Input-output control order release mechanism in a job-shop: how workload control improves manufacturing operations

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Abstract: This paper presents and evaluates an order release decision rule in a job-shop, based on the input-output control concept. The order release mechanism is part of a global decision-making scheme that includes four main decisions: accept/reject orders, define the order's due date, release the accepted jobs and dispatch it on the shop floor. This paper also presents an evaluation of two acceptance rules, four release mechanisms, and two dispatching rules, using four levels of due date tightness. Extensive simulation experiments were performed to compare the different decision rules, using several criteria: mean tardiness, percent tardy, mean absolute deviation, mean queue time in the shop floor and in the system, and machine usage. We conclude that considering the four decisions simultaneously improve the job-shop performance, and planning both the input and the output when deciding to release a job, leads to an improvement of the operational performance measures.

Keywords: job-shop; input-output control; order release; simulation.

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1 Introduction

In make-to-order production environments the concept of workload and input-output control is of crucial importance to improve manufacturing operations. Despite a clear early concern about workload control (Wight, 1970), input-output control with the four decisions taken into consideration simultaneously is quite recent (Riezebos et al., 2003; Henrich et al., 2004; Stevenson, 2006; Stevenson and Hendry, 2007; Stevenson and Silva, 2008; Weng et al., 2008; Hendry et al., 2008; Moreira and Alves, 2009; Fredendall et al., 2010; Thurer et al., 2011). The first basic research model considers a job as a series of operations to be processed with a limited number of machines that comprise the shop. As the job proceeds along the shop floor, it encounters other jobs competing for the same resources and queues develop at each machine. Most of the research has concentrated on developing mechanisms to prioritise these jobs in order to optimise some shop performance parameter (Yang and Sum, 1994; Holthaus and Ziegler, 1997; Jayamohan and Rajendran, 2000; Reeja and Rajendran, 2000a, 2000b). This control decision is often referred to as 'dispatching'. The due-date assignment decision is another important decision (Vig and Dooley, 1991; Raghu and Rajendran, 1995; Gordon et al., 2002; Hsu

and Sha, 2004; Chiang and Fu, 2007; Sawik, 2009; Shabtay, 2010; Vinod and Sridharan, 2011).

The order releasing decision has been receiving more attention (Roderick et al., 1992; Hendry and Wong, 1994; Sabuncuoglu and Karapinar, 1999; Fernandes and Carmo-Silva, 2011; Lu et al., 2011). The arriving jobs are usually collected in some sort of backorder file (frequently called pre-shop pool). Jobs are then released by some mechanism, trying to ensure completion before the due date. For a complete classification and review of the order release mechanisms see Thurer et al. (2010), Cigolini et al. (1998), Bergamaschi et al. (1997) and Wisner (1995). The order acceptance decision has been, for the most part, ignored, since it was usually assumed that all incoming orders were accepted, and only recently has it been the object of research (e.g., Slotnick, 2011; Foreest et al., 2010; Oguz et al., 2010; Ebadian et al., 2008; Ebben et al., 2005; Nandi and Rogers, 2004).

The decision-making scheme considered in this paper includes these four main decisions. At each decision stage, benchmark rules are considered [e.g., total acceptance (TA), immediate release (IMR) or first come-first served dispatching], as well as some rules proposed in earlier studies [e.g., acceptance based on total accepted workload or earliest due date (EDD)]. A new decision rule is considered at the release phase, based on the workload and the input-output control concepts, as it tries to control the amount of work in the shop floor. The release mechanism takes into consideration not only the input control but also the output control and the capacity adjustment problem. The central idea of the proposed job release mechanism, labelled planned input-output control (PIOC), is to control the input, in terms of jobs released to the shop floor, and the output, in terms of shop production capacity, at the same time. The PIOC rule includes information about the jobs, the shop floor and the shop capacity, increasing capacity if necessary and controlling the workload on the shop floor by appropriately releasing jobs.

Simulation experiments are performed to compare the proposed rule with the benchmark rules, as well as with other rules presented in previous studies. They led to the conclusion that considering the four decisions simultaneously can improve the job-shop delivery and workload related performance measures, and that the four decisions are not independent of one another. The simulation results also showed that PIOC is the best release rule in almost all instances (e.g., leading to a decrease of around 40% in the average time in the shop floor).

This paper has two main objectives: firstly, to propose and study the impact on job-shop performance of a new order release rule, and secondly, to explore and understand the relationships among these four control decisions.

The paper is structured as follows: in the next section we present the job-shop characteristics, and Section 3 the multiple decision-making design. The research methodology (simulation model, experimental factors, performance measures and data collection) is outlined in Section 4. In Section 5, the results of the main experiments are discussed and Section 6 contains the conclusion, which summarises the study and presents important observations regarding the results.

2 The job-shop production process

The job-shop is one of the most common production processes, found in a great number of manufacturing and service companies. The main characteristic of a job-shop is the production of a wide variety of goods in relatively low volumes. Its environment is particularly complicated, both from an external perspective (as the shop tries to meet orders for a variety of custom products, with very different timing requirements and quantities), and from an internal one (variety of products, tasks and operations) (Newman and Maffei, 1999).

All this has a significant impact on shop floor management, because different products generally have different routings or sequences of operations, which makes it difficult to predict demand (and, therefore, equipment utilisation) as well as bottlenecks. As a result, the work-in-process inventory is usually large, as well as the products' flow time. Since each order may be for a different product, equipment and production processes should be flexible. The workers must be specialised in terms of the necessary skills to process the jobs. These features reinforce the need for a system that controls the jobs entering (job releasing phase) and the in-process stage of the different tasks, in order to estimate, as accurately as possible, completion dates and production costs for the jobs at hand. The problem is made worse because such manufacturing companies often have to compete against others in order to win customers' orders (Hendry and Kingsman, 1989).

