How to Release Orders with Sequence-dependent Setup Times?

Nuno O. Fernandes and S. Carmo-Silva

***Abstract*—Sequence-dependent setup times can have a major influence on manufacturing systems performance. Although much investigation has been given to this issue, the role of setup savings from the perspective of the workload control concept has hardly received attention. This paper reports a simulation study on this matter. The study evaluates the potential for savings in setups, dependent on the level of workload in the shop, for two alternative strategies, namely considering setup times centrally, within the release decision or locally, within the dispatching decision. These strategies are compared and assessed on the basis of two performance measures: time in system and standard deviation of job lateness. Results show that shop configuration is an important factor to choose the strategy to adopt. Moreover, the level of workload is also critical performance of the strategies.**

***Index Terms*—Order release, setup time, simulation.**

I. Introduction

Workload Control (WLC) is an approach to Production Planning and Control (PPC) particularly appropriate for jobbing and flow shops in the make-to-order (MTO) sector of industry [1]. The concept applies the basic principles of input/output control [2] to keep the length of queues on the shop floor at appropriate levels. The aim is to achieve short, stable and predictable throughput times towards meeting promised delivery dates. This requires restricting and balancing workload on the shop floor to avoid temporary overload or underload of machines. Only if workloads are balanced, the queues on the shop floor will be stable. Stable queues should result in predictable throughput times, which in turn are used to determine the planned release date of jobs. Order release is the main instrument for controlling workload [3]. It selectively releases orders (jobs) from a pre-shop pool into the shop floor. However, orders are only released if they fit workload norms, usually measured in time units, of the required capacity groups. This means that the decision to release an order is based on its influence on shop floor situation.

Setup time refers to the length of time required to prepare a machine to perform a particular operation. Most WLC literature assumed that setup time is either nonexistent or considered as part of the operation processing time. While this may be acceptable for scheduling in some production environments, in many others, such as printing, plastic manufacturing, metal and chemical processing, textile industry applications and production of compound semiconductors, production control decisions needs to consider sequence-dependent setup times, i.e. setup times that are dependent on both the job to be processed and the immediately preceding one. In this situation, shop performance cannot be effectively improved without the aid of appropriate scheduling procedures, which take setup times into account [4].

Essentially, two alternative strategies exist to deal with sequence dependent setup times: considering them centrally within the release decision or locally within the dispatching decision.

The first alternative is concerned with the role of setup in scheduling jobs on one or more machines to optimize certain objectives. References [5] and [6] provide a comprehensive review of the literature on this matter. The latter alternative is concerned with the role of setup in decision making at the higher planning levels of the WLC system. This issue has hardly received attention in the literature. A remarkable exception is the work of [7] that examined the functional relationship between work-in-process (WIP) and total setup time, in order to establish the suitable level of WIP in the shop floor.

The goal of this paper is to investigate the implications of sequence-dependent setup times in decision making at the order release level of the workload control concept. Note that as long as the savings in setup time are greater than the time the orders wait in the pre-shop pool, time in system of jobs is likely to be shortened. However, the objectives of workload balancing within the release decision may conflict with the strategy of reducing setups. Therefore, we investigate how orders should be sequenced in the pre-shop pool and on the shop floor in order to reduce the number of setups and, expectedly, improve system performance.

In this paper, the influence of shop configurations is studied. Using computer simulation, the performance of the pure job shop, the pure flow shop and the general flow shop configurations are analysed. The results of the study should contribute to the choice of the appropriate alternative to deal with sequence dependent setup times in a practical situation.

The remainder of the paper is organized as follows. Section 2 discusses the experimental design of the simulation study to test our research question. Section 3 is focused on the analysis of the results from simulation experiments, and in Section 4 some concluding remarks and directions for future research work are put forward.

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II. Simulation Study

A. Simulation model

The simulation model was written in Arena 7.01. A shop without an explicit bottleneck was considered. The shop consists of six capacity groups, each containing a single multi-propose machine that processes different types of jobs by changing setups. The jobs are divided into four types. We assume that no setups are required for the same type of job. Each of the four types of jobs has an equal probability of being assigned to an arriving order. Orders inter-arrival time at the production system follows a negative exponential distribution.

Orders arrive at the production system over time and are kept in a pre-shop pool until they are selected for release. An order (job) can be released into the shop floor if the direct load on the first machine, or capacity group, in its routing is equal or below the established norm. Direct load of a machine is the quantity of work resulting from jobs waiting and being processed at a machine. Among the set of job in the pool with the first operation on a particular machine, jobs are selected for release based on their priority and are released until the norm is exceed. Once a job is released, the processing time of each operation is accounted for updating workload on each machine.

