Integration of Order Review and Release and Output Control with Worker's allocation in a pure flow shop

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Abstract: With the increase of competitiveness and customer customization requirements, companies' capability to predict and shorten lead-time is becoming an order winner factor. This is particularly crucial for high variability mix and low volume make-to-order companies. Production Planning and Control aims at the alignment between capacity and demand in order to improve production system performance along with lead-time reduction. Workload control is a planning production and control concept developed for high-variety low-volume companies. It aims at controlling the workload in the system by mean of two mechanisms: the input control and the output control. The former regulates the release of new orders in the system, while the latter controls the production capacity. Most of the existing studies focused only on input control, while the output control has been quite overlooked. Moreover, the few studies that combine the two controls were interested in showing the effect on performances and did not consider a specific output control strategy: they operationalized capacity adjustments as decreases of the processing time. This paper is a preliminary step in filling this gap: input control in the form of order review and release and worker's allocation, as capacity adjustments strategy, are integrated in a pure flow shop. Worker's allocation is meant not to increase the overall capacity of the system but to shift idleness periods of workers. Order review and release and Output Control integration (ORROCI) model is presented, showing how the two control mechanisms can be integrated and tested, through simulation. It takes into account both load distribution and capacity available in the system and it transfers workers only when there are imbalances amongst stations load. Preliminary results show that order review and release and worker's allocation can be successfully integrated, achieving superior performances. Further researches can be pursed testing different labor flexibility and efficiency levels, along with different where, when and who rule concerning worker's allocation. Copy-right © 2019 IFAC

Keywords: Workload Control, Order Release, Output Control, Worker's Allocation, Pure Flow Shop, Simulation.

1. INTRODUCTION

Due to changes in customer needs and the increase of competition, customization has become the focus for more and more companies. Then, due date adherence for companies is increasing always its importance and so, speeding up lead times has become a priority for managers; thus, many companies started looking at the flow, rather than at single resources (Fullerton, Kennedy, & Widener, 2014), streamlining their production processes. In order to cope with such variability, it is crucial for companies to choose the right production planning and control (PPC) mechanism (Małachowski & Korytkowski, 2016; Reuter & Brambring, 2016). PPC mechanisms allow companies to deal with demand variability, to manage systems complexities, to reduce the impact of other sources of uncertainty, and they strongly rely on data in order to perform different functions. Among them, we can find the detailed scheduling of jobs inside the production process, the production control and the production monitoring. The successful implementation of these three processes results in improvements in both manufacturing and logistical performances (Reuter & Brambring, 2016).

Workload Control (WLC) is a PPC mechanism that was developed for high-variety contexts, such as small and medium-sized make-to-order (MTO) companies (Stevenson, Hendry, & Kingsman, 2005). WLC is specifically designed for MTO companies as it helps the management of orders inside the system and provide good margins of improvements. Its purpose is to keep stable and limited system queues, reducing the impact of shop congestions and allowing products to quickly flow through the production process. WLC is based on two control mechanisms, the input control (IC) and the output control (OC). The former uses information about jobs in the system in order to decide when incoming orders can be released to the production process - Order Review and Release phase(ORR) - while the latter uses information about the production capacity in order to regulate the workload in the system. Most of the researchers in the WLC literature developed models for IC (especially ORR), thoroughly neglecting the management of systems resources (Fernandes, Thürer, Silva, & Carmo-silva, 2016). The purpose of this paper is to show how information about production capacity can be integrated in the ORR and assess the impact on performances of this new release method that integrates production capacity information in the ORR. Among the different techniques used to control the output: overtime, subcontracting and worker's allocation; this last one will be considered here in this paper as OC mechanism. The remainder of this paper is structured as follows: in section Literature Review, authors review relevant literature on IC and OC, and outline the gap that motivates the study. The specific approach to deal with IC, OC and the integration of the OC in the ORR are then described in the section Simulation Model. Results are presented and discussed in the section Preliminary Results before Conclusions and further developments are presented.

2. LITERATURE REVIEW

IC may be exercised at different points within the WLC concept (job entry, order release, etc.), we focus on order release since it is the most widely applied approach in literature. In section 2.1, we review the WLC literature on ORR to describe the release method used in this study. Then, section 2.2 reviews the WLC literature that focuses on OC and outlines how IC (in the form of ORR) and OC (in the form of worker allocation) can be integrated within WLC.

2.1 INPUT CONTROL

There are many order release methods in WLC literature; for example, see the reviews by Sabuncuoglu & Karapinar, (1999) and Fredendall, Ojha, & Patterson, (2010). In this paper, we use a limiting approach. One of the early implementations of limiting approach is the Bertrand's workload concept presented in Land, Stevenson, Thürer, & Gaalman, (2015). It has received much attention in the literature with researchers testing different methodologies for the accounting of jobs workload (Oosterman, Land, & Gaalman, 2000), investigating the integration of due date information (Thürer et al., 2017), and trying to integrate the OC (Thürer, Stevenson, & Land, 2016). In all the cases, the most implemented version of this algorithm is the following and it is the one considered in this study:

1. All jobs in the PSP are prioritized according to the dispatching rule (e.g. FCFS or SPT).
2. The job i with the highest priority (defined at the previous step 1) is considered for release first.
3. Release job i whether its corrected contribution to stations load (PTi,j/p) together with the current stations load (Wj) does not exceed the workload norm (Nj) for all the stations at the same time. This requirement can be expressed through the following formula:

   $$\frac{PT_{i,j}}{p_{i,j}} + W_j \le N_j \qquad \forall j \; (1)$$

   where
   - $PT_{i,j}$ is the processing time of job i at station j.
   - $p_{i,j}$ is the position of station j in the routing of job i
   - W_j is the current load of station j
   - N_j is the workload norm of station j

   Jobs that do not satisfy the previous equation are retained in the PSP, and they do not contribute to station's workload.
4. If there are jobs in the PSP that have not been considered for release, then return to step 2 and select the next job with the highest priority. In case all jobs have been considered for release, wait for the next release period.