The definition of the capacity required for each resource, the scheduling of specific resources to meet each order, the determination of the best release date to avoid earliness and tardiness, and the assignment of due dates form a very complicated mathematical problem in even the smallest job-shops. This is why the general model of a job-shop can be seen as a network of machines, each with a set of jobs waiting to be processed. Haskose et al. (2002) described how job-shop environments may be formulated as an open network of queues.

3 The multiple decision-making design

In a broad sense, the production control system for a job-shop can be viewed as consisting of four stages. Associated with each stage is a control decision:

1 to accept or to reject an order

2 to define the order's due date

3 to release or not an order to the shop floor

4 to define the sequence in which the orders on the shop floor are processed.

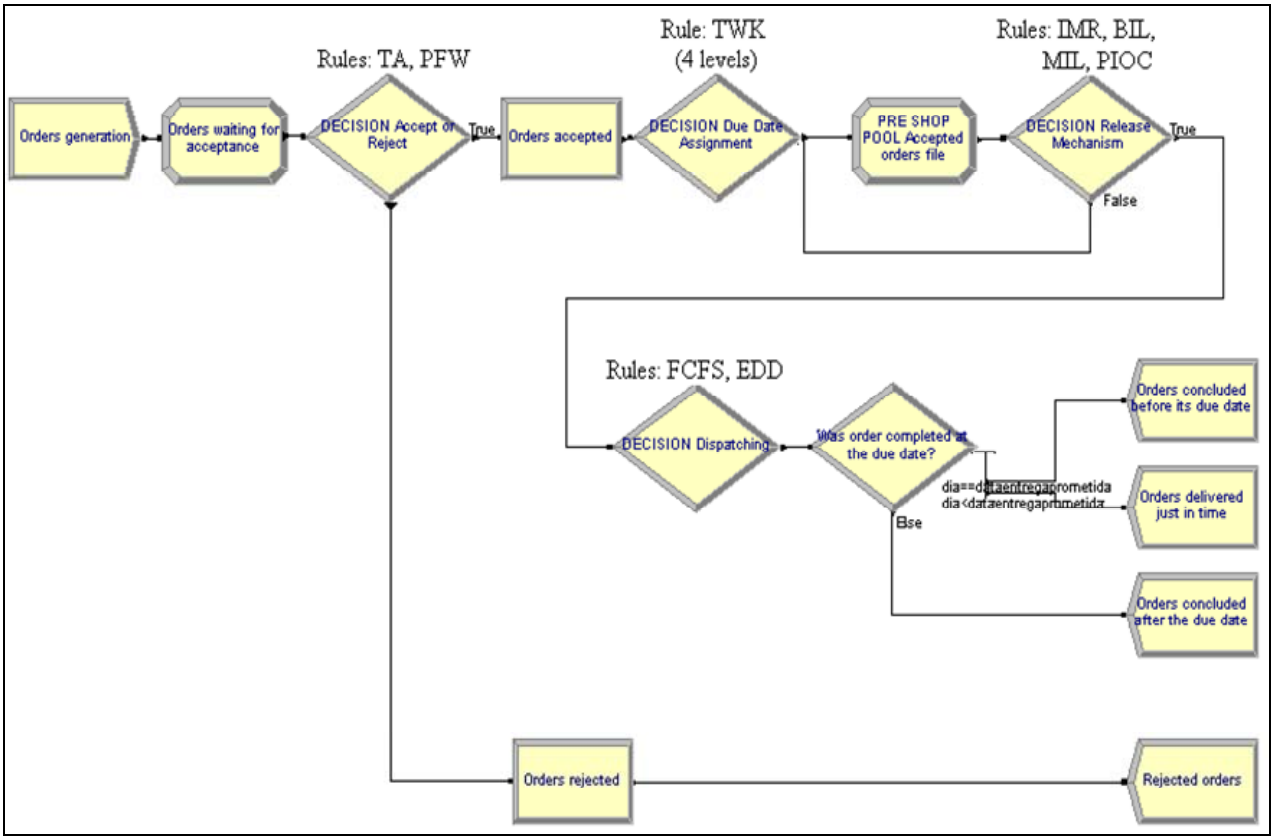
Figure 1 illustrates these four decisions and the relationships among them. Arena was the simulation software used in this paper.

Order arrivals follow a Poisson process with a mean of one arrival per hour. Besides the widespread use of the Poisson distribution, there is some theoretical evidence that it provides a good approximation of the arrival process (Albin, 1982). The routing for each order and the processing time at each station are generated at this stage. The routing is purely random: the number of operations follows a discrete uniform probability distribution between one and six machines. The order has an equal probability of having its first operation in any of the six machines, and of going to the others. After the definition of its characteristics, the job is placed in a pending orders file. Now, the company has to make the first decision: to accept or to reject the order, taking into account information such as price, due date, product specifications, quality levels, shop capacity, and so on.

The literature on order acceptance/rejection is quite recent. The common assumption of the early published literature is that all orders received by the shop are accepted, regardless of shop conditions or order characteristics. Philipoom and Fry (1992) were the first to relax this assumption: in times of high shop congestion it may be better to reject an order, allowing the costumer to look for another supplier, than to accept the order and deliver it late. The question is that when the shop floor is highly congested, accepting more orders may put the ability of the shop to fulfil the other orders' due dates at risk. Wester et al. (1992), Wouters (1997), Raaymakers et al. (2000), Ebadian et al. (2008), Oguz et al. (2010) and Slotnick (2011) are some of the papers where the possibility of rejection is considered.

