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Drum-buffer-rope and workload control in High-variety flow and job shops with bottlenecks: An assessment by simulation

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ABSTRACT

Two key concepts in the production planning and control literature that incorporate an order release function are the Theory of Constraints, with its drum-buffer-rope release method, and Workload Control, with its load-based release methods. When order release is applied, jobs are not directly released to the shop floor – release is controlled to realize certain performance measures. The performance impacts of drum-buffer-rope and Workload Control order release have been assessed separately, but the two approaches have not been directly compared in one study. This is a major shortcoming that leaves practitioners without guidance on which release method to select. This study assesses the performance of drum-buffer-rope and Workload Control release in a pure job shop and a general flow shop with varying levels of bottleneck severity. Both bottleneck oriented and non-bottleneck oriented Workload Control release methods are included. Simulation results show that Workload Control release methods lead to better performance than drum-buffer-rope if bottleneck severity is low. But Workload Control, including its bottleneck oriented release methods, is outperformed by drum-buffer-rope if a strong bottleneck exists. Workload Control gains an advantage in balanced shops due to its unique load balancing function, which attempts to evenly distribute workloads across resources. But this becomes functionless when there is a strong bottleneck. Our sensitivity analysis suggests that the performance differences between release methods are not affected by routing characteristics or the proportion of jobs that visit the bottleneck.

1. Introduction

This study compares the performance of the order release mechanisms contained within the Theory of Constraints (TOC) – i.e. Drum-Buffer-Rope (DBR) – and Workload Control literatures to support managers in their decision concerning which approach to apply in high-variety make-to-order flow and job shops with bottlenecks. The Theory of Constraints – originating in the seminal work of Goldratt (e.g. Goldratt and Cox, 1984, Goldratt, 1990) – is a concept that was specifically designed for shops with bottlenecks. It was originally conceived in the 1970s as a scheduling algorithm and later developed into a broad production planning and control concept (Simons and Simpson, 1997; Mabin and Balderstone, 2003). One of its main elements is Optimized Production Technology (OPT), its scheduling (or release) mechanism, that is now more commonly known as Drum-Buffer-Rope (DBR) – a descriptor of the way order release is realized (Simons and Simpson, 1997). DBR controls (or subordinates) the release of jobs to the system in accordance with the bottleneck (or constraint). The Theory of Constraints can be considered a powerful production planning and control technique in shops with bottlenecks; for example, Mabin and Balderstone (2003) reviewed the literature on more than 80 successful implementations, with 80% reporting improvements in lead time and due date performance.

Meanwhile, Workload Control is a production planning and control concept that has been developed over more than 30 years (Thürer et al., 2011). While several different approaches to Workload Control exist, a major unifying element is the use of a load-based order release mechanism. Using the principles of input/output control (Wight, 1970; Plossl and Wight, 1971), load-based release methods seek to stabilize the workload in the system by releasing work in accordance with the output rate. The Workload Control concept has been shown to significantly improve the performance of high-variety shops both through simulation (e.g. Glassey and Resende, 1988; Land and Gaalman, 1998; nd et al., 2012; Land et al., 2014a) and, on occasions,

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in practice (e.g. Wiendahl, 1992; Bechte, 1994; Hendry et al., 2013; Silva et al., 2015). Although Workload Control has been largely developed in the context of balanced shops, there is some evidence of its potential to improve performance in shops with bottlenecks (e.g. Glassey and Resende, 1988; Lingayat et al., 1995; Enns and Prongue-Costa, 2002; Fernandes et al., 2014).

In a make-to-order context, both concepts – the Theory of Constraints and Workload Control – use buffers to protect the throughput of the system from variability in the mix of jobs arriving at the shop. Further, both use order release to control the buffers so that buffer costs are minimized; if order release is applied, jobs are not released directly to the shop floor on arrival – the release of jobs is controlled to create a mix on the shop floor that meets certain performance targets, such as due date adherence and reduced levels of work-in-process. Given their similarities, the two approaches could arguably be used interchangeably or elements of the two approaches combined. In fact, Riezebos et al. (2003) used Workload Control elements to improve DBR. But while there has been a broad literature comparing DBR with Material Requirements Planning (MRP), infinite loading, and *kanban* systems (see, e.g. Rahman, 1998; Gupta and Snyder, 2009), to the best of our knowledge, the performance of DBR has not been compared with Workload Control order release. Rather, in the few prior studies that have attempted a comparison, some form of bottleneck oriented Workload Control approach has been used as a proxy for DBR (e.g. Fredendall et al., 2010). This raises the following question: which order release mechanism should be chosen in practice, DBR or Workload Control order release? In response, this study examines the performance of DBR and Workload Control order release in high-variety make-to-order flow and job shops under different levels of bottleneck severity.