We assume operation times to be identical on every machine and, on average, equal to 0.75 hours per job, following a 2-Erlang distribution. The inter-arrival time of orders or jobs was adjusted to maintain machine utilization at 90%, when ordinary rules are used. These are: at release the *Latest Release Date* (LRD) rule and at dispatching the *First-In-First Out* (FIFO) rule.

We assume that jobs follow the same dispatching discipline in every machine. Machine setup times are set at 20% of the average operation time. This value provides an environment that will differentiate the performance of the priority rules without giving undue advantage to setup-oriented ones (Kim and Bobrowski, 1994).

The following assumptions were also made: (1) due dates of orders are set externally and known upon arrival; (2) each machine can only perform one operation at a time on any job; (3) an operation of a job can be performed by only one machine at a time; (4) operation processing pre-emption is not allowed; (5) each machine is continuously available, i.e. machines are assumed not to break down; and (6) the same setup time is considered for each job type.

B. Experimental design

Table 1 summarises the four experimental factors and the associated levels studied: (1) dispatching rule; (2) selection rule for releasing; (3) shop configuration and (4) workload norm level.

Two types of dispatching rules were tested on the shop floor: the ordinary FIFO rule and the setup-oriented *SIMilar SETup* (SIMSET) rule. Applying FIFO, jobs are processed according their arrival at the machines without regarding setup time savings. SIMSET, on the other hand, gives priority to jobs that can be processed within the existing machine setup. This means that, on the completion of a job on a machine, if there is another one on the queue requiring the same setup it will be given processing priority. However, if there are no such jobs then jobs are processed in the order they arrive at machines.

Table I: Experimental factors and levels

Factor	Levels		
Dispatching rule	FIFO		SIMSET
Selection rule for releasing	LRD		SLRD
Workload norm level	stepwise down from infinite		
Shop configuration	PJS	GFS	PFS

Two selection rules were also considered for the release decision: the ordinary LRD rule and the setup-oriented *Similar setup and Latest Release Date* (SLRD) rule. With LRD, the latest release date is calculated as the job's due date minus the sum of the required processing and expected queuing time. This queuing time was estimated through pilot simulation runs. Using LRD urgent jobs have a higher probability of being released. SLRD, on the other hand, gives releasing priority to jobs of the same type. If there is not any, then the job with the planned latest release date is selected next for release.

Three types of shop configuration were studied: the pure job shop (PJS), which exhibits the most extreme type of routing variety, with complex workflows and job routing sequences that are random from job to job; the general flow shop (GFS), which has direct and by-passing workflows i.e. the flow between any combination of machines always have the same direction; and the pure flow shop (PFS) where each job has exactly the same routing. In PJS and GFS the lengths of the job routings are determined from a discrete uniform distribution on [1, 6]. In PFS each job visits all six machines.

The workload norm levels vary stepwise down from infinite, i.e. from a very large value that causes no restriction to order release, to highly restrictive order release levels. Workload norm levels are set identical for all machines.

C. Performance measures

The primary measure of system performance is time in system. It is used as an indicator of workload balancing performance of the release procedure and refers to the time a job spends waiting in the pre-shop pool plus the shop flow time. The term *workload balancing* refers to maintaining a constant direct load for each machine or capacity group. Reducing time in system has a beneficial impact on reducing the overall response time to customers. Shop flow time is also recorded. It refers to the time that elapses between job release and completion. Reducing the shop flow time has also intrinsic benefits. In particular, reduction of WIP and consequently of tied up capital is obtained. As an indicator of timing performance, the standard deviation of the job lateness is used. It indicates how close to due dates the completion times of jobs are.

III. Experimental results

During simulation runs, data were collected under system steady-state. The length of each run was 100,000 simulated hours including a warm-up period of 25,000 hours. The average values of 100 independent replications are presented as results. The statistical analysis was performed using the paired Student *t*-test with a 95% confidence level.

Table II: Control strategies by combining dispatching and selection rule for releasing

Dispatching rule	Selection rule for releasing	
	Ordinary (LRD)	*Setup-oriented* (SLRD)
Ordinary (FIFO)	A1	A2
Setup-oriented (SIMSET)	A3	Not relevant

Table 2 shows four control strategies that result from combining selection rules for releasing and dispatching rules. One of them is not relevant to this study. They have different implications for shop floor control and performance. While strategy A1 gives no importance to savings in setup time, strategy A2 considers setup times centrally, i.e. within the order release decision, and alternative A3 considers them locally, i.e. within the dispatching decision.

