Performance Analysis of Job-Shop Production Systems under Different Order Release Control Parameters

Paulo S. A. Sousa and Maria R. A. Moreira

Abstract—**Controlling the flow of materials inside job-shops involves several decisions such as the acceptance or rejection of an incoming order, the order's due date definition, the releasing and the dispatching of the job. This study applies a multiple decision-making scheme involving these four decision phases to examine the sensitivity of job-shop performance to different order release parameters. The performance criteria of shop workload and order delivery were collected to demonstrate the influence of the most significant order release parameters: the queue workload limit and the planning parameter of the latest release date. The influence of each parameter is evaluated by computational simulations. The way we compute the machine workload limit affects not only the workload but also delivery performance measures. However, surprisingly, the latest release date has not a significant impact on shop-floor performance measures. The effect of the queue workload limit in an input-output control mechanism on delivery and workload related performance measures had not been studied up to date. Neither any analysis had investigated the influence of the latest release date calculus on the performance of the job-shop.**

Index Terms — **Decision-making, Input-output control, Job-shop, Workload-control.**

I. INTRODUCTION

Scheduling of job-shops has been extensively researched over the last three decades and continues attracting the interest of both academic researchers and practitioners. The production control system for a job-shop involves several decisions: the acceptance or rejection of an incoming order, the order's due date definition, the releasing and the dispatching of the job. Despite a clear early concern about workload control [1], input-output control with the four decisions taken into consideration simultaneously is quite recent. The first basic research model considers a job as a sequence of operations to be processed with a limited number of machines.

As the job proceeds along the shop-floor, it encounters other jobs competing for the same resources and queues grow at each machine. Most of research has concentrated on developing mechanisms to prioritize these jobs in order to optimize some shop performance measures. This control decision often is referred to as "dispatching". (See, e.g., [2]-[7].)

A second wave of research has concentrated efforts to optimize due date assignment decisions. In consequence, a large amount of rules have been proposed in literature, aiming to define the promised due date the closest possible to the real due date. (See, e.g., [8]-[13].)

More recently, the topic of order releasing decision has received more attention. Incoming jobs are usually registered in some sort of back order file (frequently called pre-shop pool). Jobs are then released by the adopted mechanism, trying to guarantee completion within the time available before the due date. (For a complete review of order release mechanisms, we refer, e.g., to Wisner [14], Bergamaschi et al. [15], Cigolini et al. [16] and Sabuncuoglu and Karapinar [17].)

The order acceptance decision has been almost ignored, since typically all incoming orders are accepted. The optimality of this procedure has, however, been disputed by the recent literature. (See, e.g., [18]-[20].)

This article adopts a decision-making scheme involving the four decision phases presented to examine the sensitivity of job-shop performance to different order release parameters. Actually, a large number of parameters must be specified to support the release decision within the manifold decision-making process.

This paper aims at improving the basis for setting parameters, showing their impact on job-shop performance and analysing sensitivity. Specifically, this paper has two main objectives: firstly, to study the sensitivity of the shop performance to different values of the machine workload limit; and secondly, to identify the critical elements for setting the latest release date, showing the impact of this parameter on several performance measures.

Previous research has shown the influence of the planned centres throughput times and the time limit on the timing and balancing functions of release, and the effect of the type and level of workload on logistic performance ([21]-[23]). Nevertheless, the consequences of the queue workload limit in

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an input-output control mechanism on some delivery and workload related performance measures had not been studied before us, up to our best knowledge. Neither any analysis has been conducted about the influence of the latest release date (the way it is calculated) on the performance of the job-shop.

The remainder of the paper is structured as follows. In section II, we present the decision making scheme and the rules utilized in each decision stage. The following section describes the research methodology (simulation model, experimental design, performance measures and data collection). The results of the main experiment are presented in section IV. Finally, some concluding remarks are discussed and future research direction outlined in section V.

II. THE DECISION MAKING SCHEME AND DECISION RULES

In this section the global decision making process and the decision rules are detailed.