The decision about the due date assignment is made after acceptance. There are several ways to determine the due date; in general, due date rules include information about the order (e.g. number of operations, processing time in each machine, orders arrival date) and the shop floor (workload in each machine, queue lengths, etc.). A lot of research has been made on this issue, alone or combined with other decision rules (e.g., Bertrand, 1983a, 1983b; Ragatz and Mabert, 1984; Bobrowski and Park, 1989; Ahmed and Fisher, 1992; Tsai et al., 1997; Sabuncuoglu and Karapinar, 2000).

Figure 1 Multiple decision-making scheme in software arena (see online version for colours)



After an order has been accepted, it is placed in an 'accepted orders file'. In this study it corresponds to the pre-shop pool file, since it is assumed that materials are available when the job is accepted. The order (or job) release decision determines which of the jobs eligible for release will actually be sent to the shop floor. The releasing function controls the level of work in process inventory. It usually takes into consideration some job features (like expected total processing time, due date, number of operations, routing, etc.) or/and the shop floor congestion (total workload, workload per machine, etc.). Information about the shop capacity is hardly ever considered, notwithstanding the fact that it represents a major element of the input/output control. The proposed job release mechanism includes this information. Several order release mechanisms are suggested and studied in the literature. An extensive list can be found in Bergamaschi et al. (1997) or Cigolini et al. (1998). Bertrand and Van de Wakker (2002) investigate the effects of a number of essentially different work order release policies. Moreover, emphasis is being made on integrating the order release mechanism in the planning system (Thurer et al., 2010).

Once a job is released to the shop floor, its progress is controlled by the dispatching rule. If more than one job is waiting to be processed in one machine, then it is necessary to decide which is to be processed next. When all processing has been completed, the job is placed in the finished-goods inventory until its delivery (due) date. Early deliveries are forbidden.

3.1 Accept or reject decision

The first decision to be made when a customer places an order is to accept or to reject the order. In this study, two rules are considered: TA and acceptance based on actual and future workload (PFW). The TA rule is used as a benchmark and the PFW rule was proposed by Nandi (2000). If the arriving order will not cause the workload limit to be exceeded it is accepted, otherwise it is rejected. The purpose of the rule is to keep the workload under control rather than allowing it to grow without limit.

3.2 Due date decision

The decision about the due date assignment is made immediately after acceptance. In this study only one rule is considered, because by varying the planning factor one can convert one rule into another. The total work content rule (TWK) defines the due date by adding a certain amount, representative of the time that the job needs to be completed, to the order's arrival date. This is done as follows:

$$DD_i = AD_i + k_{TWK} * P_i \,, \tag{1}$$

where

DD_i due date of job i

AD_i arrival date of job i

P_i processing time of job i

k_{TWK} planning factor.

To vary due date tightness, the value of the planning factor (k_{TWK}) in the due date formula is set at 4.6, 12.9, 38 and 77.7. These values were selected in such a way that, if the system were operated under the benchmark rules (TA, IMR and first-come-first-served), one would obtain approximately 50%, 25%, 10% and 5% of late jobs, respectively. When k_{TWK} = 4.6, the due date is defined in a very tight way, resulting, possibly, in extra pressure on production. On the other hand, when k_{TWK} = 77.7, the due date becomes loose, resulting in long lead times. Ragatz and Mabert (1984) used similar levels for the due date parameter, corresponding to tight, medium and loose due dates, resulting in 5%, 10% and 20% of late jobs, respectively.

3.3 Order release decision

After being accepted, orders may be released to the shop floor at any time. The order release mechanism determines when and which job (in the pre shop pool) should be released. Several rules have been studied and proposed in the literature, from very simple (like IMR) to sophisticated ones [e.g., backward infinite loading (BIL)]. In this study, four order release rules are simulated: IMR, BIL, modified infinite loading (MIL) and the PIOC. The IMR release rule is used as a benchmark (as soon as an order in accepted it is released to the shop floor). The BIL mechanism deducts the expected job flow time from the due date. The MIL rule was proposed by Ragatz and Mabert (1988). It is similar to the BIL rule (because it ignores the shop capacity) but has more information to predict the job flow time (it includes a planning factor about the actual work on the shop). MIL determines the job release date as follows:

