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Time in System Performance of Workload Control Approaches

N.O. Fernandes and S. Carmo-Silva[1]
[1]Dept. of Production and Systems, University of Minho,
Campus de Gualtar, 4710-057, Braga- Portugal.
scarmo@dps.uminho.pt

ABSTRACT

This paper compares and discusses two Workload Control (WLC) approaches in terms of the time in system performance, when facing changes in the manufacturing environment. Changes that are studied result from varying both, the coefficient of variation of the inter-arrival time of orders and machine availability. This is dependent on machine breakdowns. The paper seeks to aid industrial managers to choose between two well known WLC approaches. A simulation study indicates that the WLC approaches considered perform differently and that the relative performance between them does not change when manufacturing conditions change.

INTRODUCTION

For manufacturing companies to stay competitive in the global market of today, manufacturing strategies have to be focused on speed of response to customer requirements. This means short delivery times, on time deliveries and flexibility to customer requirements.

Workload Control (WLC) is a production, planning and control (PPC) concept that has received much attention in recent years [1]. It is suitable for job shops in the make-to-order (MTO) manufacturing environment [2]. Its main principle is to keep the length of queues on the shop floor at appropriate levels to meet promised deliver dates, taking into account the system capacity and capabilities. If these queues are kept short and stable, then waiting times and therefore throughput times, will be controlled [3]. It is possible to identify three hierarchical levels, related with stages in the order flow, at which the control of these queues can be attempted, namely order entry, order release and dispatching [4]. At each level, a decision must be made relatively to the orders allowed to proceed to the next stage and whether this requires capacity adjustments.

Order release has been described as a main control element within WLC. The concept behind controlled release is to release orders selectively, at the right moments in time, to improve shop performance. An order release procedure is used to determine the moment and the orders to release into the shop floor. The orders generated by a planning system or arriving directly from customers over time, are gathered in a pre-shop pool and are only released if they fit norms, usually defined in time units, of the required capacity groups (e.g. work centres). This means that the decision to release an order is based on its influence to the current shop floor situation.

The complexity of controlled release results from the routing variety, particularly in job shops. Orders giving input to the direct load of a work centre (i.e. the load that results from jobs queuing and being processed at the work centre) may come either directly from release or indirectly from any other work centre. Two traditional approaches to WLC are:

(A) The WLC concept developed in Hannover [5] that distinguishes between direct and upstream workload (from jobs queuing at upstream work centres), and estimates the input from jobs upstream to the direct load of a work centre. The estimated direct loads, based on the probability of the job reaching the work centre in the planning period, are subjected to norms.

(B) The WLC concepts developed in Eindhoven [6] and Lancaster [7] that aggregates the direct and the upstream workload of a work centre by adding them. The aggregated loads are subjected to norms.

Previous research has pointed at strengths and weaknesses of each WLC approach. However, the robustness of these approaches, expressing their performance ability under dynamic manufacturing environments, hardly received attention in the literature.

This paper compares and discusses the two Workload Control approaches above described, in terms of time in system performance, when facing changes in the manufacturing environment. Changes that are studied result from varying both the coefficient of variation of the inter-arrival time of orders and machine availability. This is dependent on machine breakdowns.

SIMULATION MODEL

To investigate the effects of the two WLC approaches discussed in the previous section, an Arena® simulation model was developed. A job shop was modelled under the following assumptions:

1. The shop has six capacity groups each one containing a single machine, M1 to M6.
2. A machine can only perform one operation at a time on any job and an operation of a job can be performed by only one machine at a time.
3. Machines are subjected to breakdowns.
4. Operations are processed without pre-emption.
5. Job processing cannot be started at a machine before it is finished at the previous one.
6. The transportation time between machines is assumed to be zero.
7. Set-up time of each job on each machine is sequence-dependent.
8. Each capacity group has a limited buffer capacity, i.e. a limit to the workload allowed to be released to the capacity group;
9. Orders arrive continuously to the production system.

Due dates of orders are set externally and known upon arrival. Four types of jobs are considered, each of which with an equal probability of being assigned to an arriving order. Orders arrive to the production system over time and flow directly into the pre-shop pool. At release time t, orders in the pool are selected for eventual release, accordingly to its planned release date. An order is released only if, as a consequence of such the accounted workload of each capacity group in its routing do not exceed its workload norm (i.e. an upper workload bound). If one or more workload norms are exceeded the order must wait in the pool until, at least, the next release period. Once an order is released the workload of each capacity group in the order routing is updated with the workload contribution of the selected order. This procedure is repeated until all orders in the pool, at release time t, have been considered for release. Therefore, only a subset of orders currently waiting in the pool is released each time order release is activated, i.e. at release time t.

After release, the *frist-in-frist-out* (FIFO) priority dispatching rule is used to control the progress of the jobs through the shop floor. Operations processing times are stochastic following a 2-Erlang distribution with a mean of 1 hour per job. Setup times are equal to 20% of the mean operation time. For simplicity we assume the same set-up time for each job type.

