are to be distributed among several mixers by certain pre-established rules. Then, trucks and pumps are to be dispatched in close coordination with the production by the mixers.

In this study, a scheduling problem in an RMC plant with multiple mixers is discussed, and a time-space network flow model, which integrates RMC production and distribution, is presented. An integrated model on RMC production scheduling and truck dispatching developed by Yan et al. [1] has been characterized as NP-hard and formulated as a mixed-integer network flow problem with side constraints. The integrated model developed in this study considers trucks and pumps dispatching simultaneously with production scheduling; this is more complex and also NP-hard. A heuristic algorithm will be developed to obtain effective schedules and to determine effective conjoint scheduling rules for various types of practical cases. A conjoint-rule consists of rules for production scheduling and trucks and pumps dispatching. The variations among the cases are in terms of the quantity of orders from construction sites and of the discrete degree of construction sites. Therefore, it is likely to provide a realistic guideline for plant managers to determine the most appropriate RMC production and vehicle dispatching schedule in various types of practical cases.

The remainder of this paper is organized as follows. The next section is a literature review on the challenges in RMC production and vehicle dispatching. Section 4 introduces practical operation and logistics management processes in an RMC plant. Section 6 develops a heuristic algorithm of RMC production combined with dispatching of trucks and pumps. In Section 5, computational experiments are presented for analyzing the scheduling results with various sets of conjoint-rules in various types of practical cases.

2. Literature review

A few related works in RMC operation scheduling problems are available in the following literature, which contain a variety of models and methods:

From the perspective of scheduling models, Yan et al. [1] proposed an integrated model, which was formulated as a mixed-integer network flow problem with side constrains. They considered both RMC production scheduling and truck dispatching problems. Liu et al. [2,3]

* Corresponding author at: School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China.
E-mail address: zyliu@mail.hust.edu.cn (Z. Liu).

http://dx.doi.org/10.1016/j.autcon.2017.08.013
Received 8 July 2016; Received in revised form 3 June 2017; Accepted 9 August 2017
0926-5805/

proposed a mixed-integer programming model, which included an RMC mixer, several construction sites, and a few trucks and pumps with various specifications. Kinable et al. [4] presented a fundamental version of concrete delivery problem incorporating a mixed-integer programming model and solved using constraint programming. Sawhney et al. [5] concentrated their attention on a Petri network with advanced features, which was used as a model and analysis tool to study the operation processes in a ready-mixed concrete plant. Wang et al. [6] developed a simulation model based on data collected in Singapore. In order to analyze the influence on productivity of concrete plant and proper arrival times of trucks, they calculated charts with computers. Feng and Wu [7] presented a model based on genetic algorithm to obtain a near-optimal solution of a delivery problem. This solution is capable of minimizing the total waiting time of RMC trucks at construction sites and satisfying the demand from each site. In another study, they [8] introduced a system model that adopted fmGA and CYCLONE to ascertain the optimal scheduling solution. Considering the process of RMC production and delivery, Matsatsinis [9] analyzed a routing problem with time windows, multiple plants, and multiple vehicles including trucks and pumps. Graham et al. [10] addressed a delivery problem with a specialized neural network including a feed-forward network and Elman neural network. Park et al. [11] established a dynamic model based on the analysis of the RMC delivery process; this model offered a scientific procedure to instruct the RMC operation. Feng et al. [12] presented a systematic model aimed at optimizing the scheduling of dispatching trucks, which could minimize the total waiting duration of trucks. Yan and Lai [13] constructed a network flow model that employed a time-space network technique to solve the problem of production and dispatching of ready-mixed concrete that took into consideration the overtime in a plant in Taiwan. Lin et al. [14] developed a multi-objective programming model for the dispatching operation of RMC trucks as a job shop problem with recirculation. In this study, intrinsic and imposed constraints that affected truck dispatching of RMC plants were presented. Garcia and Lozano [15] addressed the problem of selecting and scheduling RMC orders to satisfy the demands of sites expeditiously. The objective was to maximize the total value of orders served under two scenarios: arbitrary and uniform profit margins for orders. Sarker et al. [16] reviewed various planning and design models developed for various aspects of the construction industry, which incorporated mathematical models and simulation based on certain actual data including those on scheduling and dispatching of trucks at an RMC plant. For the exception in operations management of an RMC plant, Yan et al. [17] considered the adaptations for supplying ready-mixed concrete following incidents with a time-space network flow model. In another study of theirs [18], a systematic scheduling model was developed that would enable RMC carriers/suppliers recalibrate schedules after temporary breakdown of mixers. Azambuja and Chen [19] provided a systematic method to assess supply chain risks, identify vulnerabilities, and measure the impact of disruptions in an RMC supply chain.

