ARTICLE IN PRESS

AUTCON-02227; No of Pages 11

Automation in Construction xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

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

Optimal crew routing for linear repetitive projects using graph theory

Ahmed Gouda [a,*], Ossama Hosny [b], Khaled Nassar [b]

[a] Construction Engineering Department, British University in Egypt, Egypt
[b] Construction Engineering Department, American University in Cairo, Egypt

ARTICLE INFO

Article history:
Received 11 August 2015
Received in revised form 6 February 2017
Accepted 15 March 2017
Available online xxxx

Keywords:
Line-of-balance
Optimal crew route
Graph theory
Optimization model
Repetitive projects
Linear projects

ABSTRACT

The line-of-balance (LOB) technique is considered as an effective tool for planning and scheduling linear repetitive construction projects. One of the main assumptions of the LOB technique is the uniformity and constancy of production rate for an activity. Moreover, some aspects of the LOB technique can be modified in order to suit the nature of construction projects. This paper proposes a hybrid approach for scheduling linear projects that optimizes resource allocation using the LOB scheduling technique. The paper presents an optimization model for resolving resource constraint dilemmas in linear scheduling projects. The proposed model utilizes a Matrix Laboratory (MATLAB) code using graph theory as a searching algorithm to automate the model formulation. The novelty of the model is that it supports decision makers in formulating the optimal crews routing among various activities and also considering the allocation of multitasking skilled crews. A case study for a repetitive 4-km sewage pipeline installation is used to test the capabilities of the proposed model. Results show that the model can feasibly reduce the number of crews employed in linear repetitive construction projects.

1. Introduction

Linear scheduling techniques are concerned with planning and scheduling linear repetitive projects, which are categorized by sequential activities repeated for a substantial number of units. One of the main aspects of linear schedules is ensuring the continuation of work without any interruptions or idle time.

Several techniques have emerged to enhance the application of the line of balance (LOB) in scheduling linear repetitive construction projects. Arditi and Psarros [5] developed a system for repetitive unit scheduling (SYRUS) to assist in scheduling linear projects that relies on integrating both network and LOB techniques. Hegazy et al. [9] proposed a computer program called BAL to schedule and monitor linear projects with uniform sequential activities. Senouci and El-din [18] presented a non-serial dynamic programming technique for scheduling linear projects with non-serial sequential activities, in which time/cost trade-off is implemented to manipulate project duration and total cost.

Many researchers have tackled problems in LOB performance and developed computerized systems to facilitate its implementation. Wang and Huang [22] introduced a new scheduling approach to overcome LOB limitations regarding controlling the interval times between activities in repetitive projects. Their proposed Multistage Linear Scheduling (MLS) method is based on the multistage decision making concept that reduces the total project duration without decreasing the duration of each activity at each unit. Arditi et al. [4] employed a computerized system for the application of LOB called RUSS. This system generates schedules for high-rise buildings that satisfy constraints in resources.

Tokdemir et al. [21] developed a computerized system for LOB called ALISS. This system has the capability of accelerating the project duration to meet a specified deadline by increasing the number of crews of selected activities. Many researchers have attempted to integrate the benefits of Critical Path Method (CPM) and LOB techniques as a new concept for planning and scheduling ([1,2,10,20]; Ammar, [3]; Jung et al. [12]).

Likewise, resource management in linear schedules is considered a crucial key for the accuracy in performing reliable construction schedules [13]. Hinze [11] states that one of the main reasons for delays in construction projects is overseeing the limitation in resource availability during the planning phase that results in generating unrealistic schedules.

Senouci and Naji [19] implemented a computerized system for scheduling non-serial linear projects. This system optimizes total project cost by determining optimum crews formation using Genetic Algorithms. Liu and Wang [14] established an optimization model for resolving linear scheduling problems using Constraint Programming (CP). The model optimizes the total project cost and duration. Gafy and Ghanem [8] proposed an ant colony optimization model that relies on the foraging behavior of ants to allocate resources in repetitive construction schedules. This model is constrained by activity precedence and multiple resource limitations. Liu and Wang [15] presented an optimization model that integrates the usage of single/multiple-skilled

* Corresponding author.
E-mail address: ahmedgouda@aucegypt.edu (A. Gouda).

http://dx.doi.org/10.1016/j.autcon.2017.03.007
0926-5805/© 2017 Published by Elsevier B.V.

Please cite this article as: A. Gouda, et al., Optimal crew routing for linear repetitive projects using graph theory, Automation in Construction (2017), http://dx.doi.org/10.1016/j.autcon.2017.03.007

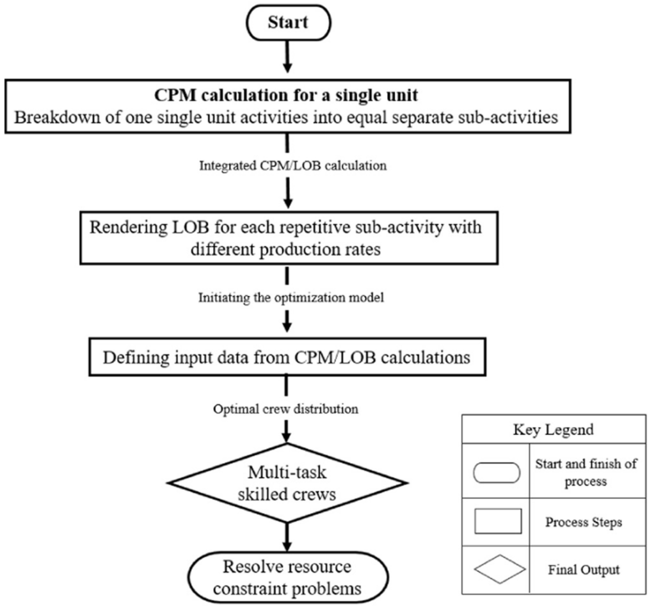

Fig. 1. Framework of the proposed scheduling approach for repetitive projects.

crews at the same activity to enhance work performance and minimize project duration using Constraint Programming.

