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Comparison and renaissance of classic line-of-balance and linear schedule concepts for construction industry

Yi Su[a], Gunnar Lucko[a]*

[a] *Department of Civil Engineering, Catholic University of America, 620 Michigan Avenue NE, Washington, DC 20064, USA*

Abstract

Line-of-Balance (LOB) is a useful analytical tool for repetitive activities in construction projects, which allows showing which crew is assigned to what repetitive work unit of an activity. LOB is closely related to the linear scheduling method, but possesses some challenges: It must be clarified how it counts, as previous studies displayed an apparent measurement gap at the origin, implicitly representing that LOB starts at the first unit finish. Slopes in linear scheduling and LOB are different, even though both portray a measure of progress of an activity. This paper therefore tracks evolution and current use of LOB versus linear schedules. Its contribution to the body of knowledge is threefold: First, based on a literature review, LOB is found to be rooted in Activity-on-Arrow (AOA) diagrams, which makes it event-centered, not progress-centered. Differences in representing the start and productivity between LOB and linear scheduling are reviewed and explained both mathematically and graphically. Second, different LOB concepts are extracted and assessed to facilitate comparing LOB from its original use in manufacturing against the limited application of its objective chart in the construction industry. Third, a mathematical formulation based on singularity functions is developed, which can model staggering, continuity, and interruptability scenarios.

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Keywords: Line-of-Balance; linear scheduling; modeling; singularity functions.

1. Introduction

Repetitive activities require deploying similar resources (e.g. crews) that finish these jobs successively, which is a common phenomenon in construction. Scheduling such projects requires a method that can properly manage "the allocation of shared resources over time to competing activities" [1, p. 1]. The network-based Critical Path Method

* Corresponding author. Tel.: +1-202-319-4381; fax: +1-202-319-6677.
E-mail address: lucko@cua.edu.

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(CPM) is limited in that it "focuses strongly on the time aspect" [2, p. 711] rather than the workflow, which hinders its application to scheduling repetitive activities. Researchers have therefore studied approaches that chart both time and work; linear and repetitive scheduling techniques. While many methods exist under a plethora of names [3], such two-dimensional work-time progress profiles can clearly express important data in which researchers are interested; starts and finishes, durations, speed (productivity) of activities, buffers, criticality, and so forth. The Line-of-Balance (LOB) is "a variation of linear scheduling methods that allows the balancing of operations such that each activity is continuously performed" [4, p. 545], which is a resource-driven scheduling technique with the "primary objective … to determine a balanced mix of resources and synchronize their work such that they fully employed" [5, p. 44]. But there appear to exist differences between LOB and the slightly more well-known Linear Scheduling Method (LSM): In linear schedules, an activity is represented as one line, work starts from 0, and velocity (productivity) is calculated as the slope of the line; whereas in LOB, two lines (start and finish events) are needed to represent an activity, work starts from 1, and the slope of either of its two lines represents the delivery rate. Since LSM and LOB are related models of repetitive projects, understanding the similarities and differences of their characteristics is important. Yet in Table 1 they appear to be mismatched even in their basic geometry. Since simply comparing these definitions cannot directly explain this surprising finding, the root of such substantial differences must be explored. An approach should therefore be developed that aligns features of these two promising scheduling techniques to understand their conceptual differences, as far as they may exist, and enable a more seamless use. Recommendations for creating a unified method should be derived, which could provide an integrated, powerful tool for decision-makers in the construction industry and could lead to a renaissance of linear and repetitive scheduling.

Table 1. Basic differences of Linear Scheduling Method and Line-of-Balance

Characteristic	LSM	LOB
Activity is represented as	One line	Two parallel lines
Work starts at	0	1
Progress rate is represented as	Slope of the line	N/A
Delivery rate is represented as	N/A	Slope of any line (parallel)

Therefore a comprehensive literature review needs to be conducted to clarify how such differences, possibly due to only partial application, have occurred and can be resolved. This research will address three Research Objectives:

- Identifying differences between LOB and linear schedule models and their original source from the literature;
- Comparing different LOB concepts that were used in manufacturing versus construction project management;
- Developing mathematical expressions for LOB in analogy to LSM equations, which are based on singularity functions, with the capability of modeling staggering, continuous, and interruptible scenarios for work progress.

2. Literature Review

"The LOB methodology considers the information of how many units must be completed on any day to achieve the programmed delivery of units" [6, p. 681]. According to various studies [5, 6, 7, 8, 9], basic steps of LOB are: (1) Draw a unit network of the repetitive activities for a single work unit; (2) estimate the crew size for each activity; (3) establish a target rate of output (delivery units/day); and (4) derive the LOB as the number of units that must be completed at a given time. Activities in an LOB quantity chart, which first appears in Lumsden's report [10], but not in the report by the Office of Naval Material [13], are enveloped by two parallel lines whose slopes are the rate of output. Equation 1 models the rate of delivery m as "the slope of the line of balance joining the start times of the repetitive activity in each unit" [9, p. 413], where Q_i, Q_j and t_i, t_j are the numbers and start times of the i^{th} and j^{th} units. Setting the finish time of the first unit ($Q_1 = 1$) as t_1, Equation 2 returns the finish of the i^{th} unit in that chart.

$$m = (Q_j - Q_i)/(t_j - t_i) \quad where\ i < j \tag{1}$$