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Minimizing duration and crew work interruptions of repetitive construction projects

Ayman Altuwaim[a,b], Khaled El-Rayes[a,*]

[a] Department of Civil and Environmental Engineering, University of Illinois at Urbana–Champaign, Urbana, IL 61801, United States
[b] Department of Civil Engineering, King Saud University, Riyadh, Saudi Arabia

A R T I C L E I N F O

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A B S T R A C T

This paper presents the development of a novel scheduling model for minimizing the duration and crew work interruptions of repetitive construction projects. The main contributions of the developed model are its ability to (1) generate early and late start schedules that minimize the duration of repetitive construction projects while keeping the total work interruptions of their utilized crews to a minimum; (2) calculate novel types of crew work-continuity floats that consider the impact of delaying the early start of repetitive activities on crew work continuity; (3) develop a wide range of intermediate schedules between the early and late start schedules that maintain the least project duration and minimum total crew work interruptions; and (4) compare shortest duration schedules with and without interruptions to identify the best schedule that fits the specific project needs. The model performance was evaluated using an application example of a repetitive construction project.

1. Introduction

Repetitive construction projects require construction crews to repeat their work in a number of locations in the same project, moving from one location to the next. This continuous movement of crews on site is often encountered during the construction of high-rise buildings, housing projects, highways, pipeline networks, and bridges. Traditional scheduling methods such as bar charts and critical path method are ineffective in scheduling this class of projects due to their inability to consider and maximize work continuity for the construction crews on these projects [1–12]. Maximizing work continuity improves construction productivity by minimizing crew idle and non-productive times and by maximizing the benefits of the learning curve effect for working crews [1,8,13,14]. To realize these benefits, a number of scheduling models were developed for repetitive construction projects that are capable of considering and maximizing crew work continuity.

Existing scheduling models for repetitive construction projects that consider crew work continuity can be classified in two main categories: (1) models that strictly enforce work continuity for all construction crews without allowing any interruptions [2,4,6,9,11,15–25]; and (2) models that maximize work continuity for all construction crews while allowing selected interruptions to minimize project duration, as shown in Fig. 1[5,7,8,18,26–36]. The scheduling models in the first category are capable of maintaining full work continuity for all crews, however their generated schedule often leads to longer project duration due to the strict enforcement of the crew work continuity constraint, as shown in Fig. 1. The scheduling models in the second category provide shorter project duration than those in the first category because they provide the flexibility of enabling selected interruptions only when needed to minimize the project duration [2,5,8,29].

Scheduling models in the second category can be further classified into optimization models and heuristic models. First, optimization models in this category utilized various optimization techniques such as linear programing, dynamic programing or genetic algorithms to minimize project duration, cost, and/or work interruptions [5,8,14,18,26–32,35,36]. For example, linear programing was utilized by Ipsilandis [32] to minimize crew work interruptions in scheduling repetitive projects under a specified project duration. Dynamic programming was also used by Russell and Caselton [5], El-Rayes and Moselhi [8], and El-Rayes [14,26] to optimize the scheduling of repetitive construction projects to minimize project duration, work interruptions, project cost, and/or total combined bid price for A + B highway contracts. Similarly, genetic algorithms were utilized by Nasser [30], Hegazy and Wassef [18], Hegazy et al. [27], Hyari and El-Rayes [28,29], Long and Ohsato [35], and Hyari and El-Rayes [36] to either minimize project duration and work interruptions, minimize project cost, trade-offs between project duration and work interruptions, or trade-offs between project duration and cost. Second, heuristic scheduling models in the second category utilized various algorithms and heuristics to schedule repetitive projects with selected work

* Corresponding author.
E-mail address: elrayes@illinois.edu (K. El-Rayes).

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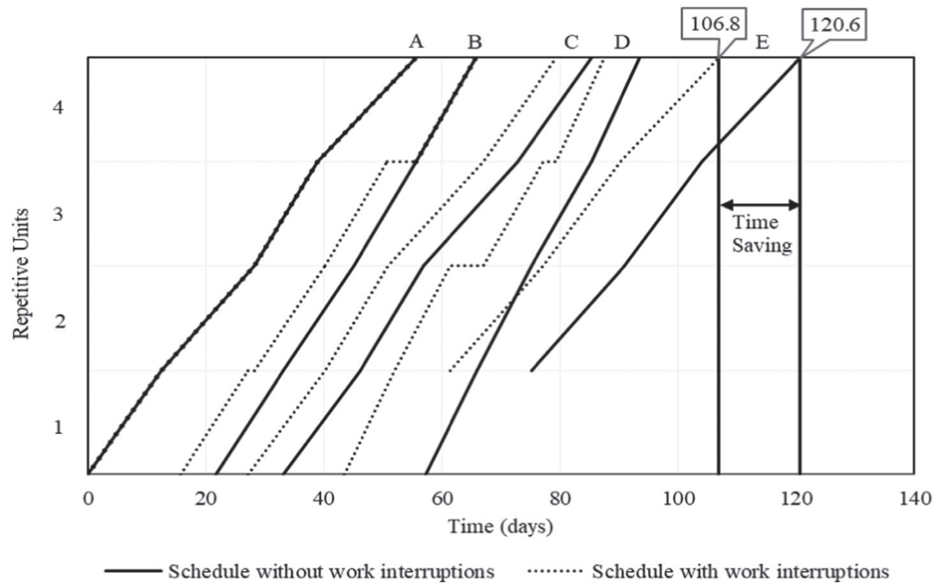