Several researchers emphasized the importance of work productivity, resource assignments and optimum crew formulation for linear construction projects. However, few researchers have tackled the premise of LOB that assumes the constancy and linearity in the production rate of each repetitive activity. This may be unrealistic due to the stochastic nature of linear construction projects (O'Brien, [16]; [17,23]). The flexibility of altering crews movement and assigning multitasking skilled crews in linear construction projects have been neglected. Researchers claim that using multitasking skilled crews can increase the productivity, quality, and ensure the continuity of work [6,7]. Multitasking skilled crews can be defined as a workforce strategy to decrease indirect labor costs (minimize the daily indirect labor cost of the crews assignment), improve productivity and reduce turnover.

The main challenge of this paper stems from the desire to create an innovative framework that attempts to enhance the LOB implementations in scheduling linear repetitive construction projects. The purpose of the paper is to: 1) take the advantage of CPM/LOB's calculations, which accounts for the breakdown of repetitive activities into sub-activities to formulate more precise linear schedules; 2) introduce the concept of assigning multitasking skilled crews in linear construction projects between different activities; 3) supplement a new resource assignment algorithm that can provide optimal crews routing. The proposed algorithm promotes the existence of multitasking skilled crews between different activities in different project units using graph theory networks. Fig. 1 illustrates the proposed framework used in dealing with linear repetitive construction scheduling problems.

2. Problem definition

2.1. Areas requiring enhancement in LOB

Often, linear construction projects are subjected to limitations that mandate the occurrence of float or non-critical repetitive activities in order to accommodate resource constraints. In the LOB scheduling technique, the production rate of a repetitive activity is assumed to be constant along the entire number of units of a repetitive project. Furthermore, the LOB scheduling technique does not represent the repetitive activities as partially critical, mainly because each repetitive activity is a single undivided parallelogram with a specific duration. This assumption hinders LOB in restricting each activity to be accomplished by the same crew in a linear sequential manner, and eliminates the probability of allocating resources among entire project units [23]. This hypothesis is not applicable as the repetitive activity can be composed of several sub-activities. These sub-activities may have different production rates and may acquire different crew's due to the probability of relaxing the sub-activities production rate. Fig. 2 illustrates an example of a repetitive construction project that is composed of three repetitive activities I, J and K respectively. CPM calculations of the three activities for a one single unit show the criticality of the three activities with no total float as shown in Fig. 2(a). This consequently leads to the constancy of crews productivity rates of the three activities along seven typical units as shown on the LOB diagram in Fig. 2(b).

3. The developed approach for scheduling linear repetitive projects

In contrast to the traditional manner of reviewing activities in the LOB, a repetitive activity is represented as a number of separate sub-activities that are connected together to sum up the total duration of the activity. This method permits the representation of any logical relationship between the broken-down activities using only the finish to start relationship. The splitting down of activities in the LOB diagram generates more efficient schedules, which results in creating critical and non-critical sub-activities as shown in Fig. 3. Accordingly, this reflects the stochastic nature of construction projects. Although, the breaking

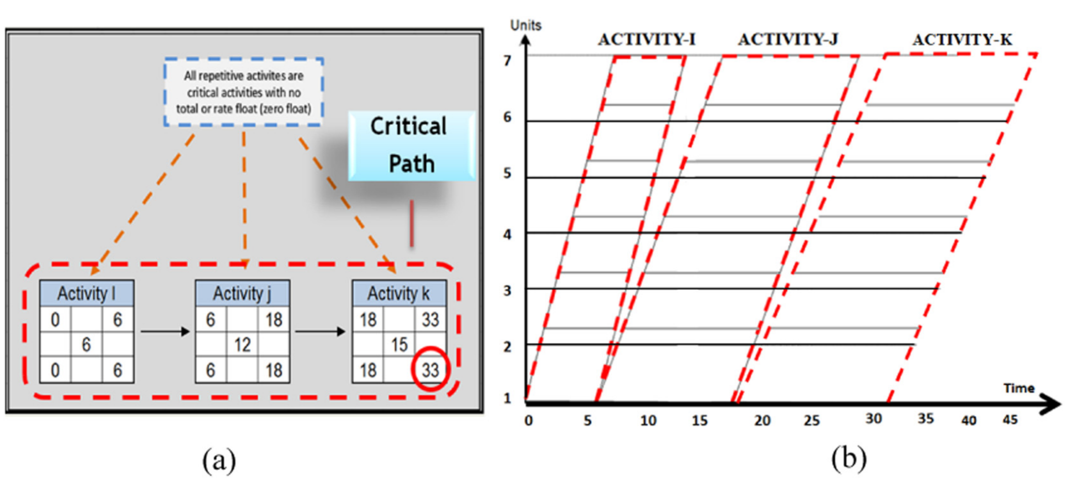

Fig. 2. Traditional LOB scheduling technique; (a) CPM for a single unit showing the criticality of all activities; (b) Rendering of activity I, J and K on LOB format.

Please cite this article as: A. Gouda, et al., Optimal crew routing for linear repetitive projects using graph theory, Automation in Construction (2017), http://dx.doi.org/10.1016/j.autcon.2017.03.007