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On the integration of input and output control: Workload Control order release

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ABSTRACT

Workload Control is a production planning and control concept developed for high-variety job shops. It integrates two control mechanisms: (i) input control, to regulate the inflow of work to the system; and (ii) output control, which uses capacity adjustments to regulate the outflow of work from the system. Much Workload Control research has focused on input control, while output control has been largely neglected. Only recently has research emerged that uses Workload Control theory to guide capacity adjustments. Yet this literature focuses on capacity adjustments (output control) only – it fails to integrate it with Workload Control's input control element. In response, this study explores the performance impact of Workload Control when input control (controlled order release) and output control (capacity adjustments) are combined. Job shop simulation results demonstrate that input and output control can and should play complementary roles. Both elements significantly enhance performance in isolation, and performance effects appear to complement each other. Further, results indicate that the choice of the workload threshold that triggers capacity adjustments has a stronger impact on performance than the actual size of the adjustment. The measure of workload used to guide the load-based order release decision is also used to determine the workload threshold that triggers the capacity adjustment. This facilitates implementation in practice. Finally, although our study is on Workload Control, the findings have important implications for other production planning and control concepts.

1. Introduction

Workload Control is a production planning and control concept that was developed for high-variety contexts, such as small and medium-sized make-to-order companies, which often have a job shop configuration (Zäpfel and Missbauer, 1993; Stevenson et al., 2005). The concept has been shown to significantly improve the performance of job shops both through simulation (e.g. Thürer et al., 2012, 2014a) and, on occasions, in practice (e.g. Wiendahl et al., 1992; Bechte 1994; Hendry et al., 2013; Silva et al., 2015). While there exist several different approaches to Workload Control (Thürer et al., 2011), a major unifying principle driving Workload Control is input/output control, i.e. that the input rate to a shop should be equal to the output rate (e.g. Wight, 1970; Plossl and Wight, 1971). Consequently, there are two control mechanisms within the Workload Control concept (e.g. Land and Gaalman, 1996; Kingsman, 2000): (i) *input control*, which regulates the work that can enter the shop and/or shop floor; and (ii) *output control*, which uses capacity adjustments to regulate the outflow of work. While input control has received much attention in the Workload Control literature (e.g. Melnyk and Ragatz, 1989; Philipoom et al., 1993; Bergamaschi et al., 1997; Sabuncuoglu and Karapinar, 1999; Land, 2006; Fredendall et al., 2010; Thürer et al., 2012, 2015a), how output control can be effectively realized has been largely neglected. Recently, research has emerged that uses Workload Control theory to guide output control decisions – in particular, when to adjust capacity (Land et al., 2015; Thürer et al., 2014b, 2015b). But this recent research has neglected the input control element of Workload Control. In response, this study examines the combined impact of input control (in the form of order release) and output control within Workload Control.

Order release is one of the key mechanisms for realizing input control within Workload Control. Order release decouples the shop floor from higher level planning. Jobs are not released onto the shop floor immediately but flow into a pre-shop pool from

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which they are released to meet due dates while also keeping work-in-process within limits or norms. This buffers the shop floor against variance in the incoming order stream (Melnyk and Ragatz, 1989; Thürer et al., 2012). Although order release can stabilize the workload on the shop floor, there remains variability in the workload accepted by a company: the planned workload. Order release does not affect the rate at which work arrives at the shop; it just controls the release rate to the shop floor. It typically shifts variability from the shop floor to the pre-shop pool. This means that the probability of temporary periods of high and low (planned) loads occurring is not, or only moderately, affected. These high load periods, i.e. periods during which more work arrives at the shop than a particular station can handle, have a direct detrimental effect on performance. The longer such a period persists, the more probable it is that congestion will increase workloads to a degree that causes the due dates of orders to be exceeded (Land et al., 2015).

Since the probability of high load periods is not reduced by order release control, another control mechanism is required. Thürer et al. (2014a) showed how influencing the probability of winning an order through the competitiveness of the bid can be used to level the planned workload over time. However, this hinges on the assumption that jobs can be rejected (and so never enter the planned workload) without affecting the average throughput rate, i.e. it is assumed that there is a competitive environment where the work available exceeds the amount of work accepted or won. An alternative approach for handling high load periods is output control on the shop floor in the form of capacity adjustments.

