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Incorporation of activity sensitivity measures into buffer management to manage project schedule risk

Xuejun Hu[a,*], Nanfang Cui[a,1], Erik Demeulemeester[b,2], Li Bie[c,3]

[a] *School of Management, Huazhong University of Science and Technology, Wuhan, Hubei 430074, PR China*

[b] *Research Center for Operations Management, Department of Decision Sciences and Information Management, Faculty of Economics and Business, Katholieke Universiteit Leuven, BE-3000 Leuven, Belgium*

[c] *School of Management, South-Central University for Nationalities, Wuhan, Hubei 430074, PR China*

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ABSTRACT

Critical Chain Scheduling and Buffer Management (CC/BM) has shown to provide an effective approach for building robust project schedules and to offer a valuable control tool for coping with schedule variability. Yet, the current buffer monitoring mechanism faces a problem of neglecting the dynamic feature of the project execution and related activity information when taking corrective actions. The schedule risk analysis (SRA) method in a traditional PERT framework, on the other hand, provides important information about the relative activity criticality in relation to the project duration which can highlight management focus. It is implied, however, that control actions are independent from the current project schedule performance. This paper attempts to research these defects of both tracking methods and proposes a new project schedule monitoring framework by introducing the activity cruciality index as a trigger for effective expediting to be integrated into the buffer monitoring process. Furthermore, dynamic action threshold settings that depend on the project progress as well as the buffer penetration are presented and examined in order to exhibit a more accurate control system. Our computational experiment demonstrates the relative dominance of the integrated schedule monitoring methods compared to the predominant buffer management approach in generating better control actions with less effort and an increased tracking efficiency, especially when the increasing buffer trigger point is combined with decreasing sensitivity action threshold values.

1. Introduction

In today's highly competitive and rapidly changing marketplace, projects are increasing subject to a wide range of constraints, such as resource scarcity, network complexity and various uncertainties, demanding more effective techniques to improve the monitoring of the project schedule so as to ensure a successful scheduling outcome (Herroelen & Leus, 2005; Hu, Cui, & Demeulemeester, 2015). Traditional project schedule management methods, namely the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT), can no longer meet the diversified needs of modern projects. To this end, Glodratt (1997) applied the theory of constraints (TOC) to project management and proposed the Critical Chain Scheduling and Buffer Management (CC/BM) methodology, which has proven to be a popular and effective approach regarding both project scheduling and project control under enormous complexity and uncertainty (Bevilacqua, Ciarapica, & Giacchetta, 2009; Ma, Wang, Li, Gu, & Ai, 2014; Peng & Huang, 2014; Yang & Fu, 2014; Yang et al., 2007; Zhang, Song, Chen, & Shi, 2005b, 2015a, among others).

CC/BM relies on deterministic scheduling techniques in order to build a resource feasible schedule that is made robust by inserting various types of buffers (*project buffer, feeding buffer, resource buffer*), and improves the schedule performance during project execution to meet the deadline through *buffer monitoring*. Consequently, the size of buffers and how they are monitored directly determine the project completion time as well as the schedule risk, and hence play

* Corresponding author at: Room 326, School of Management, Huazhong University of Science and Technology, 1037 Luoyu Road, Hongshan District, Wuhan, Hubei 430074, PR China. Tel.: +8615927657485.

E-mail addresses: huxuejun0626@hust.edu.cn, huxuejun0626@foxmail.com (X. Hu), nfcui@mail.hust.edu.cn (N. Cui), Erik.Demeulemeester@econ.kuleuven.be (E. Demeulemeester), libie@mail.scuec.edu.cn (L. Bie).

[1] Postal address: Room 517, School of Management, Huazhong University of Science and Technology, 1037 Luoyu Road, Hongshan District, Wuhan, Hubei, 430074, PR China. +86 13808697263.

[2] Postal address: Hogenheuvelcollege, Naamsestraat 69, BE-3000 Leuven, Belgium. +32 16326972.

[3] Postal address: Room 516, School of Management, South-Central University for Nationalities, 182 Minyuan Road, Hongshan District, Wuhan, Hubei, 430074, PR China. +86 15807157883.

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crucial role in the successful application of CC/BM (Khemakhem & Chtourou, 2013). The vast majority of the research efforts on buffer management (BM) have concentrated on buffer sizing (see Bie, Cui, and Zhang, 2012; Tukel, Rom, and Eksioglu, 2006; for good overviews). However, interest in buffer monitoring techniques, an issue of major importance in practice, is generally insufficient among the research community.

