Improving the Delivery Performance of the WLC concept

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ABSTRACT

Order release based on Workload Control (WLC) is an important instrument to achieve short and predictable flow times and thus to improve the delivery performance of make-to-order enterprises. In this paper, we report a simulation study on the role of order release and dispatching in the delivery reliability of these enterprises. Two order release procedures and two types of dispatching rules were evaluated assuming the continuous release of orders to the shop floor. The obtained results provide new directions for the development of the release and dispatching functions of WLC concepts.

INTRODUCTION

An issue of particular concern for many manufacturing enterprises, particularly make-to-order (MTO), is the ability to deliver their products on time. Short and reliable due dates and consequently short and predictable flow times are an important goal for these enterprises, especially when they increasingly need to offer more customized and unique products in order to attract customers. To attain this goal the production planning and control (PPC) system must be designed appropriately.

Workload Control (WLC) is a Production, Planning and Control (PPC) concept with particular relevance to the MTO and the job shop production [1]. It has been described in many publications since the 1980s, e.g., [2], [3], [4], [5] and [6]. WLC emphasis is on firmly controlling orders’ flow times through the whole production system by means of input and output control decisions.

WLC assumes that by controlling the workloads on the shop floor, short and predictable flow times may be achieved and the lead time syndrome [7] may be prevented. This makes order release (input control) as an essential decision function and a core part of WLC [8]. Order release aims at restrict and balance workload on the shop floor and across capacity groups, i.e., groups of capacity resources. An important part of the research developed on the WLC concept is related to the order release function. For an overview see [9]; for setting order release parameters see [10]; for implementing issues see [11] and [12]; for workload norms considerations and the influence of the flow characteristics see [13] and [14]; for decision on grouping machines and on the control of capacity groups see [15]; for setup considerations see [16].

A common denominator in this body of work is the use of (1) a pre-shop pool that buffers the shop floor against the external dynamics and (2) an order release mechanism that decides on the release of individual orders. Once released, the progress of the orders on the shop floor is controlled by priority dispatching rules in the queues of the capacity groups.
A key indicator of delivery reliability performance often used in practice is the percentage of orders (jobs) delivered late i.e. the percentage of tardy jobs. A high tardiness percentage can result from either: (1) a high average lateness; or (2) a high variance of lateness across orders. This paper concentrates on the contribution of order release and dispatching functions within WLC. Next, the simulation study, involving the simulation model, the experimental design and the performance measures, is detailed and the simulation results are presented and analysed. Concluding remarks and directions for future research work are put forward in last Section of the paper.

ORDER RELEASE FOR WORKLOAD CONTROL

Within WLC an order release mechanism is used to determine the time and the orders to release into the shop floor. This mechanism considers both, (1) the relative urgency of the orders, which is designated as the timing function of the mechanism and (2) the current shop floor situation in terms of the workload in each capacity group, which is designated as the balancing function.

The pool of orders is usually assessed periodically, at the beginning of each release period $T$ and those orders with a planned release date within a time limit from the current date are considered for release. The planned release date (PRD) of an order is determined by backward scheduling from the due date using the lead times of each capacity group in the routing of the order. To determine their relative urgency, the orders in the pre-shop pool are sequenced accordingly to the PRD value. To restrict and balance workload on the shop floor and across capacity groups, an order $j$ is released only if it doesn’t violate the workload norm $\Delta_w$ of each required capacity group $w$ in the orders’ routings (set $S_j$). Two basic release or trigger procedures are as follows [9]:

Procedure I: 
$$L_w + d_{jw} \cdot p_{jw} \leq \Delta_w \text{ for all } w \in S_j$$  \hspace{1cm} (1)

Procedure II: 
$$L_w \leq \Delta_w \text{ for all } w \in S_j$$  \hspace{1cm} (2)

Where, $L_w$ is the current workload of $w$, $d_{jw}$ is a depreciation factor for workload accounting and $p_{jw}$ the operation processing time of $j$ at $w$. The depreciation factor determines the fraction of $p_{jw}$ i.e., the parcel that is accounted for the direct workload of $w$.

While procedure I is focused on balancing the direct loads across capacity groups, by releasing only those orders whose workload contribution $(d_{jw} \cdot p_{jw})$ do not make any workload norm to be exceed, procedure II relax this focus and try to keep the priority of urgent orders. Phan et al. [18] compares both procedures by means of a simulation study. Authors showed that a small percentage of tardy jobs can be achieved by release procedure I. Whether the combination of both procedures gives place to improved delivery performance remains to be investigated.
Once an order is released, the workload of each capacity group in the order’s routing is updated with the load contribution of the selected order. The release procedure is repeated until all orders in the pre-shop pool have been considered for release.

