How to Release Orders in Assembly Job Shops?

Nuno O. Fernandes[1], S. Carmo-Silva[2]
[1]Polytechnic Institute of Castelo Branco, School of Technology
Av. do Empresário, 6000-767, Castelo Branco – Portugal
Email: nogf@ipcb.pt
[1,2] University of Minho, CITEPE-Centro Interdisciplinar em Tecnologias de Produção e de Energia,
Campus de Gualtar, 4710-057, Braga – Portugal
E-mail: scarmo@dps.uminho.pt

Abstract

This paper addresses the problem of controlling the production of complex products needing assembly operations. It presents a simulation study of how WLC release methods behave in an assembly job shop where due dates are set by customers. In particular two alternative strategies to drive the release of work orders are investigated, namely: (1) assigning the same due date and different planned release dates to each work order according to the routing length of each work order and (2) assigning the same due date and the same planned release date to each work order according to the routing length of the largest work order in the assembly order. These strategies are compared and assessed on the basis of two primary performance measures, i.e. total throughput time and mean absolute deviation of the lateness. Results contribute for understanding the implications of dealing with more complex environments than haven't been dealt with in the past by WLC research.

Keywords

Workload Control, Assembly Job Shops, Simulation**.**

Introduction

For manufacturing companies to stay competitive in the global marketplace of today they must ensure short delivery times and high delivery reliability, especially in environments where customized and unique products are required in order to attract customers. Production conditions in the shop should then be controlled such that selected throughput times may be realised.

Workload Control (WLC) is a Production, Planning and Control (PPC) approach primarily designed for the make-to-order (MTO) and job shop production aligned towards achieving these objectives. WLC aims at controlling the orders' throughput times by means of input and output control decisions mainly at order entry, order release and priority dispatching.

Order release has been described as an essential decision function and a core part of WLC [1]. It controls the release of customer orders to the shop floor, smoothing order release in spite of the uncertainties typical of shops. The concept prioritizes orders before release in order to meet due dates and often uses simple flow conserving rules to control the progress of the orders on the shop floor [2].

In manufacturing systems it is usual to find shops that process assembly orders. An assembly order refers to an order that consist of a set of work orders that have to be assembled together after its processing is completed [3]. However, most WLC research assumed that production orders are independent and that no assembly operations exist. This manufacturing environment introduces the problem of coordinating work orders that belong to the same assembly order, i.e. the coordination of interrelated work orders. Despite the importance of this problem [4], few contributions have been provided. The works of [5], [6] and [7] may be seen as exceptions to the rule.

Bertrand and Wakker [5] showed that releasing interrelated work orders separately at their planned release times leads to poor performance. However they didn't use WLC release methods. Lu et al. [6] showed that the influence of priority dispatching should not be neglected in spite of controlled release. Both studies assumed that due dates are specified by the company. Recently Thurer [7] concluded that when due dates are predominantly set by the company the due date setting policy should play the leading role while when due dates are predominantly specified by customers, the importance of order release increases.

None of the studies use detailed workload information, such as about the distribution of the workload over time, at assembly work centres. The current simulation study assesses the performance of WLC order release methods in assembly job shops when due dates are specified by customers. In particular we want to know how to release orders in this manufacturing environment. Detailed workload information at assembly was considered in the study. It is assumed that the total throughput time of assembly orders and the mean absolute deviation of the lateness of assembly orders are the primary performance measures.

The remainder of this paper is organized as follows. The next two Sections describe the simulation study and presents and analyses simulation results. Concluding remarks and directions for future research work are put forward in the last Section of the paper.

Simulation Study

A simulation study was carried out using Arena® software. During simulation runs, data were collected under system steady-state. The length of each run was for 20,000 time units including a warm-up period of 3,000 time units. The average values of 100 independent replications are presented as results.