Furthermore, there are a few related studies on production and delivery scheduling of RMC. Ghasri et al. [20] investigated concrete pouring duration affected by construction site features and supply chain parameters including supply process, location of the project, and traffic conditions. Based on the linear regression model and hazard-based model, their study provided decision-makers with a practical tool to enhance concrete pouring productivity. Thawongklang and Tanwanichkul [21] mainly concentrated on the total tardiness of truck dispatching plans and optimum number of trucks. Wang et al. [22] developed an integrated model, which considered the mold manufacturing, precast components storage, and transportation processes. Two case studies were conducted to test the validity of the model, and the results demonstrate that optimal scheduling is related to the traveling time of precast components. Wu [23] studied a ready-mixed concrete plant in Singapore and attempted to expand the classical economic order quantity (EOQ) with a price discount model to obtain the EOQ-JIT cost indifference point. Deligiannis and Manesis [24] developed a hybrid model for a concrete batching and mixing plant, which can be used to adopt a development environment and actualize the influence of the operation parameters on RMC plant.

A variety of algorithms such as genetic algorithm, heuristic algorithm, and a few hybrid algorithms are developed. Zegordi and Beheshti [25] presented a genetic algorithm with three populations to solve the problem of integration of production and transportation. Naso et al. [26] proposed a genetic algorithm combined with the heuristic method to solve delivery problems in the RMC operation. Liu et al. [2] also applied a genetic algorithm to determine a suitable sequence for dispatching trucks and production for construction sites. Silva et al. [27] presented a new meta-heuristic algorithm, a combination of the GA and ACO algorithm, to solve the RMC dispatching problem. By analyzing a practical case, the advantage of this method was evident. Ko and Wang [28] introduced a multi-objective genetic algorithm to balance production resources and optimize the buffer size between stations. Maghrebi et al. [29] proposed a sequential meta-heuristic method, which can solve large-scale RMC problems efficiently. They developed a robust sequential genetic algorithm and a new formulation for minimizing the number of trucks. Maghrebi et al. [30] also developed a column generation algorithm for vehicle routing problem with time windows (VRPTW) problem. They employed the Dantzig-Wolfe method to reformulate the problem. In another study [31], they tested a robust genetic algorithm and column generation with various sizes of actual RMC problems. In order to compare the optimization models and expert-based decisions, Maghrebi et al. [32] selected four examples of various sizes and tested them. It could be concluded that optimization models only attempt to achieve the lowest cost, whereas the expert prefers a more stable dispatching system with a marginally higher cost. Cheng and Tran [33] developed a DES-COMODE algorithm, which integrated discrete event simulation and chaotic initialized opposition multi-objective differential evolution to solve an RMC dispatching truck problem. Low et al. [34] presented an integrated scheduling problem in which RMC was delivered to retailers within time windows, which was also a zero-inventory concept similar to RMC in production and delivery problem. Two types of genetic-algorithm-based heuristics were designed to solve the problems. For the case of multiple plants, Schmid et al. [35] employed an effective hybrid approach for RMC delivery, which consisted of an integer multi-commodity flow optimization component and a variable neighborhood search component.

With respect to the solution method, Lu et al. [36,37] developed a computer software for simulation and used it to analyze the management of ready-mixed concrete in Hong Kong. With respect to the study of scheduling processes, Zayed and Halpin [38] proposed a replaceable solution to simulate RMC delivery operations. Schmid et al. [39] developed a method to solve the concrete delivery problem involving multiple plants, multiple construction sites, and a variety of trucks and pumps, which aimed to minimize the overall traveling fee. In this research, he proposed certain combinatorial algorithms such as the combination of variable neighborhood search (VNS) and exact method. Matsatsinis [9] developed a Decision Support System using a heuristic algorithm to analyze the model. A vehicle routing problem with soft time-windows (VRPSTW) in a fuzzy random environment was studied by Xu et al. [40]. They proposed a GLNPSO-ep to solve this problem. Asbach et al. [41] studied the problem involving multiple plants, multiple construction sites, and various vehicles; however, he did not consider specialized pumps. He developed a local search algorithm to solve the model and obtained a perfect solution. Feng et al. [12] developed a computer program to enable managers to dispatch trucks. Pierre et al. [42] used CPLEX to solve mixed-integer programs with a variable neighborhood search heuristic. Maghrebi et al. [43,44] presented a machine learning based method to select techniques using various approaches. This method had demonstrated the potential to solve RMC dispatching problems to match experts' decisions with high accuracy. They also used bender decomposition to solve RMC