Previous studies on periodic order release, e.g., [19] and [10] showed that the release period $T$, i.e., the time period between two consecutive executions of the order release procedure, may have an important influence on the delivery performance. Long release periods may unnecessarily delay orders in the pre-shop and increase the system flow times. Short release periods may hold back the release of large orders that do not fit workload norms and thus negatively affecting the timing of release. Continuous order release does not need the specification of the release period parameter. The release of orders into the shop floor is allowed at any time during the system operation. Continuous order release may hinder the release of large orders, but it has the advantage of leading to a continuous updating of the shop floor control situation with improved smoothing and stabilization of workload at capacity groups. Though most of the past research on the WLC concept has focused on periodic order release, continuous order release reflects the competitiveness of industry and the short lead time expectations of customers. Order release mechanisms that implement continuous release have been suggested by [20], [21], [22] and [23].

To control the progress of the orders through the shop floor simple dispatching rules are used. The First-Come-First-Serve (FCFS) dispatching rule is commonly used, supporting the predictability of flow times. These, in turn, are used to establish accurate planned release dates for the orders. Due date oriented dispatching rules may also be used, as a means to reduce lateness variation across orders and thus influencing the percentage of tardy jobs.

As due date compliance is the primary concern of MTO enterprises, this study concentrates on investigating the influence the above referred order release and dispatching strategies with regard to delivery reliability performance. In particular the paper explores ways for reducing the percentage of tardy jobs under WLC.

**SIMULATION STUDY**

The simulation study was carried out using the Arena® software. The following sections details the simulation model, the experimental design and the performance measures used in the study.

**Simulation Model**

The study is based on a small job shop model described in [24] and used in several simulation studies of the WLC concept such as [13], [10] and [14]. This allows comparing simulation results of this study with the referred studies. The model consists of a shop with six capacity groups, each with a single multipurpose machine. Machines’ capacity is equal and remains constant over time. A machine can perform only one operation at a time on any order (job) and an operation of an order can be performed by only one machine at a time. Job pre-emption is not allowed in the simulation. The routing lengths are uniformly distributed between one and six operations, without return visits. Processing times are stochastic, following a 2-Erlang distribution with a mean $\mu$ of 1 time unit per order and assumed to be identical for all the operations of an order. Set-up times are defined to be sequence
independent and are modelled as part of the operation processing times. The mean inter-
arrival time of orders results in a machine utilisation rate of 90%. The externally set due
dates of the orders are determined by the order arrival time at the system plus a uniformly
distributed due date allowance. The simulated shop characteristics are summarised in
Table1.

Table 1 Simulated shop characteristics

<table>
<thead>
<tr>
<th>Shop type</th>
<th>job shop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing sequence</td>
<td>Random routing, no re-entrant flows</td>
</tr>
<tr>
<td>Operations per order</td>
<td>Discrete uniform [1, 6]</td>
</tr>
<tr>
<td>Operation processing times</td>
<td>2-Erlang with a mean of 1 time unit</td>
</tr>
<tr>
<td>Inter-arrival times</td>
<td>Exponential distributed</td>
</tr>
<tr>
<td>Due-date allowance</td>
<td>Uniform [35, 60] time units</td>
</tr>
</tbody>
</table>

Design of Experiments

Table 2 summarises the different experimental settings. Two order release procedures
were applied in this study, namely:

- Procedure I, as described in the previous section;
- Hybrid. If a product in the pre-shop pool becomes urgent, it should be released in
  order to achieve on-time delivery. Due to the importance of releasing urgent
  orders to management objectives, the release probability for these orders should
  be increased. Hybrid combines both procedures I and II, to do so. Under hybrid
  release, procedure I is used for releasing non-urgent orders and procedure II is
  used for releasing urgent orders.

Two dispatching rules were also applied for prioritizing the orders on capacity groups:

- First-Come-First-Served (FCFS), where the sequence of the orders in the
  outgoing flow at a capacity group is the same as the sequence in the incoming
  flow. FCFS is a flow conserving rule most often used;
- Operation planned starting date (OSD), which is intended to reduce job lateness
  variation. The OSD of an order j on a capacity group s is determined by
  backward scheduling from the due date using the lead times of the operations still
  to be done.

Workload norms were tested at twelve levels of restriction. These are deterministic
parameters, setting the maximum workload that can be released from the pre-shop pool to
each capacity group. In the simulation, workload norms are stepwise down, in order to
gradually increase the level of restriction to order release.

Table 2 Experimental settings

<table>
<thead>
<tr>
<th>Experimental factor</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release procedure</td>
<td>I</td>
<td>hybrid (I and II)</td>
</tr>
<tr>
<td>Dispatching rule</td>
<td>FCFS</td>
<td>OSD</td>
</tr>
<tr>
<td>Workload norms</td>
<td>tested 12 levels of restriction</td>
<td></td>
</tr>
</tbody>
</table>
release procedures and dispatching rules. The resulting strategies have different implications for shop floor control and performance. On one extreme strategy A1 is focused on providing capacity groups with a good workload balancing over time and in assuring the predictability of flow times to control the average lateness of the orders and thus to achieve high delivery reliability. On the other extreme strategy A4 puts the emphasis on keeping the priority of urgent orders at release and on the capacity groups of shop floor to reduce the dispersion of the lateness across the orders and thus to improve the delivery reliability.