Fig. 1. Impact of allowing work interruptions on project duration.

interruptions [7,35]. An example of heuristic scheduling models that allow interruptions for repetitive construction projects is the resource-driven scheduling model developed by El-Rayes and Moselhi [7] that enables decision makers to assign multiple crew formations for each repetitive activity, and to specify work interruptions between the repetitive units in order to minimize the project duration. Another heuristic scheduling model was developed by Long and Ohsato [35] for repetitive projects which is capable of identifying work interruptions between repetitive units in order to minimize the project duration and keep work interruptions to a minimum.

Despite the contributions of the aforementioned scheduling models for repetitive construction projects that allow selected work interruptions, they have a number of limitations as they are incapable of (1) generating an early start schedule that minimizes both the duration project and its total work interruptions; (2) calculating important types of floats for repetitive construction projects that can be used to analyze the impact of delaying the early start of repetitive construction activities on the work continuity of construction crews; and (3) providing planners with the early start and late start schedules for each repetitive activity which provides them the flexibility to generate a wide range of intermediate schedules. Accordingly, there is a pressing need for a novel scheduling model for repetitive construction projects that is capable of circumventing these three main limitations of existing heuristic models.

2. Objective

The goal of this paper is to develop a novel scheduling model for repetitive construction projects that overcomes the aforementioned three main limitations of existing heuristic models. To accomplish this goal, the three main research objectives of this paper are to (1) develop an innovative heuristic methodology for generating an early start schedule that simultaneously minimizes project duration and total work interruptions; (2) create novel types of floats to calculate and analyze the impact of delaying the early start of repetitive construction activities on the work continuity of construction crews; and (3) generate a wide range of intermediate schedules to provide planners with alternative schedules that minimize both project duration and work interruptions. These three objectives are accomplished in four main phases: early schedule computation phase, work-continuity float calculation phase, strict work continuity phase, and performance evaluation phase, as shown in Fig. 2. The following sections of the paper describe these four development phases of the scheduling model.

3. Phase 1: early schedule computation

This phase of the model focuses on developing a novel scheduling algorithm for repetitive construction projects that seeks to minimize project duration by allowing selected work interruptions while maximizing work continuity. The scheduling algorithm is designed to (1) calculate early start ($ES_{i,j}$), late start ($LS_{i,j}$), early finish ($EF_{i,j}$), late finish ($LF_{i,j}$) and work interruptions ($Inter_{j,\ j-1}{}^{i}$) for each section (j) in the repetitive activities (i), as shown in Fig. 2; (2) compute the project duration (D) and total work interruptions (TR), as shown in Fig. 2; (3) comply with crew availability and precedence relationships constraints; (4) maximize work continuity; and (5) enable the scheduling of activities with varying durations in its repetitive units (see Fig. 1).

The required input data for this schedule computation phase include: (a) repetitive activities data that include the total number of activities (I) and their logical precedence relationships; (b) number of the repetitive units (J); (c) the quantity of work ($Q_{i,j}$) for each repetitive section (j) in each activity (i); and (d) daily productivity rates for the specified crew in each activity (P_i), as shown in Fig. 2. The computations of this phase are performed using the following two stages.

3.1. Stage 1

This stage creates an initial project schedule that provides the shortest possible duration for the project while complying with the job logic/precedence relationships and crew availability constraints. This is achieved in two main steps that are designed to calculate: (1.1) the duration of each activity (i) at each repetitive unit (j); and (1.2) the early start and finish dates of construction for each activity (i) at each repetitive unit (j), as shown in Fig. 3.

3.2. Stage 2

This stage is designed to revise the initial schedule generated in Stage 1 to maximize compliance with the crew work continuity constraint. This is achieved by identifying for each repetitive activity (i) the required shift for the start date of its earlier repetitive sections (j = 1 to J-1) while maintaining the initial/earliest possible start and finish dates for its last repetitive section (j = J) to minimize work interruptions for all assigned crews while maintaining the shortest project duration, as shown in Fig. 4. The revised final schedules generated in this stage identifies the early start, early finish, late start, and late finish for each activity (i) at all its repetitive unit (j). The scheduling computations in