$$RD_i = DD_i - k_{1MIL} * n_i - k_{2MIL} * Q_i \,, \tag{2}$$

where

RD_i release date of job i

DD_i due date of job i

n_i number of operations of job i

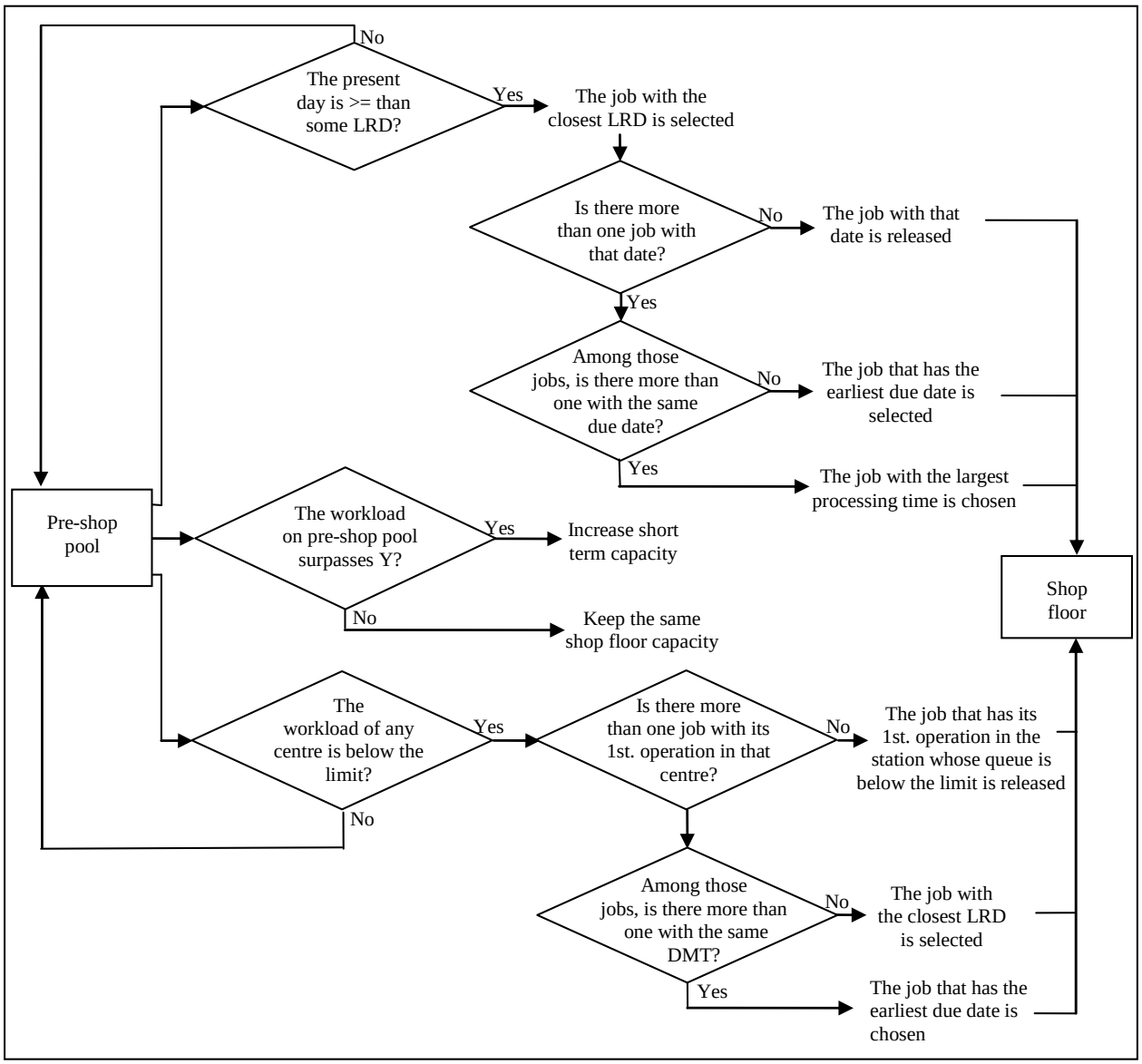
Q_i number of jobs in queue on job i routing

k_{1MIL}, k_{2MIL} planning factors.

The planning factors are appropriate constants, used to transform the job's number of operations in (a good prediction of) the job flow time, and the number of jobs in queue in the waiting time, respectively.

The PIOC rule includes information about the orders (due date, processing time, number of operations and routing), about the shop floor (workload in all machines), and information related to the shop capacity. Figure 2 shows how the PIOC mechanism works.

Figure 2 The PIOC mechanism



There is a job release whenever one of the following events occurs:

- the latest release date (LRD) of an order is reached
- the workload (corresponding to the jobs in queue) of any station goes below a pre-defined lower limit.

The LRD is computed as follows:

$$LRD_i = DD_i - P_i - k_{PIOC} * n_i, \quad (3)$$

where

LRD_i job i LRD,

DD_i due date of job i,

P_i processing time of job i

n_i number of operations of job i

k_{PIOC} planning factor.

The planning factor is a constant used to transform the job's number of operations in (a good prediction of) the job queue time in any machine.

In the first case, the job that has that date is released. If several jobs have the same LRD, the job that has the EDD is selected; if there is still a tie, the job with the largest processing time is chosen. In the second trigger mechanism, the job that has its first operation in the station whose queue is under the lower limit is released; if more than one job are tied, the job with the closest LRD is selected; if a tie still exists, the job with the EDD is chosen.

The output control is performed by setting an upper limit on the workload corresponding to the jobs in the

pre-shop pool and by computing the workload of the shop. If the workload (in the pre-shop pool) is above the defined upper limit, then the short-term capacity is increased at most 12.5% through the reallocation of operators or by working overtime. The value of 12.5% corresponds to an increase of one working hour per day in each machine.

3.4 Dispatching decision

Once a job is released to the shop floor, its progress through the shop is controlled by the dispatching rule. The dispatching rules considered are the first come, first served (FCFS) and the EDD. The FCFS does not consider job or shop information in setting priorities, and was selected as a benchmark. EDD rule uses the job's due date to compute its priority.

4 Research methodology

4.1 Simulation model

The simulation model was developed using the software Arena 7.1 (Kelton et al., 2004). The characteristics of the hypothetical job-shop are identical to those used by Melnyk and Ragatz (1989). The shop consists of six work centres operating 40 hours per week. Each work centre contains a single machine and can process only one job at a time. No preemptions are allowed. Job routings are random, with no return visits. The number of operations per order is uniformly distributed between one and six. Order arrivals follow a Poisson process with a mean of one per hour. The processing time distribution for all six machines is identical: exponential with a mean of 1.5 hours. These characteristics result in a steady state utilisation of 87.5% for each machine.

4.2 Experimental factors

In testing the acceptance/rejection rule and the releasing mechanism, it is important to assess whether their performance is affected by other factors in the planning system, such as the due date and the dispatching rules being used. Therefore, a full 2 × 4 × 4 × 2 experimental design was used. The two accept/reject rules, described above, were simulated in combination with four levels of due date tightness, the four order release rules presented and the two priority dispatching rules considered.

To vary due date tightness, the value of the planning factor (k_{TWK}) in the due date formula was set at 4.6, 12.9, 38 and 77.7 (see Section 3.2).