- **Job shop configuration**

A job shop without an explicit bottleneck has been considered. The structure of the shop consists of six manufacturing capacity groups and one assembly capacity group. Each capacity group has a single machine that is continuously available. The assumptions of the simulation model are as follows:

- Order arrivals occur according to an exponential distribution with a mean inter-arrival time that results in a machine utilisation rate of 90%.
- Routing lengths are uniformly distributed between 1 and 6 operations, without return visits.
- Machines capacities are identical and remain constant over time.
- A machine can perform only one operation at a time on any order.
- An order can be processed by only one machine at a time.
- Pre-emption, i.e. interrupting the processing of an order to put a different one on a machine, is not allowed.
- Processing times both at assembly and at manufacturing are assumed to be stochastic following a 2-Erlang distribution.
- Set-up times and transportation times are assumed to be negligible.

Tables 1 summarize the simulated model characteristics.

Each order is assembly from a number of work orders uniformly distributed between 2 and 5 after work orders belonging to an assembly order are processed. Thus the total throughput time of an assembly order consists of the pool delay, a combination of the throughput time of its work orders, the assembly time and the assembly delay, i.e. the delay encountered by work orders coming into an assembly work centre when they have to wait for one other before their assembly can start.

Each arriving order is assigned a due date d_k accordingly to Equation 1 to reflect due dates specified by customers.

$$d_k = \mathrm{r_k} + \mathrm{NORM}(100, 10) \qquad (1)$$

Where r_k is the arrival time of the customer order *k*. The due date was set such that the percentage of tardy orders was approximately 20% under immediate release and first-come-first-served (FCFS) dispatching. This due date tightness is in accordance with previous studies, e.g. [6] and [8].

Table 1: Model characteristics.

Shop type	Job shop
Orders inter-arrival times	Exponential distributed
Due date allowance	NORM (100, 10) time units
Routing length	Discrete UNIF(1, 6)
Work orders per assembly order	Discrete UNIF(2, 5)
Machines capacities	All equal and constant over time
Machines utilisation rate	90%
Manufacturing processing times	2-Erlang, µ=1 time unit
Assembly processing times	2-Erlang, µ=2 time units
Dispatching rule	PST

As in recent simulation studies, e.g. [7], [9] and [10], it is assumed that all orders are accepted and either immediately released or kept in a pre-shop pool to await release. Work orders *l* in the pool are considered for release according to its planned release date (PRD_l), calculated by backward scheduling as follows:

$$PRD_l = d_l - assembly\ delay - \left(\sum processing\ time + number\ of\ operations * k_1\right) \qquad (2)$$

Where d_l is the due date of work order *l* at assembly, calculated as follows:

$$d_l = \mathrm{d_k} - (\text{assembly time} + k_2) \qquad (3)$$

Where k_1 and k_2 are flow time allowances to account for manufacturing and assembly operations waiting time, respectively. Based on the results of an 'a priori' pilot simulation study using immediate release and planned start times (PST) dispatching, k_1 and k_2 were set to 9 and 12 time units, respectively. When a WLC release method is in place k_1 is set to 6 time units and k_2 is set to 11 time units.

Since part of the assembly order total throughput time is the assembly delay, it is important that interrelated work orders are completed at about the same time. To achieve this, a planned start time is assigned to the operation in the routing of a work order and dispatched accordingly to the earliest PST.

- **Experimental setting**

Two alternative strategies for establishing planned release dates of interrelated work orders were considered in the experiments, namely:

- Strategy 1: backwards scheduling from the due date of work orders at assembly based on the operations lead times and the number of operations required by each work order;
- Strategy 2: backwards scheduling from the due date of work orders at assembly based on the planned lead times and number of operations in the largest work order, i.e. largest number of operations.

Note that under the first strategy interrelated work orders may have different planned release dates. Under second strategy all work orders of an assembly order have the same planned release date. This strategy plans for short work orders to be completed as soon as possible.

Three release methods have also been considered in the experiments. They are:

- Immediate release (IMR);
- Backward infinite loading (BIL);
- WLC release.

