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Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models

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ABSTRACT

This paper documents an investigation of *drum-buffer-rope* (DBR) scheduling and flow control methodology in single-product serial production lines. In particular, DBR flow control is reviewed and the importance of correctly representing this type of flow control mechanism in serial lines is discussed. Departures from valid DBR conceptual and simulation modeling are illustrated. It is shown that the model of a previously published paper is a push system not a DBR system, and that related conclusions regarding protective capacity and constraint location are unsupported. Correct modeling of DBR flow control is shown using discrete simulation experiments that compare the DBR model and a similar push model. Suggestions for additional research are offered.

1. Introduction

Theory of constraints (TOC) has evolved over the past 25 years, and DBR has been implemented successfully in a number of very different manufacturing environments (Mabin and Balderstone, 2000). Several simulation studies relating to the DBR scheduling methodology have been published (Atwater and Chakravorty, 1994, 1997, 2002; Wu et al., 1994; Duclos and Spencer, 1995; Guide, 1995, 1997; Russell and Fry, 1996, 1997; Steele et al., 1996, 2005; Huang and Sha, 1998; Kosturiak and Gregor, 1998; Simons Jr. et al., 1999; Kadipasaoglu et al., 2000; Umble and Umble, 2000; Gilland, 2002; Gupta et al., 2002; Guo and Qian, 2006; Park et al., 2007). Many of these simulations model just a few workstations, a serial line, simplified DBR, one product, and no setups. None uses the terminology initially given in *The Haystack Syndrome* (Goldratt, 1990) and as updated and presented by the Theory of Constraints International Certification Organization[1] (TOCICO) Dictionary (Sullivan et al., 2007). This paper attempts to apply TOCICO terminology in a consistent manner to all models discussed, and uses definitions from the TOCICO Dictionary and other sources.

The purpose of this paper is fivefold. First, based on the theory of constraints literature, we review several key aspects of DBR flow control (FC) and discuss the importance of correctly modeling this type of flow control mechanism (FCM) in serial production lines. Second, to illustrate some common departures from valid DBR modeling, we focus on a paper by Kadipasaoglu et al. (2000) (KXHK hereafter). Third, we show how to incorporate DBR FC into single-product serial line models. Fourth, we describe several simulation exercises using both our DBR model and a version of the model by KXHK, and we compare our findings to those of KXHK. Finally, we discuss

[1] TOCICO is a global not-for-profit certification organization for TOC practitioners, consultants and academics to develop and administer certification standards, and facilitate exchange of latest developments. TOCICO administers certification examinations in supply chain logistics, finance and measures, project management, business strategy, and thinking process. Certified members are considered TOC experts.

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the results of our DBR model simulations, provide a summary of our findings, and suggest additional research.

2. *Drum-buffer-rope* flow control and the theory of constraints philosophy

DBR FC is part of the production application of the TOC management philosophy. Dr. Eliyahu M. Goldratt is the principal developer of the TOC management philosophy and DBR scheduling methodology. Watson et al. (2007) provide a study of the evolution of TOC as a management philosophy. Goldratt authored a number of discussions of DBR (Goldratt and Cox, 1984, 1986, 1992; Goldratt and Fox, 1986; Goldratt, 1990, 1999). *The Haystack Syndrome* is a text discussing DBR scheduling in detail. A number of commercial software packages have been developed based on Goldratt's detailed discussion of *drum-buffer-rope* (DBR) scheduling in *The Haystack Syndrome*.

To implement DBR FCM, one should understand the elements of that methodology. In addition one should appreciate the concepts of a system constraint and its implications, the steps to maximize constraint use, the relevant measures of system performance, the productive and protective uses of both capacity and inventory, and the fact that concepts such as starvation and blockage have special meaning and importance when applied in TOC, beyond their traditional usage.