The production control system comprises four sequential stages:

1) acceptance, negotiation or rejection of an order;
2) due date assignment;
3) order release; and
4) order dispatch.

The Fig. 1 illustrates these four decisions and the relationships among them, using Arena software layout. Arena was the software used in simulations of this paper.

A. Acceptance, negotiation or rejection of an order

The accept/negotiate/reject decision is made when a customer places an order. In this paper three rules are considered:

- the total acceptance (TA), used as a benchmark;
- the present and future workload (PFW), developed by Nandi [24]; and
- the due date negotiation (DDN), introduced by Moreira and Alves [25].

The reason why using those (non-benchmark) two rules is that both incorporate order and/or shop information to reject or accept an order: the first one takes into consideration only the workload level while the second one cares about both the workload level and the due date.

B. Due date assignment

The decision about the due date assignment is made together with the acceptance decision, and a negotiation with the customer may take place. We consider only one due date assignment rule because, by varying the planning parameter, it is possible reverting one rule into another one. We specify four levels regarding the due date assignment tightness. The total work content (TWK) rule defines the due date by adding a certain amount, representative of the job completion time, to the order's arrival date.

C. Order release

After an order has been accepted, it is placed in a pre-shop pool file. The order release rule establishes when a release must take place and which of the orders will be released to the shop-floor. To test the sensitivity of the shop performance to different values of the order release parameters, we consider a mechanism that takes into consideration the input, in terms of orders released to the shop-floor, and the output, in terms of capacity of the set of working machines. Actually, the input-output control is at the heart of the workload control.

The order release mechanism used considers not only the shop workload but also the shop capacity and was proposed by Moreira [26].

The planned input-output control (PIOC) rule integrates information about the orders (due date, processing time, number of operations and routing), regarding the shop-floor (workload in all machines) and also information related with the shop capacity. The main idea of this release mechanism 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.

A job release is triggered whenever one of the following events occurs:

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

In the first case, the job that has that date is released. If several jobs have the same LRD, the job that has the earliest due date is selected; if there is still a tie, the job with the largest processing time is chosen.

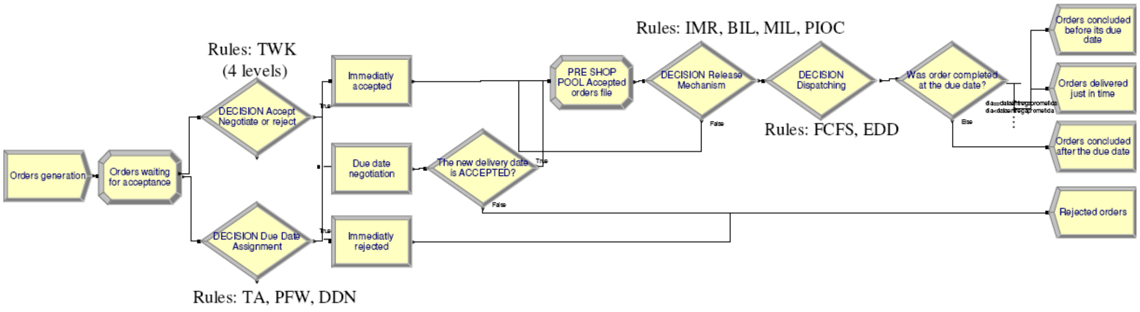

Fig. 1 – Multiple decision-making process in software Arena

The latest release date is computed in the following way:

$$\mathrm{LRD_i} = \mathrm{DD_i} - \mathrm{P_i} - \mathrm{k_{PIOC}} \times \mathrm{n_i}\ , \qquad (1)$$

where: $\mathrm{LRD_i}$: job i latest release date;
$\mathrm{DD_i}$: due date of job i;
$\mathrm{P_i}$: processing time of job i;
$\mathrm{n_i}$: number of operations of job i;
$\mathrm{k_{PIOC}}$: planning factor.