4.3 Performance measures

In order to assess the impact of the proposed rule, specific performance criteria were selected. Nine measures of performance were recorded in the simulation, broken down in two categories: due-date related and workload related measures.

1 due date related performance measures, related to costumer satisfaction and deliverability: mean tardiness, percent tardy, and mean absolute deviation

2 workload related performance measures, used to evaluate the impact of the load observed on the shop floor: mean queue time in the shop floor, mean total time in the system, and machine utilisation.

4.4 Data collection

During simulation runs data are collected with reference to the steady state of the system. In order to remove the effects of job-shop start-up, several runs of the simulation model were considered. Performance criteria and utilisation levels reached steady state after, approximately, 4,000 simulated hours. All statistics were set to zero and restarted after a warm-up period of 10,000 simulated hours. Statistics were, then, collected for 90,000 hours. Ten replications were performed for each set of experimental conditions.

5 Results of the main experiment

The results of the simulation runs are summarised in Tables 1 to 4, with Tables 1 and 2 containing the results for the due date related performance measures and Tables 3 and 4 including the results for the workload related performance measures. Each exhibit breaks down observations by accept/reject rule, due date tightness, release procedure and dispatch mechanism, and presents the mean values of the ten completed runs.

Table 1 presents the results for the mean tardiness. One can see that, in almost all combinations, the delay decreases when the due date becomes less tight. Moreover, when the EDD dispatching rule is used there is a decrease in the value of mean tardiness, whatever accept/reject or order release rule used. The use of a mechanism that limits order acceptance leads to a decrease in the mean tardiness. In Table 2, one can observe that there is a decrease in the proportion of orders delivered late when the due date increases (increase in k_{TWK}), when there is the possibility of rejecting orders, and when the EDD rule is used.

As expected, the presence of an accept/reject rule does have a significant effect on the percentage of rejected orders. However, this fact can be minimised if we combine its use with the PIOC order release mechanism (Figure 3).

Table 1 Mean tardiness (days)

A/R	*O/R*	*Dispatching rules*							
		FCFS				*EDD*			
	D/D	*4.6*	*12.9*	*38*	*77.7*	*4.6*	*12.9*	*38*	*77.7*
TA	IMR	3.8	3.7	3.6	3.5	1.9	1.1	1.1	1.1
	BIL	3.7	3.6	3.3	3.2	2.1	1.8	2.0	2.1
	MIL	3.9	4.2	3.8	3.3	2.2	1.9	2.1	2.5
	PIOC	2.5	2.8	2.5	2.3	1.7	12	2.1	3.4
PFW	IMR	1.4	1.4	1.4	1.4	1.1	1.1	1.1	1.1
	BIL	1.4	1.1	0.8	0.1	1.0	1.0	0.2	0.0
	MIL	1.3	1.0	0.4	0.1	1.0	1.0	0.3	0.0
	PIOC	1.4	1.4	1.4	1.5	1.1	1.1	1.0	2.0

Table 2 Percent tardy

A/R	*O/R*	*Dispatching rules*							
		FCFS				*EDD*			
	D/D	*4.6*	*12.9*	*38*	*77.7*	*4.6*	*12.9*	*38*	*77.7*
TA	IMR	0.52	0.26	0.10	0.05	0.14	0.01	0.000	0.00
	BIL	0.52	0.27	0.13	0.08	0.20	0.03	0.02	0.01
	MIL	0.52	0.30	0.15	0.09	0.24	0.05	0.03	0.03
	PIOC	0.36	0.13	0.05	0.03	0.02	0.00	0.00	0.01
PFW	IMR	0.17	0.06	0.02	0.01	0.01	0.00	0.00	0.00
	BIL	0.14	0.01	0.00	0.00	0.01	0.00	0.00	0.00
	MIL	0.12	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	PIOC	0.17	0.06	0.02	0.01	0.01	0.00	0.00	0.00

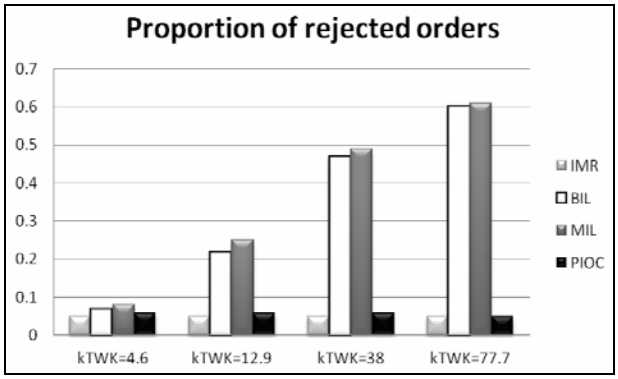
Table 3 Mean queue time in the shop floor

A/R	*O/R*	*Dispatching rules*							
		FCFS				*EDD*			
	D/D	*4.6*	*12.9*	*38*	*77.7*	*4.6*	*12.9*	*38*	*77.7*
TA	IMR	3.93	3.93	3.93	3.93	2.04	1.74	1.72	1.70
	BIL	3.87	3.93	3.90	3.92	2.29	2.54	3.17	3.39
	MIL	4.03	4.44	4.37	4.14	2.42	2.67	3.38	3.59
	PIOC	2.29	1.84	2.08	2.11	0.95	0.95	0.93	0.90
PFW	IMR	1.25	1.25	1.25	1.25	0.77	0.76	0.77	0.77
	BIL	1.11	0.31	0.06	0.03	0.71	0.25	0.06	0.02
	MIL	1.01	0.25	0.05	0.02	0.65	0.21	0.05	0.02
	PIOC	1.25	1.24	1.23	1.17	0.77	0.76	0.76	0.75