According to the TOCICO Dictionary, DBR is the TOC method for scheduling operations. DBR uses (1) the drum or constraint to create a schedule based on the finite capacity of the constraint; (2) a (time) buffer which protects the drum (and shipping) schedule from variations; and (3) a rope mechanism to choke early release of raw materials to the production system (Sullivan et al., 2007, p. 18). In DBR FC, the drum is considered to be the pacing schedule of the constraint resource, by which an attempt is made to obtain full use of the constraint's available capacity. The rope is the schedule for release of materials as dictated by the constraint buffer. The rope ensures that no job is released to the line until the constraint buffer status dictates such release is needed. Shipping and assembly buffers[2] are also part of the schedule management in DBR; however, there are no assembly or shipping activities in the simple serial system modeled here. Ample physical space must be provided in any line design to accommodate the physical content of various line segments, especially including the constraint buffer. Additionally, a space buffer must also be provided downstream of the constraint resource. The TOCICO Dictionary defines a space buffer as, Physical space immediately after the constraint that can accommodate output from the constraint when there is a stoppage downstream that would otherwise force the constraint to stop working (Sullivan et al., 2007, p. 43). Successful application of DBR depends on active management of the constraint feeding buffer in this case, as well as the assembly and shipping buffers in more complex systems. Management must decide on the size of each time buffer.

In a simple flow line, the constraint can typically be identified as the resource that runs out of capacity first, or any policy that limits system *throughput*. The TOCICO Dictionary defines *throughput* as, *The rate at which the system generates "goal units". Because throughput is a rate, it is always expressed for a given time period such as per month, week, day or even minute*… (Sullivan et al., 2007, p. 47). For a one-product serial line system like ours, exploiting the constraint fully is the same as obtaining 100% use of the constraint, which means making productive use of all the constraint's *available* capacity (Goldratt, 1990).

Goldratt (1990) defines three kinds of available capacity. These are *productive capacity*, *protective capacity*, and *excess capacity*. Protective capacity and excess capacity together are also referred to as *idle capacity* (Sullivan et al., 2007, p. 27). Productive capacity is capacity needed for actual production (to meet demand). By definition, the constraint has only productive capacity. Protective capacity is additional capacity used to guard against disruption of the constraint. Blackstone Jr. and Cox III (2002, p. 419) describe protective capacity as *the capacity needed at non-*constraint *workstations to restore WIP* [work-in-process] *inventory to the location adjacent to and upstream of the* constraint *workstation to support full utilization of the* constraint *workstation. This protective capacity balances the flow among the workstations based on the* constraint *workstation capacity. Protective capacity maintains flow to the* constraint *buffers—upstream it keeps sufficient WIP in the inventory buffer and downstream protective capacity takes completed items from the space buffer.* Any capacity beyond productive and protective capacity (defined above) is excess capacity.

Starvation is defined in TOC as the condition where the constraint resource is without work to perform. This is in opposition to the traditional view of starvation as applying to any resource that is idle and waiting for work. From a system perspective, if the constraint buffer is empty and the constraint is idle or starved; system *throughput* is lost. Goldratt (1990) recognizes non-constraint resource starvation, but refers to it as a level of free time that must be enforced at non-constraints. This is an important distinction because "starvation" is often seen as negative. In fact, for resources upstream of the constraint, starvation and protective capacity are directly related. If a resource never starves, it has no protective capacity. Constraint starvation is generally caused by an inordinately long process time at an upstream workstation or by that workstation breaking down, or by some other delay[3] at a preceding workstation which disrupts the flow of work to the constraint. A constraint buffer measured in time on the constraint resource is used to eliminate or minimize starvation of the constraint (Goldratt, 1990). The only real protection from starvation afforded the constraint resource at any given time is the work-in-process

[2] There are other TOC terms that relate to lines and DBR such as the assembly and the shipping buffers, market constraint, simplified DBR, V, A, and T structures, etc. that are significant to understanding TOC designed and managed lines but unimportant with respect to this study.

[3] Such as setups, or resources being used on some other product or product line, neither of which is included in this study.