In the second trigger mechanism, the job that has its first operation in the centre whose queue is below 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 earliest due date 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 considering the possibility of overtime work. As the capacity of the shop-floor is established by the machines working hours, the rise in capacity has to be made through the amplification of the working period. The value of 12,5% corresponds to an increase of one working hour per day, in each machine.

D. Order dispatching

Once a job is released to the shop-floor, its progress is controlled by the selected dispatching rule. We consider two dispatching rules:

- the first-come-first-served rule, used as a benchmark; and
- the earliest due date (EDD) rule.

When the whole processing has been completed, the order is placed in a finished-goods inventory until delivery (at the due date).

III. EXPERIMENTAL CONDITIONS

A. Simulation model

The simulation model was developed using the software Arena 7.1. [27]. The characteristics of our job-shop are identical to those used by Melnyk and Ragatz [28]. The shop consists of six work centres operating 40 hours per week. Each work centre contains a single machine, which 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 1 and 6. Order arrivals follow a Poisson process with a mean of 1 order 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 utilization rate of 87,5% for the shop and for each work centre.

B. Experimental factors

We use a full $3 \times 4 \times 1 \times 2$ experiment design as a benchmark: the three accept/reject rules above described were simulated in combination with four levels of due date tightness, the order release rule presented and the two priority dispatching rules just displayed.

To vary due date tightness, the value of the planning factor ($\mathrm{k_{TWK}}$) in the due date formula was set at 4,6, 12,9, 38 and 77,7. The value of these parameters was selected in such a way that if the system were operated under the benchmark rules (total acceptance, immediate release and first-come-first-served), the system would imply approximately 50%, 25%, 10% and 5% of late jobs, respectively. When $\mathrm{k_{TWK}}$=4,6, the due date is defined in a very tight way, resulting, possibly, in extra pressure on production. At the other extreme, when $\mathrm{k_{TWK}}$=77,7, the due date becomes too loose, resulting in long lead times. Ragatz and Mabert [11] 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.

In testing the sensitivity of job-shop performance to different order release parameters, we use a full $3 \times 4 \times 2 \times 2$ experimental design: the three accept/reject rules are simulated in combination with four levels of due date tightness, two priority dispatching rules and two levels for the queue workload limit, Q_{min} (Q_{min}=0 and Q_{min}=5). Q_{min}=0 corresponds to the situation where a job release occurs when no jobs are in the queue. In the other case, when the jobs in any queue have a workload corresponding to 5 days of work, a release should take place.

The sensitivity of job-shop performance to the planning parameter of the latest release date (computed in Eq. (1)) is also tested. Here, we use a 48 experimental design: the 3 accept/reject rules are simulated in combination with 4 levels of due date tightness, the 2 priority dispatching rules and 2 levels for the planning parameter of the latest release date (k_{CIOP}=3,8 and k_{CIOP}=5). If k_{CIOP} is equal to 3,8 days, the LRD is computed in a tighter way than when k_{CIOP} =5 days.

C. Performance measures

In order to assess the impact of the decision rules on the manufacturing performance, and the sensitivity of the shop performance to different order release parameters, specific performance criteria must be selected. Six measures of job-shop performance are considered. These measures can be grouped in two categories:

(i) Due date related performance measures, which are indicative of customer satisfaction and deliverability: mean tardiness and percent tardy.

(ii) Workload related performance measures that are used to evaluate the impact of the workload on the shop-floor: mean earliness (mean waiting time in the final products inventory), mean total time in the system, mean queue time in the shop-floor and machine percent utilization.

D. Data collection

During simulation runs, data are collected with reference to the steady state of the system. In order to remove the effects of the warm-up period, several runs of the simulation model were made to see when the steady state was reached. All statistics were set to zero and restarted after a warm-up period of 10.000 simulated hours. The statistics were, then, collected for a period of 90.000 hours. Ten replications were performed for each set of experimental conditions. The data collection conditions are the same used by Melnyk and Ragatz [28] and Hendry and Wong [29], and based on the recommendations of Law and Kelton [30].