Table 4 Mean total time in the system

A/R	*O/R*	*Dispatching rules*							
		FCFS				*EDD*			
	D/D	*4.6*	*12.9*	*38*	*77.7*	*4.6*	*12.9*	*38*	*77.7*
TA	IMR	7.4	12.9	29.4	55.4	4.5	9.5	26.0	52.0
	BIL	7.2	11.6	26.9	52.5	4.8	9.5	25.7	51.6
	MIL	7.2	11.9	27.1	52.5	4.9	9.5	25.8	51.6
	PIOC	6.0	10.9	26.7	51.8	3.7	8.4	22.9	45.7
PFW	IMR	4.5	9.3	24.0	47.1	3.6	8.4	23.0	13.1
	BIL	4.3	6.2	10.0	14.7	3.5	6.1	10.0	14.7
	MIL	4.1	5.8	9.7	14.4	3.5	5.7	9.7	14.4
	PIOC	4.5	9.3	23.9	46.6	3.6	8.4	23.0	45.8

Figure 3 Percentage of rejected orders



Another important measure is the mean absolute deviation, because it determines how far delivery dates are from the promised due dates. From results analysis, we can notice that when due dates are tightly defined, there is not much difference among the values obtained from the order release rules. Nevertheless, if due dates are not tight, the rules BIL and MIL become better than the PIOC.

Concerning the results for the workload related performance measures, the measure 'mean wait time in pre shop pool' is affected by the consideration of the accept/reject decision. Once the acceptance limits are based on the total workload (due to orders accepted but not yet completed), when the quantity of work corresponding to the orders waiting in the pre shop pool reach that limit the new incoming orders are rejected (or placed for negotiation). When the PIOC rule is implemented, the time orders spend in the pre shop pool is very short. This is explained by the definition of the PIOC mechanism: the release can be initialised by the occurrence of one of two events: the LRD of an order is reached, or the workload (corresponding to the jobs in queue) of any station goes below a pre-defined lower limit.

Another way to analyse the performance of the PIOC rule is the time that, on average, an order spends in final products inventory. This time corresponds to the mean earliness. The simulation results show that when the EDD rule is employed, the mean earliness decreases, independently of the other decision rules.

Finally, we examine the total time in the system and the mean time in queue. Results show that both performance measures can be reduced if the PIOC rule is used, almost in all combinations (Tables 3 and 4).

5.1 Performance evaluation of the PIOC mechanism

The control mechanism proposed, PIOC, does have a better performance in the majority of the performance measures (except MAD) when due dates are not tightly defined. However, the situation of due date tightness is much closer to reality than the definition of long due dates. The implementation of the PIOC rule has a significant effect on the performance of the production system. It allows for a significant improvement in several performance measures, like the 'mean tardiness' (Figure 4) and the 'mean queue time on the shop floor' (Figure 5).

Figure 4 Mean tardiness (see online version for colours)

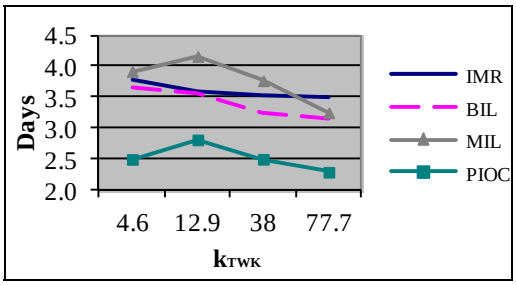
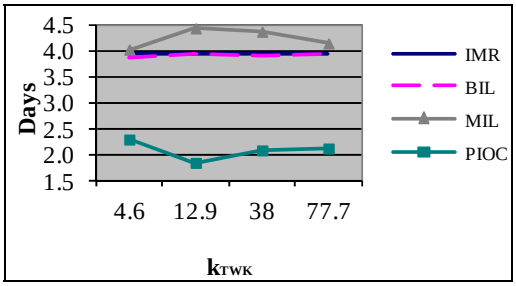


Figure 5 Mean queue time in the shop floor (see online version for colours)



6 Conclusions

A job shop is a transformation system characterised by the production of many different products, usually in small batches, according to specifications that are customer specific. Many studies have focused on the development of methodologies with the objective of improving the operational efficiency of the shop. Most of these studies provide planning and control methods for large firms (usually flow shops). However, in most countries, small firms (typically job shops) represent an important portion of the economic activity and contribute significantly to the overall production level.

The main goal of this research was to introduce a new release method as a way of controlling the workload of the job-shop and to complete the orders as close as possible to the due-dates. Moreover, a multiple decision-making scheme was proposed with the aim of planning and controlling operations, and improving delivery and workload related performance measures.

The interactions among the four groups of decisions (accept/reject orders, set due-dates, release orders, and dispatch) and their effects on the measures of performance (mean tardiness, mean flow time, capacity utilisation, etc.) were analysed, and the performance of the proposed order release mechanism (PIOC) was compared, using simulation, with the main rules presented in the literature. From this analysis, it can be seen that the proposed rule leads to a significant improvement of most operational performance measures.

References

Ahmed, I. and Fisher, W.W. (1992) 'Due date assignment, job order release and sequencing interaction in job shop scheduling', *Decision Sciences*, Vol. 23, No. 3, pp.633–647.

Albin, S.L. (1982) 'On Poisson approximations for superposition arrival processes in queues', *Management Science*, Vol. 28, No. 2, pp.126–137.

Bergamaschi, D., Cigolini, R., Perona, M. and Portioli, A. (1997) 'Order review and release strategies in a job shop environment: a review and classification', *International Journal of Production Research*, Vol. 35, No. 2, pp.399–420.

Bertrand, J.W. (1983a) 'The effects of workload dependent due-date on job shop performance', *Management Science*, Vol. 29, No. 7, pp.799–816.