Under IMR work orders do not wait in the pre-shop pool and are all released each time order release is activated. BIL releases work orders on the planned release date without taking into account the current workload on the shop floor. WLC releases work orders only if the resulting workload do not exceeds established work load norms or limits. Workload at each capacity group is measured for the manufacturing using the corrected aggregated load approach [9] and for assembly the aggregated load approach [9]. If a work order couldn't be released the next order in queue is then considered for release. Each time an operation is finished the load contribution of the order is removed from the corresponding capacity group. WLC have been studied under both periodic and continuous release. Periodic release means that work orders are considered for release periodically - every 5 time units in the study and continuous release means that orders may be release at any time during the system operation, triggered by workload levels of capacity groups.

- **Performance measures**

The performance measures considered in the study were the following: work order throughput time (WO_{TT}), work order total throughput time (WO_{TTT}), assembly order total throughput time (AO_{TTT}), percentage tardy (P_{TARDY}) and mean absolute deviation of the lateness (MAD) of order, i.e. assembly orders. MAD refers to a measure of the deviation of order completion dates from their respective due dates.

WO_{TT} refers to the time that elapses between work order release and work order completion at manufacturing. WO_{TTT} also includes the pool delay before release and AO_{TTT} refers to the time that elapses between order entry in the production system and order completion at assembly.

Results

Simulation results are presented separately as follows. First performance results when WLC release methods do not consider workload information from assembly are presented. After, results for the situation which considers workload information from assembly are shown.

- **Performance results without using workload information from assembly**

Tables 2 and 3 presents the results of the simulation experiments conducted to analyse the performance of WLC release methods. These were compared with Backward Infinite Loading (BIL) and Immediate Release (IMR). IMR was tested combined with both PST and Due date oriented (DD) dispatching.

Table 2 shows the methods performance when the planned release dates are determined following Strategy 1, while Table 3 shows the methods performance when Strategy 2 is adopted.

Periodic and Continuous WLC methods were tested at different workload norm levels corresponding to tightness steps increments of 15% from 55% to 85% of the observed workload under unrestricted release. Unrestricted release means that the workload norm N = Infinity. Note that continuous WLC with N = Infinity is IMR.

Table 2: Performance Results Performance for Strategy 1.

Release Method	Dispatching	WO_{TT}	WO_{TTT}	AO_{TTT}	MAD
IMR	DD	32.9	32.9	52.8	49.6
IMR	PST	35.2	35.2	56.9	45.8
BIL	PST	32.3	73.4	93.6	20.7
Periodic WLC (N=Infinity)	PST	35.5	38.0	59.7	43.4
Periodic WLC (N=8.5)	PST	22.1	38.3	58.9	45.2
Periodic WLC (N=7)	PST	19.4	39.1	60.4	44.6
Periodic WLC (N=5.5)	PST	15.7	42.9	66.1	42.8
Continuous WLC (N=29.8)	PST	33.1	33.8	54.2	48.3
Continuous WLC (N=24.6)	PST	32.3	33.6	54.2	48.8
Continuous WLC (N=19.3)	PST	30.8	33.1	54.1	50.0

Table 3: Performance Results for Strategy 2.

Release Method	Dispatching	WO_{TT}	WO_{TTT}	AO_{TTT}	MAD
IMR	DD	=	=	=	=
IMR	PST	=	=	=	=
BIL	PST	35.0	59.9	81.3	27.3
Periodic (N=Infinity)	PST	=	=	=	=
Periodic (N=8.5)	PST	=	=	=	=
Periodic (N=7)	PST	=	=	=	=
Periodic (N=5.5)	PST	=	=	=	=
Continuous (N=29.8)	PST	=	=	=	=
Continuous (N=24.6)	PST	=	=	=	=
Continuous (N=19.3)	PST	=	=	=	=
Continuous (N=14.0)	PST	=	=	=	=

$^{=}$ Means identical values to those of Table 2.

The results show a quite important reduction of the assembly order total throughput time, AO_{TTT}, under IMR when using DD dispatching, relative to PST dispatching, but at the expense of an increase of MAD. BIL, on the other hand, results in a very low MAD comparatively too all other situations. However AO_{TTT} is the highest at a far distance from values of any other experiment.