IV. ANALYSIS OF THE RESULTS

In this section, we present the main results of the experiments. The analysis is divided in two parts: the first one discusses whether the *Qmin* parameter influences the performance of the job-shop, while the second one presents the main results of the sensitivity analysis to the k_{CIOP} parameter.

Tables I to IV show the simulation results for the most relevant performance measures. Each table displays observations by accept/reject rule, due date tightness, dispatch mechanism and the levels of *Qmin* for the mean values of the completed simulation runs.

To analyse the sensitivity of the selected performance measures to different values of the queue workload limit, all the other parameters are kept fixed. As mentioned earlier, *Qmin* ranges from 0 to 5. To see whether the variations are caused by the use of different rules or are due to the workload limit variation, we present several tables, each one exhibiting all combinations of decision rules.

Table. I – Mean tardiness (days)

A/R		**Dispatching rules**							
		FCFS				**EDD**			
	kTWK	**4,6**	**12,9**	**38**	**77,7**	**4,6**	**12,9**	**38**	**77,7**
AT	*Qmin*=0	2,50	2,80	2,50	2,30	1,70	1,20	2,10	3,40
	Qmin=5	3,19	3,15	3,17	3,09	1,12	1,07	1,03	1,06
PFW	*Qmin*=0	1,40	1,40	1,40	1,50	1,10	1,10	1,00	2,00
	Qmin=5	1,42	1,43	1,42	1,37	1,04	1,04	1,09	1,00
DDN	*Qmin*=0	2,50	3,10	2,90	2,60	1,40	1,10	1,10	2,50
	Qmin=5	2,84	3,04	3,24	2,78	1,49	3,06	4,95	3,87

Table II – Percent Tardy

A/R		**Dispatching rules**							
		FCFS				**EDD**			
	kTWK	**4,6**	**12,9**	**38**	**77,7**	**4,6**	**12,9**	**38**	**77,7**
AT	*Qmin*=0	0,36	0,13	0,05	0,03	0,02	0,00	0,00	0,01
	Qmin=5	0,46	0,23	0,09	0,05	0,02	0,00	0,00	0,00
PFW	*Qmin*=0	0,17	0,06	0,02	0,01	0,01	0,00	0,00	0,00
	Qmin=5	0,17	0,06	0,02	0,01	0,01	0,00	0,00	0,00
DDN	*Qmin*=0	0,37	0,16	0,06	0,03	0,06	0,00	0,00	0,00
	Qmin=5	0,45	0,23	0,09	0,04	0,06	0,00	0,00	0,00

Table III – Mean earliness (days)

A/R		**Dispatching rules**							
		FCFS				**EDD**			
	kTWK	**4,6**	**12,9**	**38**	**77,7**	**4,6**	**12,9**	**38**	**77,7**
AT	*Qmin*=0	2,9	8,0	23,8	48,8	2,1	6,9	21,4	44,1
	Qmin=5	2,9	8,3	24,7	50,7	2,1	6,9	21,4	44,1
PFW	*Qmin*=0	2,7	7,5	22,0	44,8	2,3	7,1	21,6	44,5
	Qmin=5	2,7	7,5	22,1	45,4	2,3	7,1	21,7	44,7
DDN	*Qmin*=0	8,3	9,6	25,1	50,7	7,0	8,8	24,2	50,0
	Qmin=5	11,1	10,3	25,1	51,1	7,1	8,5	24,2	49,9

Table IV – Mean total time in the system (days)

A/R		**Dispatching rules**							
		FCFS				**EDD**			
	kTWK	**4,6**	**12,9**	**38**	**77,7**	**4,6**	**12,9**	**38**	**77,7**
AT	*Qmin*=0	6,0	10,9	26,7	51,8	3,7	8,4	22,9	45,7
	Qmin=5	6,9	12,4	28,9	54,9	3,7	8,4	22,9	45,6
PFW	*Qmin*=0	4,5	9,3	23,9	46,6	3,6	8,4	23,0	45,8
	Qmin=5	4,5	9,3	24,0	47,2	3,6	8,4	23,1	46,0
DDN	*Qmin*=0	11,7	13,1	28,8	54,3	9,8	11,3	26,7	52,4
	Qmin=5	15,8	14,6	29,6	55,3	10,0	11,0	26,7	52,3