Land et al. (2015) recently demonstrated that small, timely capacity adjustments that alleviate capacity shortages in high load periods can significantly improve performance. These capacity adjustments were triggered when the workload at a station surpassed a certain workload threshold. But although Land et al. (2015) used a measure of the workload that was derived from Workload Control theory, their procedure was not applied to a shop using Workload Control's input control mechanism. To the best of our knowledge, no work exists in the Workload Control literature that looks at the combined effect of input and output control. In response, this study has two objectives:

(i) To outline how Workload Control order release (input control) and the output control procedure for capacity adjustments introduced by Land et al. (2015) can be combined; and,
(ii) To use simulation to assess – for the first time – the performance impact of Workload Control as a concept that combines input control (in the form of order release) with output control (in the form of capacity adjustments).

The remainder of this paper is structured as follows. In Section 2, we review the Workload Control literature on order release (input control) and capacity adjustments (output control) to identify the methods to be applied in this study. 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

Although it is acknowledged that input control may be exercised at several points within the Workload Control concept (job entry, order release, etc.), we focus on order release since it is the most widely applied approach in the literature. In Section 2.1, we first review the Workload Control literature on order release to identify the release method to be considered in our study. Section 2.2 then reviews the Workload Control literature that focuses on output control and outlines how input control (in the form of order release) and output control can be combined within Workload Control.

2.1. Workload Control Order Release Method (input control)

There are many order release methods in the Workload Control literature; for examples, see the reviews by Wisner (1995); Land and Gaalman (1996); Bergamaschi et al. (1997); Sabuncuoglu and Karapinar (1999) and Fredendall et al. (2010). In this paper, the LUMS COR (Lancaster University Management School Corrected Order Release) method is used because it was recently shown to be the best order release solution for Workload Control (Thürer et al., 2012a). LUMS COR uses a *periodic* release procedure, executed at fixed intervals, to control and balance the shop floor workload. This procedure keeps the workload W_s released to a station s within a workload norm pre-established by management as follows:

(1) All jobs in the set of jobs J in the pre-shop pool are prioritized according to a pool sequencing rule (e.g. planned release date).
(2) The job $j \in J$ with the highest priority is considered for release first.
(3) Take R_j to be the ordered set of operations in the routing of job j. If job j's processing time p_{ij} at the ith operation in its routing – corrected for station position i – together with the workload W_s released to station s (corresponding to operation i) and yet to be completed fits within the workload norm N_s at this station, that is

$$\frac{p_{ij}}{i} + W_s \le N_s \quad \forall i \in R_j \tag{1}$$

then the job is selected for release. That means it is removed from J, and its load contribution is included, i.e.

$$W_s := W_s + \frac{p_{ij}}{i} \quad \forall i \in R_j \tag{2}$$

Otherwise, the job remains in the pool and its processing time does not contribute to the station load.
(4) If the set of jobs J in the pool contains any jobs that have not yet been considered for release, then return to Step 2 and consider the job with the next highest priority. Otherwise, the release procedure is complete and the selected jobs are released to the shop floor.

A released job contributes to W_s until its operation at this station is completed. Early studies on Workload Control typically focused on limiting the aggregate of the full processing times to a station, but this ignored variance in the indirect workload (i.e. the amount of upstream work), which is dependent on the position of a station in the routing of jobs. Therefore, the load contribution to a station in LUMS COR is calculated by dividing the processing time of the operation at a station by the station's position in the job's routing. Using this "corrected" measure of the aggregate workload (Oosterman et al., 2000) recognizes that a job's contribution to a station's direct load is limited to only the proportion of time that the job is actually queuing and being processed at the station instead of the full time between release and completion at a station.

In addition to the above periodic release mechanism, LUMS COR incorporates a *continuous* workload trigger. If the load of any station falls to zero, the first job in the pool sequence with that station as the first in its routing is released irrespective of whether this would exceed the workload norms of any station. The