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Multiobjective design of Work-In-Process buffer for scheduling repetitive building projects

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ABSTRACT

Variability in production is one of the largest factors that negatively impacts construction project performance. A common construction practice to protect production systems from variability is the use of buffers (Bf). Construction practitioners and researchers have proposed buffering approaches for different production situations, but these approaches have faced practical limitations in their application. A multiobjective analytic model (MAM) is proposed to develop a graphical solution for the design of Work-In-Process (WIP) Bf in order to overcome these practical limitations to Bf application, being demonstrated through the scheduling of repetitive building projects. Multiobjective analytic modeling is based on Simulation–Optimization (SO) modeling and Pareto Fronts concepts. Simulation–Optimization framework uses Evolutionary Strategies (ES) as the optimization search approach, which allows for the design of optimum WIP Bf sizes by optimizing different project objectives (e.g., project cost, time and productivity). The framework is tested and validated on two repetitive building projects. The SO framework is then generalized through Pareto Front concepts, allowing for the development of the MAM as nomographs for practical use. The application advantages of the MAM are shown through a project scheduling example. Results demonstrate project performance improvements and a more efficient and practical design of WIP Bf. Additionally, production strategies based on WIP Bf and lean production principles in construction are discussed.

1. Introduction

Variability in production is one of the largest factors that negatively impacts construction project performance. It can induce dynamic and unexpected conditions, unsteadying project objectives and obscuring the means to achieve them. To understand the effect of variability on production processes, Hopp and Spearman [1] distinguished two kinds of variability in manufacturing systems: 1) the time process of a task and 2) the arrival of jobs or workflow at a workstation. Koskela [2] proposes a similar classification to variability in construction systems, where the processes duration and the flow of preconditions for executing construction processes (e.g., space, equipment, workers, component and materials, among others) are understood as variable production phenomena. From a practical standpoint, construction practitioners everyday observe this behavior in the project environment through varying production rates, labor productivity, schedule control, cost control, etc.

Several researchers have shown that variability is a well-known problem in construction projects, which leads to a general deterioration of project performance on dimensions such as: cycle time [3–7], labor productivity [8,9], project cost [10], planning efficiency [11,12], among others. A way to deal with variability impacts in production systems is through the use of buffers (Bf). By using a Bf, a production process can be isolated from the environment as well as the processes depending on it [2]. Buffers can circumvent the loss of throughput, wasted capacity, inflated cycle times, larger inventory levels, long lead times, and poor customer service by shielding a production system against variability [1]. Hopp and Spearman [1] define three generic types of Bf for manufacturing, which can be applied in construction as:

1. Inventory: In-excess stock of raw materials, Work in Process (WIP) and finished goods, categorized according their position and purposes in the supply chain [13].
2. Capacity: Allocation of labor, plants and equipment capacity in excess so that they can absorb actual production demand problems [14].
3. Time: Reserves in schedules as contingencies used to compensate for adverse effects of variability. Float in a schedule is analogous to a Bf for time since it protects critical path from time variation in non-critical activities.

Theoretically, the analysis of Bf in this paper is based on lean production principles. Lean production is a management philosophy focused on adding value from raw materials to finished product. It allows avoiding, eliminating and/or decreasing waste from this so-called value stream. Among this waste, production variability decreasing is a central point within the lean philosophy from a system standpoint [15]. Lean

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production, as applied in construction, focuses mainly on: i) decreasing non-value-adding activities or waste (e.g. wait times); ii) increasing value-adding activities efficiency (e.g. process duration); iii) decreasing variability [2]; and iv) optimizing the production system performance as a whole [15].

In construction, current buffering practices generally follow an intuitive and/or informal pattern, leading to poor variability control [3,5,7,14,16–24]. Recently, several researchers and practitioners have proposed new Bf approaches to manage variability in construction, which have allowed industry to partially avoid informal and intuitive methods of designing and managing Bf in construction [3,7,14,18,25–27]. However, these methods have been either too theoretical in design or too difficult to apply in practice. In Fact, there is limited evidence showing any use of practical buffering design approaches in construction practice [28].

This paper presents a buffering approach that is applicable for Work-In-Process (WIP) in repetitive building projects. In construction, WIP can be defined as the difference between cumulative progress of two consecutive and dependent processes, which characterizes work units ahead of a crew that will perform work (e.g., work units that have not been processed yet, but that will be). This definition of WIP is clearer in repetitive projects where processes are repeated continuously (e.g. highways, railways, pipelines, sewers, etc.) or in discrete repeated units (e.g. high-rise buildings, multistorey building, and repetitive residential projects, etc.) [29]. Existing research explores, the use of WIP Bf in repetitive projects, both implicit and explicitly, and demonstrates the limitations of its application [3,5,23,26–28,30–34]. This body of research suggests opportunities to improve the use of WIP Bf and to overcome practical limitations in current buffering approaches.