The stochastic inter-arrival time of orders to the pool was adjusted was adjusted to maintain machine utilization at 90% with a coefficient of variation of 0.6. Each machine works with an availability of 95% combined with a mean time to repair (MTTR) of 4h.

The simulated shop characteristics and the reference environment used to evaluate the WLC approaches performance and its robustness is summarized in tables 1 and 2.

Table 1: Simulated shop characteristics

Characteristic	**value**
Shop type	Pure job shop
Routing variability	Random routing, no re-entrant flows
No. of machines	Six
Machine capacities	All equal
Machine utilisation	90%
Shop floor dispatching rule	FIFO

Table 2: Simulated reference manufacturing environment

Characteristic	**value**
inter-arrival time CV	0.6
MTTR	4 hrs
Operations processing times	2-Erlang, $\mu=1$
Setup times	20% of the mean processing time
Machine availability	95%

RESULTS AND DISCUSSION

During simulation runs, data were collected under system steady-state. The length of each run was for 125,000 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.

Time in System Performance

The main performance measures recorded is time in system. Time in system refers to the time a job spends waiting in the pre-shop pool plus the shop flow time. The benefits of reducing time in system are related with reducing the overall response time to customers. Shop flow time was also recorded. The shop flow time refers to the time that elapses between job release and job completion. Reducing the shop flow time has also intrinsic benefits, which implies a smaller WIP (work in process) and therefore reduced capital tied up.

Figure 1 shows time in system behaviour for each one of the WLC approaches studied. These are the results of varying workload norms in combination with the workload control approach. In this figure, time in system is plotted against shop flow time. A superior approach yield lower time in system for a given shop flow time, i.e. will have a curve which is shifted down and to the left. A point on the curve is the result of simulating a workload control approach at a specific workload norm level. Note that norms are equally tight if they result in the same shop flow time.

As can be seen, curves converge at the point (43.0, 45.5) for the shop flow time and time in system, respectively. This is the result of unrestricted workload norm levels, meaning that jobs do not wait in the pre-shop pool of orders, i.e. release is uncontrolled. As could be expected, in these circumstances, both approaches give the same results. By lowering the norm levels, lower values of time in system are obtained, up to a *minimum,* Figure 1. The smallest values of time in system, 41.6 and 44.7, are achieved for the shop flow times of 23.1 and 36.1, under the approaches A and approach B, respectively. This represents an 8.6% and 1.8% reduction in time in system and a 46.3% and 16.0% reduction in the shop flow time, respectively, in relation to the uncontrolled release situation. Tighter workload norms lead to an increase in time in system. This means that waiting time in the shop floor is partially replaced by waiting time in the pre-shop pool of orders. Thus, since the time in system is the sum of the pool time and the shop floor time, we may conclude that waiting times in the pool increase more than waiting times on the shop floor decrease. This means that to avoid deterioration of time in system, norms cannot be set excessively tight.

For the whole range of workload norms, approach A performs better than approach B, i.e. it results in the same or less time in system.

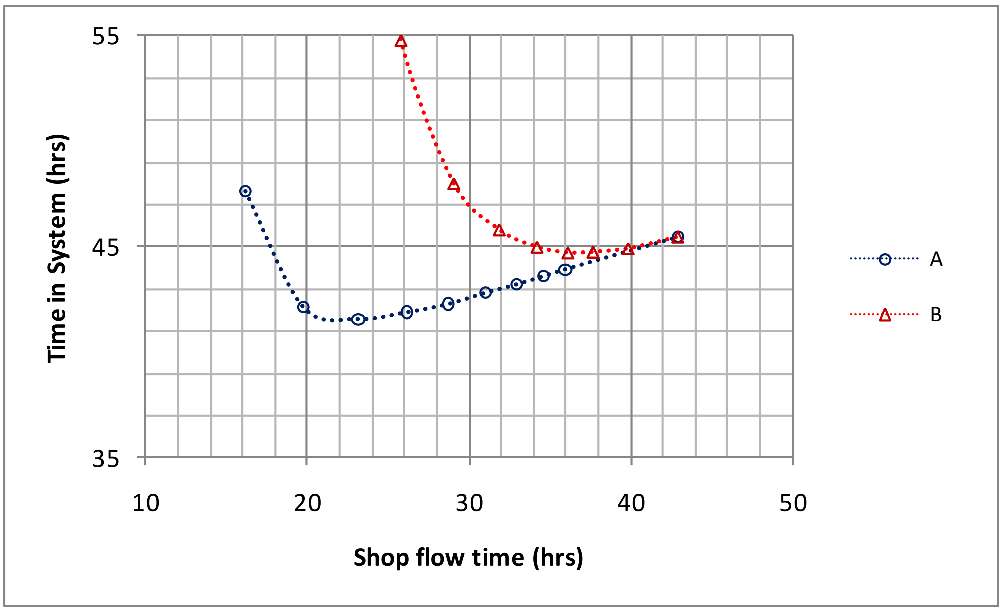

Figure 1: Time in system performance of WLC approaches A and B.