The existing buffer monitoring mechanism mainly follows the practice established by Goldratt (1997) for production operations (Kuo, Chang, & Huang, 2009; Umble & Umble, 2006). That is, the buffer is divided into three regions (the "green–yellow–red" system) and explicit action levels for decision-making are set in terms of the buffer penetration along with the project progress. Herroelen and Leus (2001) for the first time included an activity crashing mechanism in their factorial experiment based on the three-stage buffer control system. Leach (2005) questioned Goldratt's static monitoring notion by maintaining that buffer trigger points are set to make the tracking process in line with the actual execution of a project, thus minimizing false warning signals and ensuring needed actions. Therefore, he recommends the two buffer trigger lines (i.e. the green-to-yellow transition and the yellow-to-red transition) vary linearly over the planned project duration in order to more accurately monitor or respond to schedule deviations. We refer to this method as *relative buffer management approach (RBMA)*, which is currently widely used in practice and will be compared to our proposed methods. Bie and Cui (2010) presented a more realistic buffer monitoring method by dynamically calculating the buffer size and the time instant for monitoring, so that the two control trigger points are timely adjusted according to the dynamic environment of project implementation. In a more recent study, Hu et al. (2015) put forward a new CC/BM-based schedule monitoring procedure that evaluates the probability of successful project completion relative to the cost of crashing and that determines when to expedite which activity in a cost-effective manner. Zhang, Shi, and Diaz (2015b) established an effort buffer deviation monitoring and control model for software projects based on the grey prediction model which proves to provide reliable control results in an empirical study. Colin and Vanhoucke (2015) cleverly combined the earned value management/earned schedule (EVM/ES) method with the concept of buffers inspired by CC/BM and proposed two new project control approaches with multiple control points for the purpose of minimizing the effort spent by the project manager.

In general, the buffer monitoring logic well indicates the project schedule progress as a whole and informs decision-making about whether to take control action or not. However, we find it has two problems that cannot be neglected in a real world application: (1) it does not provide the activity-level information through the buffer-related performance measures. Namely, the various impacts of individual activity duration variability on the project completion time are not discretely analyzed, which might lead to inaccurate warning signals and hence, inefficient control actions can be taken; (2) it fails to clarify which activities deserve more of management control when drilling down to lower WBS (Work Breakdown Structure) levels to take corrective actions. To counter these practical issues, we introduce the activity sensitivity measure from the *schedule risk analysis* method that enables critical activities to be identified for control purposes. First, a new buffer threshold is defined that distinguishes the control effort into two aspects, namely "*take action/more attention*" and "*no action/less attention*". Then we explore how the activity-based tracking policy can be incorporated into the project-based buffer management system by the use of a (static) sensitivity action threshold. Next, two new ways of dynamically setting up the sensitivity action thresholds are proposed according to the portion of project completion or the penetration level of the buffers. Our computational studies show that, relative to the previous BM approach, the integration of the activity sensitivity measure is capable of improving the project schedule performance with comparatively less control effort, especially in the case where decreasing sensitivity action threshold values are used.

The outline of this paper is as follows. Section 2 briefly reviews relevant research related to the schedule risk analysis method and gives an introduction to its working principles. In Section 3, the primary BM system as well as the activity sensitivity based tracking system is described and then the integrated schedule risk management framework is proposed. Section 4 presents a simulation study to illustrate the application of the proposed methods and also to testify their superiority in comparison to an alternative BM approach. In the last section, we discuss the implications of this study and identify some future research directions.

2. Activity-based schedule risk analysis

Since the introduction of the well-known PERT analysis in project management, the *schedule risk analysis* (SRA, Hulett, 1996) method has been set up to implement schedule control principally on a subset of highly sensitive activities that are considered to have high schedule risk (i.e. contribute most to the delay of a project or have a high impact on project completion). Various sensitivity measures have been proposed in the literature to measure activity importance, so that the most targeted actions can be taken to effectively control the project duration (Elmaghraby, 2000; Fortin, Zieliński, Dubois, & Fargier, 2010; Vanhoucke, 2010; Williams, 1992; etc.). Table 1 lists the four basic sensitivity measures that have been widely acknowledged or investigated in previous studies. The literature has also presented other ranking indices for activity importance (see, for example, Bowman, 2003, 2006, 2007; Cho & Yum., 1997; Creemers, Demeulemeester, & Van de Vonder, 2014; Madadi & Iranmanesh, 2012), which will not be further discussed due to the scope of this research.

In general, this type of *activity-based* project tracking approach divides activities into two classes, namely *highly sensitive* activities and *insensitive* activities, by setting up an *action threshold* that defines the degree of management attention/control. All activities with a sensitivity value higher than or equal to the action threshold are said to be highly sensitive activities and thus they deserve more attention during the project tracking process and require corrective actions in case of delays (Vanhoucke, 2010). In the example case of Fig. 1 below, the sensitivity threshold has been set to 0.4 such that only the most sensitive activities 1, 4, 6 and 7 need to be considered when corrective actions are necessary.

While the SRA method offers a great measure (activity sensitivity) to identify important/influential activities for control purposes, it faces a problem that action decisions are independent from the overall project schedule performance during the tracking process. To put it another way, corrective actions are required to be taken whenever highly sensitive activities experience delays regardless of the current project executing state (i.e. the degree of project catch-up or project delay), which seems **not** to be an appropriate practice in reality.

3. An integrated schedule monitoring model

From what has been illustrated, we can see that BM and SRA have both outstanding merits and intrinsic flaws, stimulating the research interest of this paper for a more systematic approach to improve the monitoring of the project schedule. In this section, we will first elaborate on the BM system and the CRI-based measurement system, respectively. Then an integrated schedule monitoring framework is presented. Throughout the paper, our primary focus is on the time performance of a project without regard to the cost measurement. Besides, the assumption, which is consistent with the past application of CC/BM, is made that one considers only one execution mode (one duration with the corresponding resource requirements) for each activity.