However, WIP Bf application in a production system is neither an apparent nor a direct task. The use of WIP Bf is controversial from a lean production perspective since the lean ideal suggests that zero inventories, or non-buffered production systems, are desirable [15]. Nevertheless, a production system without WIP implies a production system without throughput. Hopp and Spearman [1] recognize this issue and state that pull mechanisms in a production system do not avoid the use of buffers. However, the use of large WIP Bf to ensure throughput in production systems will inherently increase cycle times and costs. Therefore, it appears that a 'balance problem' exists between the use of WIP Bf to reduce variability impacts and overall production system performance based on lean principles.

Simulation–Optimization (SO) modeling can address this balance problem. Simulation–Optimization modeling can help to design appropriate WIP Bf sizes by addressing the trade-off between decreasing variability through larger WIP Bf sizes and increasing production system performance by lowering WIP Bf sizes to the theoretical limit of zero. In designing optimal WIP Bf sizes, SO modeling must account for different project objectives (project cost, time and/or productivity). Computer simulation is being actively applied as a research tool to investigate how buffering strategies affect construction production systems [3,14,23,30,31,35,36]. To date, research has only addressed specific cases of buffering strategies and it has not effectively addressed the balance problem. The first application of SO to model Bf in construction was proposed by [5], and a similar SO approach to model Bf in a construction scheduling context was also developed by [33]. Though both explicitly addressed the balance problem in theory, the research was not applied to an actual WIP Bf design in construction.

2. Research objective

The main goal of this research is to propose and validate a simple graphical approach to design WIP Bf in repetitive building projects. Accomplishment of this goal requires the development of a multiobjective analytic model (MAM) based on SO modeling which uses Evolutionary Strategies (ES) as the optimization search approach and Pareto Front concepts. To be practically applicable, this MAM should result in nomographs to facilitate its use in the process of WIP Bf design. The paper addresses the development, testing and validation of SO approach and resultant MAM and the proposed graphical approach to design WIP Bf.

3. Research methodology

The research methodology consists on three stages: 1) definition of the SO framework to design WIP Bf; 2) testing and validation of the SO frame; and 3) development and application of the MAM to design WIP Bf. A discrete event simulation modeling architecture is employed as a basis for developing the SO framework. The SO framework is then applied to two multifamily residential building projects for testing and validation. The application includes the construction of discrete event simulation models for repetitive processes, SO modeling to design optimum WIP Bf sizes, and the development and implementation of buffered construction schedules. Finally, using the SO framework and Pareto Front concepts, this research develops the MAM for practical application of the concepts, thereby achieving its goal for a simple and practical tool to design WIP Bf in repetitive building projects. Multiobjective model development involves; i) the definition of multiobjective nomographs to address the design WIP Bf sizes with various project objectives; ii) sensitivity analysis and selection of WIP Bf sizes according to project preferences; iii) development of buffered construction schedules; and iv) application on a construction project example.

4. Describing WIP Bf in repetitive construction processes

In repetitive projects, WIP Bf can be characterized by a Linear Scheduling Diagram. Fig. 1 shows the diagram for *n* processes in a

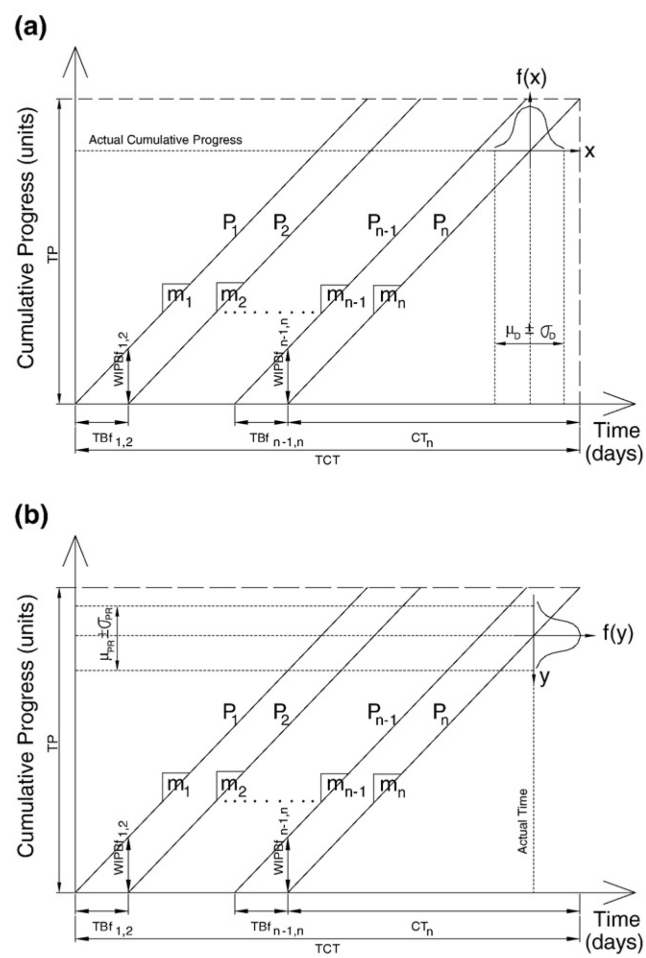

Fig. 1. Graphical representation of model for WIP Bf characterizing *n* processes: (a) unitary duration PDF, and (b) daily production rate PDF.