Table 3 Control strategies resulting from combining release procedures and dispatching rules

<table>
<thead>
<tr>
<th>Dispatching rule</th>
<th>Release procedure</th>
<th>FCFS</th>
<th>OSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>Hybrid</td>
<td></td>
<td>A3</td>
<td>A4</td>
</tr>
</tbody>
</table>

These four strategies are implemented in the simulation study under the assumption of continuous order release. Workloads are estimated using the corrected aggregate load conversion method [13]. Under this method the workload contribution of an order, at the moment of release, to the workload of a capacity group is the depreciation parcel referred in the previous section, which is determined according to the position of the capacity group in the routing of the order. The further downstream a capacity group is in the routing of an order, the higher the depreciation (i.e. the lower \( d_{IY} \) is).

During simulation runs, data were collected under system steady-state. The length of each simulation run was for 60,000 time units, in which the first 10,000 time units were considered as the warm-up period. The average values of 100 replications are presented as results. The statistical analysis was performed using the paired Student t-test with a 95% confidence level.

Performance measures

The key results we focus upon are the percentage of tardy jobs, the standard deviation of the lateness and system and shop flow times. Shop flow time refers to the time that elapses between order release and its completion and describes the performance of the shop floor. System flow time, which incorporates the pool delay, provides an overview of the performance across the whole system. The standard deviation of lateness is a measure of how spread out a lateness distribution is. It is used as an indicator of timing performance, i.e. it indicates how close to their due dates the completions of the orders are. The percentage of tardy jobs refers to orders (jobs) that are completed after the due date.

SIMULATION RESULTS AND ANALYSIS

An overview of the system performance under the four control strategies is presented in Figures 1, 2 and 3. Periodic order release under release procedure I and FCFS dispatching with \( T \) equal to five time units was also simulated for comparison purpose. The average shop flow time is set on the horizontal axis. The three measures of delivery performance, namely average system flow time, percentage of tardy jobs and standard
deviation of the lateness are set on the vertical axis of Figures 1, 2 and 3, respectively.

![Figure 1](image1.png)

Figure 1 Time in system performance of control strategies.

![Figure 2](image2.png)

Figure 2 Percentage of tardy jobs.
The points on each logistic performance curve represent twelve workload norm levels simulated. The utmost right point of each curve results from an unrestricted norm level. This means that each time order release is activated all orders due to release are in fact released. By tightening workload norms stepwise down, the system and the shop flow time are reduced, except for strategy A4, until a critical workload level where system flow time stops decreasing, see Figure 1. Taking for example the logistic performance curve of the periodic release procedure this critical level is reached for a shop flow time of 18.6 time units and a system flow time of 27.4 time units (square mark). Below this critical workload level, the increase of the system flow time means that the decreased waiting times on the shop floor are no longer compensated by the increased waiting times in the pre-shop pool. Thus, to avoid deterioration of the system flow time, workload norms cannot be set excessively tight.

Figure 2 shows that, for the percentage of tardy jobs, continuous order release, which is adopted in strategies A1 to A4, outperforms periodic order release for almost the all range of workload norms. For strategies A1 and A3 this results from decreasing the system flow time (Figure 1), while for A2 and A4 this results from reducing both, the system flow time and the dispersion of the lateness across orders, particularly, under loose workload norms (right part of the curves), Figure 3.

A particularly striking finding from results is the lowest value of the percentage of tardy jobs that can be achieved by strategy A2. In this case only 1.1% of jobs are tardy. This is achieved for a workload norm that results in a shop flow time of 20.3 time units, figure 2. This means a 70% reduction of the percentage of tardy jobs relatively to the situation of immediately release (utmost right point of the curve), where 3.7% of the jobs are tardy.

From results we may conclude that strategies A3 and, particularly A4 (both with hybrid release), show poor load balancing qualities, when compared with strategy A1 and strategy A2 where the release procedure I is implemented, as revealed by the low system flow time. Strategies A2 and A4 show improved timing qualities (particularly for loose workload norms) when compared with strategies A1 and A3, as revealed by the low variation of orders' lateness. Apparently the adoption of the delivery date oriented dispatching rule OSD, which look after the handling of urgent orders, explains this behaviour.

CONCLUSIONS

In this paper the performance of two order release procedures and two types of dispatching rules, under the assumption of continuous order release, was investigated by means of a simulation study. It was shown that continuous order release allows reducing the percentage of tardy jobs when compared with periodic order release. It was also shown that reducing the percentage of tardy jobs involve: (1) keeping the queues on the shop floor short and stable by releasing only those orders that provide capacity groups with a good workload balancing over time; (2) controlling the progress of urgent orders on the shop floor thought due date oriented dispatching.

Future planned research work will extend the study to include output (capacity) control decisions, delivery time promising and order acceptance rules.
REFERENCES


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