Robustness

The robustness of a WLC approach may be defined as its capability to perform under manufacturing dynamic conditions or environment. By changing manufacturing environment conditions, one at a time, it is possible to take conclusions about the robustness of a WLC approach. The magnitude of changes in the manufacturing dynamic environment, considered in the present study, is indicated in table 3.

Table 3: Magnitude of changes

Impact	Increased variability (%)	Decreased variability (%)
Machine availability	2%	-2%
Inter-arrival time CV	50%	-50%

The robustness under the influence of machine availability and Inter-arrival time coefficient of variation (CV) is given in Figures 2 and 3, respectively.

As can be seen a decrease or increase in machine availability does not influence the relative performance of the WLC approaches. Approach A still performs better than approach B for the whole range of workload norms. Likewise, a reduction or an increase of the inter-arrival time coefficient of variation does not change the relative performance of the WLC approaches.

It is also shown that, under restrictive workload norms, the WLC approaches become more robust to the influence of the Inter-arrival time coefficient of variation, i.e. curves of the same WLC approach tends to converge on the left side of the figure. Moreover, the variation of the time in system with the variability of the manufacturing environment conditions is quite expressive. This is particularly so under machine availability influence.

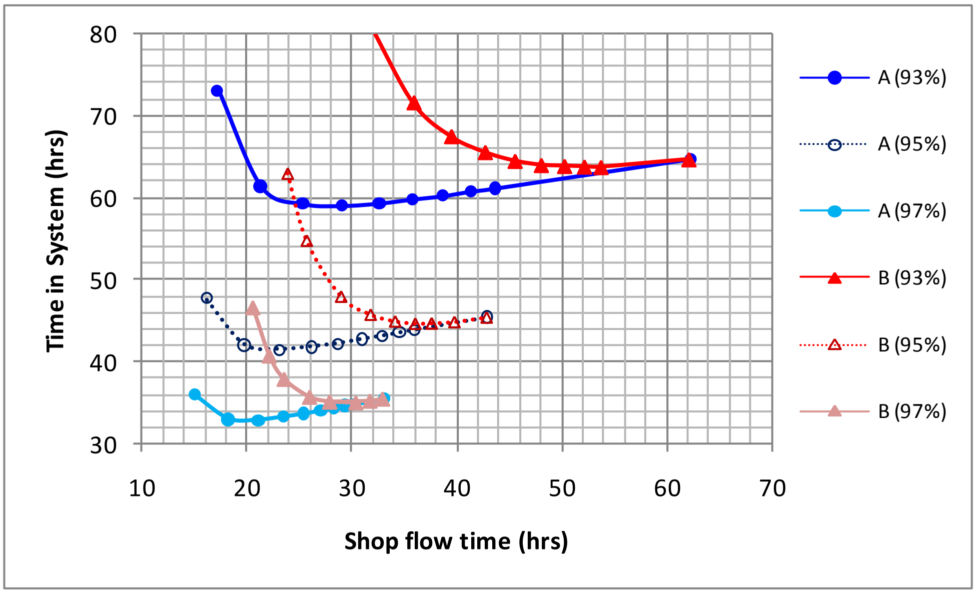

Figure 2: Machine availability influence

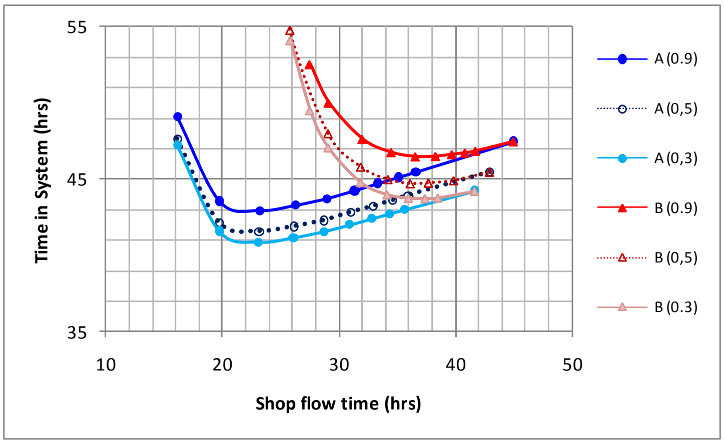

Figure 3: Inter-arrival time coefficient of variation influence

CONCLUSIONS

In this study, the time in system performance of two classical WLC approaches was evaluated via simulation, with focus on their robustness, i.e. their ability to cope with changes in the manufacturing environment conditions.

The study shows that the performance of the WLC approaches evaluated is clearly different and that it highly depends on manufacturing environment conditions. Different conditions were set by two parameters, i.e. coefficient variation of order inter-arrival time and machine availability. Results indicate that the relative performance of the WLC approaches do not change when manufacturing environment changes.

Although some useful insights could be taken from this study to support industrial managers in the choice of the specific WLC approach, it is important that further research extends the analyse to a wider spectrum of manufacturing environment conditions and WLC approaches to be possible to offer better supporting material and ensuring better choices.

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