It can be seen that when the workload limit (corresponding to the jobs in the queue) is set at 0, the mean tardiness, the percent tardy, the mean earliness and the total time in the system assume lower values than when a release occur after the queue in any station has gone below 5 days in almost all combinations. The only consistent exception is the EDD rule where the values of the measures for *Qmin*=0 are slightly higher than for *Qmin*=5. The results when FCFS rule was used were not expected, as an early release could be seen as a way to avoid tardiness. Moreover, it was not expected that early job releases increase the mean total time in the system. It has been observed in several studies (e.g., [31] and [32]) that the overall time in the system may not be reduced by the existence of a release rule, even though some shop performance measures such as work-in-process can be improved. And, in some cases, the most effective strategy to optimize due-date related performance measures such as mean tardiness is to release the jobs to the floor as soon as they are accepted. However, this is completely contrary to what is expected from an order release mechanism. It is considered by the literature as a paradox that can be partly explained if congestion of the shop-floor is properly modelled (for more details, see [31] or [32]).

To analyse the sensitivity of the selected performance measures to different values of the k_{PIOC} parameter, all the other parameters are kept fixed.

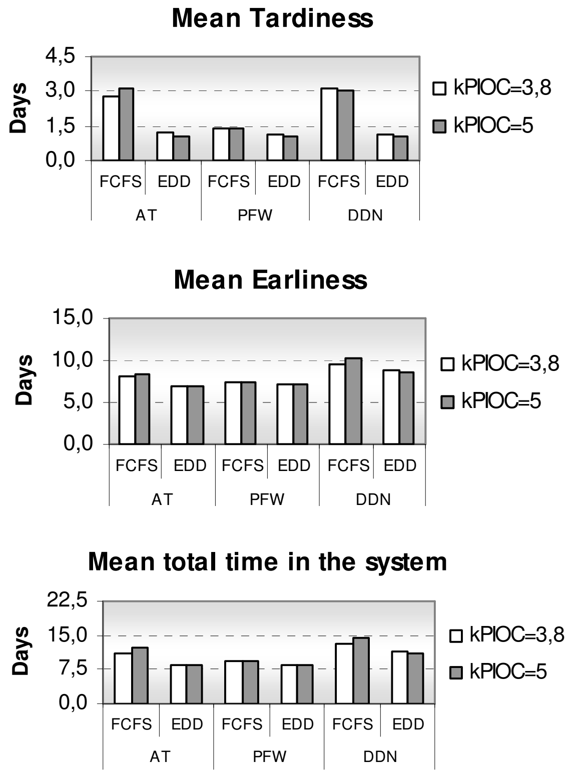

Fig. 2 – k_{PIOC} influence on some performance measures

Fig. 2 shows the results obtained for the three more relevant performance measures, when we vary the planning parameter of the LRD. Each sub-figure plots the results for different combination of decision rules, to test if the variations are due to the use of distinctive rules or are due to the variation of the planning parameter. We can see that there are small variations on the performance measures. The graphic bars corresponding to the two k_{PIOC} levels are almost at the same level for all rules combinations and for the various performance measures. Thus we can conclude that the influence of the k_{PIOC} parameter is limited. This result was not totally expected because an increase on k_{PIOC} leads to a decrease in the LRD (see Eq. (1)). If jobs are released earlier than in the original situation, one could expect that the time they need to be concluded is the same or shorter. But we see that there are combinations (AT-FCFS, EDD-FCFS) where it does not occur.

V. CONCLUDING REMARKS AND FUTURE RESEARCH

This paper aims at improving the basis for setting parameters on the order release rules, showing the impact of two parameters on performance and analysing the sensitivity of those measures. A simulation study shows that the release methods are influenced by the workload limit in use but not by the latest release date planning parameter.

Further research should look at robustness with respect to other order release parameters and other decision rules parameters (namely, accept/reject rules or dispatching mechanisms).

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