The remainder of this paper is structured as follows. In Section 2, we review the literature on DBR and Workload Control in shops with bottlenecks. The simulation model used to evaluate performance is then described in Section 3 before the results are presented, discussed and analyzed in Section 4. Finally, conclusions are drawn in Section 5, where managerial implications and future research directions are also outlined.

2. Literature review

In Section 2.1, we first review the literature on DBR. Section 2.2 then outlines the literature on Workload Control in shops with bottlenecks before an overall assessment of the literature is presented in Section 2.3.

2.1. Drum-Buffer-Rope (DBR)

A DBR system is depicted in Fig. 1 for a single bottleneck station. Its essential parts can be described as follows:

- *Drum*: This is the constraint (e.g. the bottleneck station, the market, etc.) and its schedule.
- *Buffer*: This is both the constraint buffer (i.e. the buffer before the bottleneck) and the shipping buffer (i.e. finished goods inventory; see e.g. Watson et al., 2007). Buffers are time (e.g. Radovilsky, 1998; Rahman, 1998; Schragenheim and Ronen, 1990; Simons and Simpson, 1997; Chakravorty and Atwater, 2005) or a time-equivalent amount of work-in-process.
- *Rope*: This is the communication channel for providing feedback from the drum to the beginning of the system, i.e. order release. Based on this feedback, order release aligns the input of work with the output rate of the bottleneck. In other words, a maximum limit on the number of jobs released to the bottleneck but not yet completed is established and a job is released whenever the number of jobs is below the limit (e.g. Ashcroft, 1989; Lambrecht and Segaert, 1990; Duclos and Spencer, 1995; Chakravorty and Atwater, 1996; Chakravorty, 2001; Watson and Patti, 2008). There are two ropes: Rope 1 determines the schedule at the bottleneck to exploit the constraint according to the organization's goal (Schragenheim and Ronen, 1990); Rope 2 then subordinates the system to the constraint (the bottleneck station).

2.2. Workload control in shops with bottlenecks

Much of the available literature on Workload Control order release assumes a balanced shop, i.e. with no bottleneck constraint. To the best of our knowledge, the first study to present a bottleneck oriented Workload Control release method was Glassey and Resende (1988). Glassey and Resende (1988) proposed a Starvation Avoidance (SA) methodology that essentially releases work whenever the workload queuing or on its way to the bottleneck (but not yet completed) falls below a certain level. This is similar to DBR but controls the workload instead of the number of jobs. Using simulation, Glassey and Resende (1988) showed that, in job shops, this SA approach outperforms a rule that releases a new job whenever a job is complete. A periodic version of SA (i.e. where the release decision is only taken at periodic time intervals rather than being triggered at any moment in time when starvation occurs) was later shown by Roderick et al. (1992) to be outperformed by Constant Work-in-Process (ConWIP), which also controls the number of jobs in the system, in a shop with restricted routings. It was this periodic version of SA that Fredendall et al. (2010) used as a proxy for DBR. Meanwhile, Lingayat et al. (1995) showed that SA outperforms ConWIP in a job shop, where routings are not restricted. Finally, Enns & Prongue-Costa (2002) showed that controlling the workload released but not yet completed at the bottleneck resource, rather than controlling the workload released but not yet completed by the whole shop, leads to better performance in a job shop with a bottleneck specifically when bottleneck severity is high. But it was also shown that this approach leads to worse performance in a general flow shop.

The aforementioned studies focused on either controlling the load in the shop as a whole or at the bottleneck. But a major strength of Workload Control is that it can balance workloads across resources, controlling the workload of all stations (Thürer et al., 2012) – if only the workload at the bottleneck is considered, workload balancing cannot be achieved. Fredendall et al. (2010) showed that, in job shops

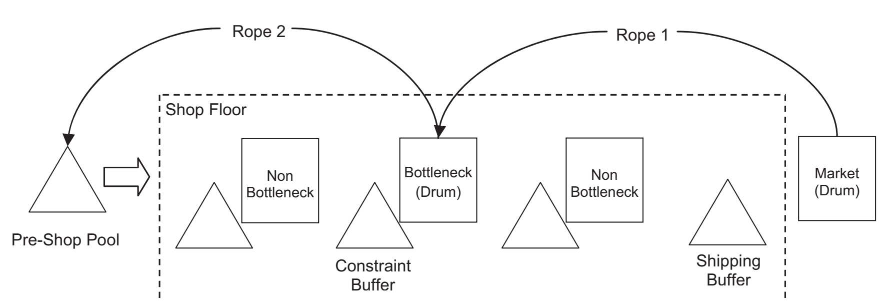

Fig. 1. Drum-Buffer-Rope.