BIL release shows a better AO_{TTT} for the planned release dates based on Strategy 2 at expenses of a visible worsening of MAD.

For the assembly order total throughput time IMR combined with DD oriented dispatching outperforms periodic WLC and to perform slightly better than continuous WLC. However, continuous WLC can reduce the average work orders throughput time on the shop, WO_{TT}, with a mean absolute deviation of the lateness identical to IMR combined with DD dispatching.

- **Performance results using workload information from assembly**

To better understand how WLC release methods perform in assembly job shops the study was extended to include detailed workload information from assembly operations at order release. Continuous WLC with N=19.3 that showed to perform best in previous experiments for AO_{TTT} was selected. Table 4 presents performance results for different workload norm levels at assembly capacity group, corresponding to tightness steps increments of 15% from 55% to 100% of the observed workload under unrestricted release.

Table 4: Performance Results with workload information from assembly.

Release Method	Dispatching	WO_{TT}	WO_{TTT}	AO_{TTT}	MAD
Continuous (N=56,9)	PST	33.1	33.8	54.2	48.3
Continuous (N=48.4)	PST	32.3	33.6	54.2	48.8
Continuous (N=39.8)	PST	30.8	33.1	54.1	50.0
Continuous (N=31.3)	PST	28.0	32.0	54.2	52.2

We can see that controlling the assembly workload at order release do not practically improve the AO_{TTT} and leads to deterioration of the MAD. This means that in assembly job shops without bottleneck capacity groups controlling work load at assembly may not be justified.

Conclusions

This paper studies the performance of WLC release methods in an assembly-type job shops. The paper is focused on the assembly order total throughput time and on the mean absolute deviation of the lateness as primary performance measures.

Results lead us to conclude that appears to be no benefits, in terms of these performance measures, in using WLC methods or in considering detail workload information from assembly capacity groups at order release. Immediate Release combined with due date oriented dispatching seems to result in the lowest assembly order total throughput time, while Backward Infinite Loading results in the lowest mean absolute deviation of the lateness.

Future research work should investigate multi-level assembly job shops and develop refinements to the WLC concept to deal in a more appropriate manner with the assembly operations.

Bibliography

[1] Missbauer, H. “Models of the transient behaviour of production units to optimize the aggregate material flow.” International Journal of Production Economics. 2009; 118, 2, 387-397.

[2] Bechte, W. “Load oriented manufacturing control just in time production for job shops.” Production Planning and Control. 1994; 5, 3, 292-307.

[3] Adam, N. R., Bertrand, J. W. M., Surkis, J. “Priority assignment procedures in multi-level assembly job shops” IEE Transactions. 1987; 19, 3, 317-328.

[4] Stevenson, M. Huang, Y., Hendry, Land, M. Soepenberg, E., “The theory and practice of workload control: A research agenda and implementation strategy”. International Journal of Production Economics. 2011; 131, 2, 689-700.

[5] Bertrand, J.W.M., and Van de Wakker, A.M., “An investigation of order release and flow time allowance policies for assembly shops”, Production Planning and Control. 2002; 13, 7, 639 - 648.

[6] Lu, H. L, Huang, G. Q. and, Yang, H. D., “Integrating order review/release and dispatching rules for assembly job shop scheduling using a simulation approach”. International Journal of Production Research. 2011; 49, 3, 647 – 669.

[7] Thurer, M. “Workload control: An Assessment.” PhD These, University of Coimbra, Portugal. 2011.

[8] Philipoom, P., Malhotra, M., and Jensen, J., “An evaluation of capacity sensitive order review and release procedures in job shops”. Decision Sciences. 1993; 24, 6, 1109–1134.

[9] Oosterman, B., Land, M. and Gaalman, G. “The influence of shop characteristics on workload control.” International Journal of Production Economics. 2000; 68, 107-119.

[10] Land, M., Su, N., Gaalman, G. “In search of the key to delivery improvement” 16th International working seminar of production economics, Innsbruck, 2010.