Bertrand, J.W. (1983b) 'The use of workload information to control job lateness in controlled and uncontrolled release production systems', *Journal of Operations Management*, Vol. 3, No. 2, pp.79–92.

Bertrand, J.W. and Van de Wakker, A.M. (2002) 'An investigation of order release and flow time allowance policies for assembly job shops', *Production Planning and Control*, Vol. 13, No. 7, pp.639–648.

Bobrowski, P.B. and Park, P.S. (1989) 'Work release strategies in a dual resource constrained job shop', *Omega – The International Journal of Management Science*, Vol. 17, No. 2, pp.177–188.

Chiang, T.C. and Fu, L.C. (2007) 'Using dispatching rules for job shop scheduling with due date-based objectives', *International Journal of Production Research*, Vol. 45, No. 14, pp.3245–3262.

Cigolini, R., Perona, M. and Portioli, A. (1998) 'Comparison of order review and release techniques in a dynamic and uncertain job shop environment', *International Journal of Production Research*, Vol. 36, No. 11, pp.2931–2951.

Ebadian, M., Rabbani, M., Jolai, F., Torabi, S.A. and Tavakkoli-Moghaddam, R. (2008) 'A new decision-making structure for the order entry stage in make-to-order environments', *International Journal of Production Economics*, Vol. 111, No. 2, pp.351–367.

Ebben, M.J., Hans, E.W. and Olde Weghuis, F.M. (2005) 'Workload based order acceptance in job shop environments', *OR Spectrum*, Vol. 27, No. 1, pp.107–122.

Fernandes, N.O. and Carmo-Silva, S. (2011) 'Order release in a workload controlled flow-shop with sequence-dependent set-up times', *International Journal of Production Research*, Vol. 49, No. 8, pp.2443–2454.

Foreest, N.D., van, Wijngaard, J. and van der Vaart, T. (2010) 'Scheduling and order acceptance for the customised stochastic lot scheduling problem', *International Journal of Production Research*, Vol. 48, No. 12, pp.3561–3578.

Fredendall, L.D., Ojha, D. and Patterson, J.W. (2010) 'Concerning the theory of workload control', *European Journal of Operational Research*, Vol. 201, No. 1, pp.99–111.

Gordon, V.S., Proth, J-M. and Chu, C. (2002) 'Due date assignment and scheduling: SLK, TWK and other due date assignment models', *Production Planning & Control*, Vol. 13, No. 2, pp.117–132.

Haskose, A., Kingsman, B.G. and Worthington, D. (2002) 'Modelling flow and jobbing shops as a queueing network for workload control', *International Journal of Production Economics*, Vol. 78, No. 3, pp.271–285.

Hendry, L.C. and Kingsman, B.G. (1989) 'Production planning systems and their applicability to make-to-order companies', *European Journal of Operational Research*, Vol. 40, No. 1, pp.1–15.

Hendry, L.C. and Wong, S.K. (1994) 'Alternative order release mechanisms: a comparison by simulation', *International Journal of Production Research*, Vol. 32, No. 12, pp.2827–2843.

Hendry, L.C., Land, M., Stevenson, M. and Gaalman, G. (2008) 'Investigating implementation issues for workload control (WLC): a comparative case study analysis', *International Journal of Production Economics*, Vol. 112, No. 1, pp.452–469.

Henrich, P., Land, M., Gaalman, G. and Van Der Zee, D-J. (2004) 'Reducing feedback requirements of workload control', *International Journal of Production Research*, Vol. 42, No. 2, pp.5235–5252.

Holthaus, O. and Ziegler, H. (1997) 'Improving job shop performance by coordinating dispatching rules', *International Journal of Production Research*, Vol. 35, No. 2, pp.539–549.

Hsu, S.Y. and Sha, D.Y. (2004) 'Due date assignment using artificial neural networks under different shop floor control strategies', *International Journal of Production Research*, Vol. 42, No. 9, pp.1727–1745.

Jayamohan, M.S. and Rajendran, C. (2000) 'New dispatching rules for shop scheduling: a step forward', *International Journal of Production Research*, Vol. 38, No. 3, pp.563–586.

Kelton, W.D., Sadowski, R.P. and Sturrock, D.T. (2004) *Simulation with Arena*, 3rd ed., McGraw-Hill, New York.

Lu, H.L., Huang, G.Q. and Yang, H.D. (2011) 'Integrating order review/release and dispatching rules for assembly job shop scheduling using a simulation approach', *International Journal of Production Research*, Vol. 49, No. 3, pp.647–669.

Melnyk, S.A. and Ragatz, G.L. (1989) 'Order review/release: research issues and perspectives', *International Journal of Production Research*, Vol. 27, No. 7, pp.1081–1096.

Moreira, M.R.A. and Alves, R.A.F.S. (2009) 'A methodology for planning and controlling workload in a job-shop: a four-way decision-making problem', *International Journal of Production Research*, Vol. 47, No. 10, pp.2805–2821.

Nandi, A. (2000) 'Input control strategies for make-to-order manufacturing systems via order acceptance/rejection', PhD thesis, University of Calgary.

Nandi, A. and Rogers, P. (2004) 'Using simulation to make-to-order acceptance/rejection decision', *Simulation*, Vol. 80, No. 3, pp.131–142.

Newman, W.R. and Maffei, M.J. (1999) 'Managing the job shop: simulating the effects of flexibility, order release mechanisms and sequencing rules', *Integrated Manufacturing Systems*, Vol. 10, No. 5, pp.266–275.

Oguz, C., Sibel Salman, F. and Bilginturk Yalcin, Z. (2010) 'Order acceptance and scheduling decisions in make-to-order systems', *International Journal of Production Economics*, Vol. 125, No. 1, pp.200–211.