Figures 1, 2 and 3 shows the impact of the norm levels on the performance of the different control strategies A1 to A3. In figures 1(a), 2(a) and 3(a) the average value of job time in system is plotted against the average value of job shop flow time, which indicates the balancing performance of the different control strategies. In figures 1(b), 2(b) and 3(b) the standard deviation of the job lateness (StDev lateness), is plotted against the average value of job shop flow time, indicating the timing performance of the control strategies. A point on a curve is the result of simulating a control strategy at a specific workload norm level. Series of simulations experiments were performed with decreasing values for the workload norms, i.e. from unrestricted norms to increasingly restrictive ones. Thus, time in system and StDev of job lateness are indicated for different levels of norm tightness. Note that the shop flow time is used as an instrumental variable that indicates the level of tightness of norms: the lower the value, the higher the tightness.

A. *Performance behaviour under random flow*

Performance curve A1 is based on the use of ordinary rules at both release and dispatching decisions. For the job shop configuration the curve starts at the point (20.2, 20.2), figure 1(a). This is the result of an 'infinite' workload norm, meaning that jobs do not wait in the pre-shop pool and are immediately released. Tightening workload norms leads to lower values of shop flow time. The curve ends at the point (6.7, 20.6), which is the result of a workload norm of zero, i.e. order release is allowed only when the direct load becomes zero. This results on a 66.8% reduction of the shop flow time with a not significant increase in time in system. Since time in system is the sum of pool time and shop flow time, this means that waiting time on the shop floor have practically been replaced by waiting time in the pool. The progressive increase of StDev of lateness of curve A1, figure 1(b), as workload norms become tighter, seems to be due to the increasing of waiting times within the pre-shop pool.

Performance curves A2 and A3 are based on the use of setup-oriented rules. A2 for order release decisions and A3 for dispatching decisions. For these two control strategies, lower values of time in system are obtained than for A1, across the whole range of workload norm tightness. This shows that setup-oriented priority rules are very effective on

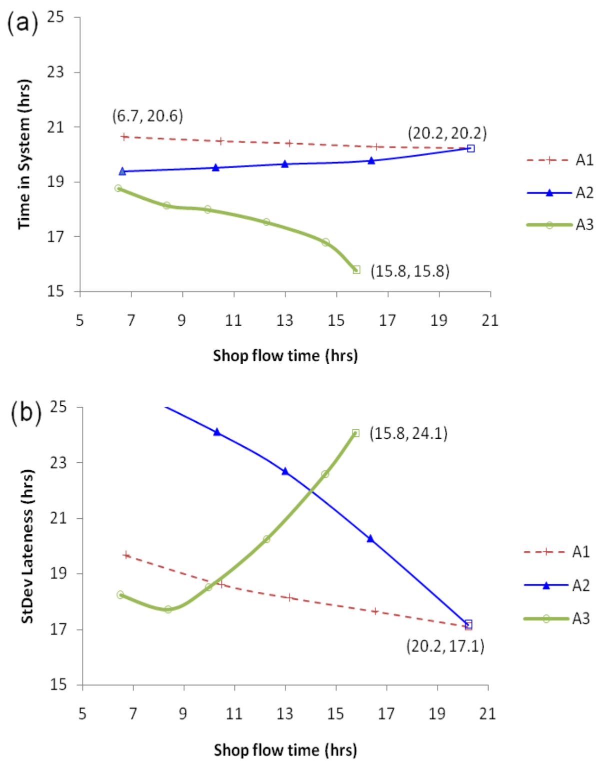

Fig 1: performance in the pure job shop configuration.

improving time in system performance. These findings are in line with previous findings by other authors, namely [4].

It can also be seen that setup oriented dispatching (A3) seems to perform better than setup oriented order release (A2) for time in system. The StDev of lateness is also better but only for tighter workload norms, i.e. for low levels of workload in the shop. Under unrestricted workload norms, the StDev is much larger for A3 than for the other two strategies. This is an important finding, taking into account that, often in practice, jobs are immediately released to the shop floor, i.e. workload is not restricted.

This behavior of curve A3 for the StDev of lateness can be explained by the disruption of the 'natural' sequence of processing jobs, introduced by setup oriented dispatching. As workload norms become tighter, the behavior of A3 is to a great extent opposite to that of A1 and A2. In fact, the StDev of lateness decreases for A3, up to a minimum, while it continuously increases for control strategies A1 and A2. This happens because, as workload norms become tighter, the release procedure tends to retain longer jobs at the pre-shop pool. Therefore, an increased choice of jobs and release based on setup-oriented savings happens. This disturbs the planned releasing sequence, holding back jobs, namely urgent jobs and thus increasing the variability of the job lateness distribution.

B. *Performance behaviour under directed flow*

For the general flow shop, figure 2, the relative behavior of control strategies A1, A2 and A3 is somewhat similar to that of the pure job shop. However, the gap between A1 and A2 increases for time in system and decreases for StDev of lateness. A relative deterioration of the StDev of lateness is also observed for strategy A3 under tight workload norms.