Philipoom, P.R. and Fry, T.D. (1992) 'Capacity-based order review/release strategies to improve manufacturing performance', *International Journal of Production Research*, Vol. 30, No. 11, pp.2559–2572.

Raaymakers, W.M., Bertrand, J.W. and Fransoo J.F. (2000) 'The performance of workload rules for order acceptance in batch chemical manufacturing', *Journal of Intelligent Manufacturing*, Vol. 11, No. 2, pp.217–228.

Ragatz, G.L. and Mabert, V.A. (1984) 'A simulation analysis of due date assignment rules', *Journal of Operations Management*, Vol. 5, No. 1, pp.27–39.

Ragatz, G.L. and Mabert, V.A. (1988) 'An evaluation of order release mechanisms in a job-shop environment', *Decision Sciences*, Vol. 19, No. 1, pp.167–189.

Raghu, T.S. and Rajendran, C. (1995) 'Due-date setting methodologies based on simulated annealing – an experimental study in a real-life job shop', *International Journal of Production Research*, Vol. 33, No. 9, pp.2535–2555.

Reeja, M.K. and Rajendran, C. (2000a) 'Dispatching rules for scheduling in assembly jobshops – Part 1', *International Journal of Production Research*, Vol. 38, No. 9, pp.2051–2066.

Reeja, M.K. and Rajendran, C. (2000b) 'Dispatching rules for scheduling in assembly jobshops – Part 2', *International Journal of Production Research*, Vol. 38, No. 10, pp.2349–2360.

Riezebos, J., Korte, G.J. and Land, M.J. (2003) 'Improving a practical DBR buffering approach using workload control', *International Journal of Production Research*, Vol. 41, No. 4, pp.699–712.

Roderick, L.M., Phillips, D.T. and Hogg, G.L. (1992) 'A comparison of order release strategies in production control systems', *International Journal of Production Research*, Vol. 30, No. 3, pp.611–627.

Sabuncuoglu, I. and Karapinar, H.Y. (1999) 'Analysis of order review/release problems in production systems', *International Journal of Production Economics*, Vol. 62, No. 3, p.2.

Sabuncuoglu, I. and Karapinar, H.Y. (2000) 'A load-based and due-date-oriented approach to order review/release in job shops', *Decision Sciences*, Vol. 31, No. 2, pp.413–447.

Sawik, T. (2009) 'Multi-objective due-date setting in a make-to-order environment', *International Journal of Production Research*, Vol. 47, No. 22, pp.6205–6231.

Shabtay, D. (2010) 'Scheduling and due date assignment to minimize earliness, tardiness, holding, due date assignment and batch delivery costs', *International Journal of Production Economics*, Vol. 123, No. 1, pp.235–342.

Slotnick, S.A. (2011) 'Order acceptance and scheduling: a taxonomy and review', *European Journal of Operational Research*, Vol. 212, No. 1, pp.1–11.

Stevenson, M. (2006) 'Refining a workload control (WLC) concept: a case study', *International Journal of Production Research*, Vol. 44, No. 4, pp.767–790.

Stevenson, M. and Hendry, L.C. (2007) 'Improving supply chain integration using a workload control concept and web-functionality', *Production Planning & Control*, Vol. 18, No. 2, pp.142–155.

Stevenson, M. and Silva, C. (2008) 'Theoretical development of a workload control methodology: evidence from two case studies', *International Journal of Production Research*, Vol. 46, No. 11, pp.3107–3131.

Thurer, M., Silva, C. and Stevenson, M. (2010) 'Workload control release mechanisms: from practice back to theory building', *International Journal of Production Research*, Vol. 48, No. 12, pp.3593–3617.

Thurer, M., Silva, C. and Stevenson, M. (2011) 'Optimising workload norms: the influence of shop floor characteristics on setting workload norms for the workload control concept', *International Journal of Production Research*, Vol. 49, No. 4, pp.1151–1171.

Tsai, C-H., Chang, G-T. and Li, R-K. (1997) 'Integrating order release control with due-date assignment rules', *International Journal of Production Research*, Vol. 35, No. 12, pp.3379–3392.

Vig, M.M. and Dooley, K.J. (1991) 'Dynamic rules for due-date assignment', *International Journal of Production Research*, Vol. 29, No. 7, pp.1361–1378.

Vinod, V. and Sridharan, R. (2011) 'Simulation modeling and analysis of due-date assignment methods and scheduling decision rules in a dynamic job shop production system', *International Journal of Production Economics*, Vol. 129, No. 1, pp.127–146.

Weng, M.X., Wu, Z., Qi, G. and Zheng, L. (2008) 'Multi-agent-based workload control for make-to-order manufacturing', *International Journal of Production Research*, Vol. 46, No. 8, pp.2197–2213.

Wester, F.A., Wijngaard, J. and Zijm, W.H. (1992) 'Order acceptance strategies in a production-to-order environment with setup times and due-dates', *International Journal Production Research*, Vol. 30, No. 6, pp.1313–1326.

Wight, O. (1970) 'Input/output control: a real handle on lead time', *Production and Inventory Management Journal*, Vol. 11, No. 3, pp.9–30.

Wisner, J.D. (1995) 'A review of the order release policy research', *International Journal of Operations & Production Management*, Vol. 15, No. 6, pp.25–40.

Wouters, M.J. (1997) 'Relevant cost information for order acceptance decisions', *Production Planning and Control*, Vol. 8, No. 1, pp.2–9.

Yang, K.K. and Sum, C.C. (1994) 'A comparison of job shop dispatching rules using a total cost criterion', *International Journal of Production Research*, Vol. 32, No. 4, pp.807–821.