For the case of pure flow shop, figure 3, a similar changing

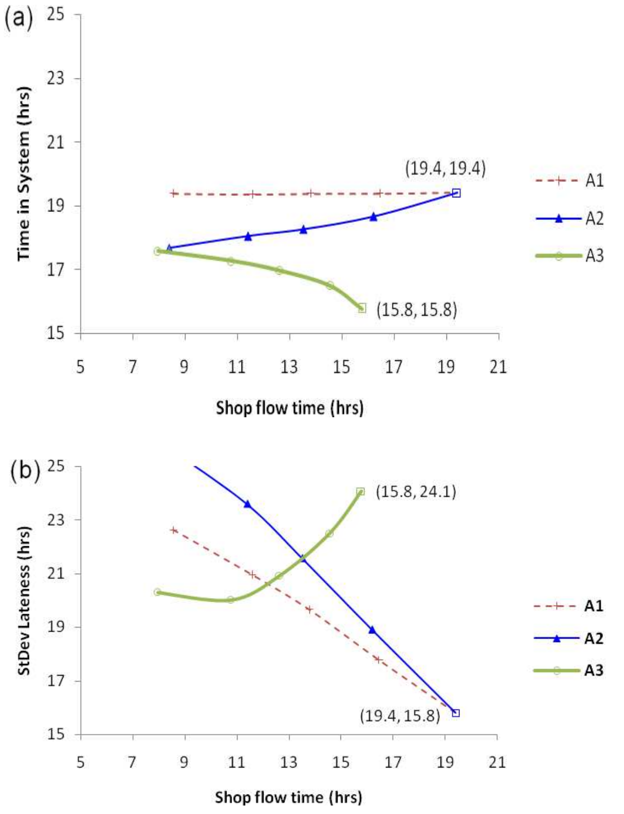

Fig 2: performance in the general flow shop configuration.

behavior of the three curves is observed. Here A3 shows a remarkable deterioration of StDev of lateness, across the whole range of norm tightness, when compared with the other control strategies. Moreover, for time in system, performance curves A2 and A3 cross each other, highlighting the importance of the workload in the decision for considering setup times centrally or locally.

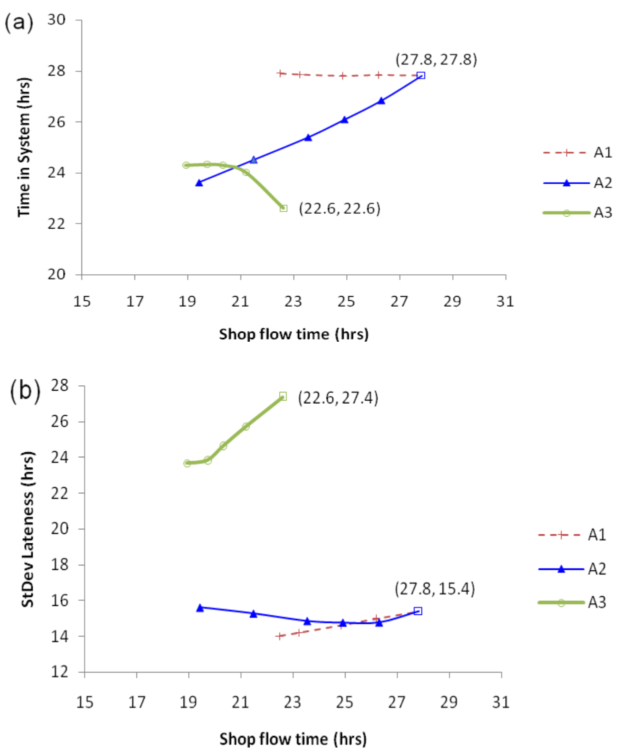

Fig 3: performance in the pure flow shop configuration.

These findings clearly indicate that the relative advantages of setup oriented release and setup oriented dispatching are highly influenced by the level of workload in the shop. Moreover, this influence is relatively different according to shop floor configuration. In particular, as we move from pure random to a directed flow an increasing relative deterioration of StDev of job lateness is observed for setup oriented dispatching. This, may hinder the applicability of this strategy in pure flow shops, favoring setup oriented releasing.

IV. Conclusion

Sequence-dependent setup times may lead to major setup savings if appropriate scheduling procedures are used. This can have a major influence on manufacturing system performance. This paper reports a simulation study of such influence in the context of Workload Control.

The results show that the shop configuration and the level of workload in the shop are critical for the balancing and timing performance of the control strategies studied. According to the obtained results, the traditional approach to deal with sequence-dependent setup times, based on setup oriented dispatching, performs well in pure job shops, particularly for time in system. However, as we move to pure flow shops the timing performance of this strategy, measured by the standard deviation of the job lateness, strongly degrades in relation to setup oriented order releasing.

The findings show that adjustments to the traditional release methods are required in order to account for sequence-dependent setup times in a more effective manner. A study on this will be carried out in the near future by the authors.

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