Moreover, every time a station's load drops to zero, the first job in PSP whose first station in its routing is the starving one is released, disregarding its impact on system workload.

2.2 OUTPUT CONTROL

OC refers to the use of production related information and consequent management of the production capacity (e.i. machines and workforce) in order to regulate the amount of work that can be processed. In contrast to IC, OC acts on the current load of the system and, instead of controlling the release of new jobs to the shop floor, it keeps the system workload within a target level by adjusting the production capacity. OC can achieve this goal by leveraging on three levers: machines, manpower and subcontracting (Huang, 2017; Kingsman, Tatsiopoulos, & Hendry, 1989).

There are very few studies that investigate OC, used together with an IC via ORR. The only two studies that have examined the combined effect of IC and OC, presented by (Hendry, Kingsman, & Cheung, 1998) and (Kingsman & Hendry, 2002), do not focus on ORR but on job entry. Both papers used IC by rejecting orders that do not fit within a certain threshold of the planned workload and OC by adjusting capacity so that an order may fit within the maximum workload norm. In a similar way, Philipoom & Fry, (1992) and Moreira & Alves, (2009) considered IC at the job entry step. Then, Thürer et al., (2014) and Thürer, Stevenson, & Qu, (2015) used WLC to guide subcontracting decisions in job shops, however, they focused on job entry to decide which jobs can enter the planned workload and which cannot. Thürer et al., (2016) integrate ORR and OC in a job shop. They did not focus on a specific OC method (subcontracting, overtime, worker's reallocation) since they were interested in showing the combined effect on performances of I/OC. They operationalized O/C by decreasing the processing time of the station whose planned load surpassed a triggering threshold that starts the capacity adjustment.

In this study, we propose a specific OC strategy in combination with an ORR applied in a pure flow shop. In our study, OC focuses on a specific way to adjust capacity: worker's allocation amongst stations of a pure flow shop. In this way, we do not increase the overall capacity of the pure flow shop considered.

In the next section the simulation model is presented along with the ORR and OC integration.

3.SIMULATION MODEL

We consider companies whose production follows a dominant flow sequence, and so it is directional. Such companies can be found, for example, in the ceramics industry and in furniture manufacturing (Portioli-Staudacher & Tantardini, 2012). A simulation model for a pure flow shop has been implemented in Python using the SimPy module. The shop is a hand driven line composed of 5 stations. Each station j is a single resource with constant capacity of 480 time units. In each station a different operation is performed on the processed job i by a worker w. A buffer is present between each station and the size is unlimited. Jobs and shop characteristics are detailed in the following table:

Shop configuration	Pure flow shop
Number of machines (j*)	5
Number of workers (w*)	5
Dispatching rule	first come first served - FCFS
Capacity of each stage	480 time units
Arrival rate distribution	Exponential
Processing time distribution	Truncated Log-normal Mean 30 time units, variance 900 Minimum 0, maximum 360 time units
Job (i*) due date	Uniform[α,β] with α, β
Workload Norms (time units)	2700; 3000; 3600; 4800; 6600

*(i,j,w have values from 1 to 5)

Due dates values are drawn from a uniform distribution between α and β, where: α is chosen so that the percentage of tardy jobs in case of immediate release of orders is equal to 20%; β is obtained through the sum of the number of stations times the ninety-fifth percentile of the processing time (83.6 time units), plus a constant allowance (2000 minutes) (Bertolini, Romagnoli, & Zammori, 2015; Thürer et al., 2016).

3.1. INPUT AND OUTPUT CONTROL INTEGRATION

ORR and OC Integration (ORROCI) tries to overcome one of the main drawback of the most common workload limiting approach presented in section 2.1: the lack of balancing in the use of resources. In particular, workload limiting approach inhibits the release of a new order whether it leads to exceed the workload norm. Clearly, it does not guarantee that all resources/stations have a sufficient number of orders to process. It happens that only some of them are fully loaded and this stops the release of new orders. As consequence, there are stations that are not fully loaded that will be idle for a certain amount of time after the release, preventing, in this way, the full exploitation of the resources. In order to overcome this limitation, ORROCI takes advantage of workforce allocation (the shift of idle resources), releasing additional orders that workload limiting approach would have left in the PSP. The additional orders released improve the workload balance among stations and increase the utilization of those stations that are not fully loaded.

ORROCI performs two different steps in sequence. The first step resides in the workload limiting (please refer to section 2.1). Then, a second step evaluates all jobs (a second time) that have been left in the PSP, after the workload limiting. In this second step, orders are released whether their load contribution to stations that are already over-loaded can be absorbed by under-loaded stations. ORROCI's second step performs the following steps (in sequence) for each order that has been selected for release from the PSP.

If we consider a job k with the highest priority for release, ORROCI performs the following steps:

5. Compute the expected workload (ExpWl) for all the stations j as follows:

$$ExpWl(j) = Station\ Load(j) + Extra\ Load(j) - Help\ Required\ (j)$$

$\forall k, \forall j$ (2)

Where Station load (j) is computed as for W_j, in section 2.1. Extra load (w) is defined as the load/work that worker w (with w=j) in station j will perform in external stations. Help Required (j) is the load/work of station j absorbed by external workers.

6. Define a set Ω of stations whose ExpWl is lower than the average load and a set φ of stations whose ExpWl is higher than the average load along the five stations. Workers allocated to stations of set Ω (Helper) are eligible to provide help to external stations. While, stations of set φ are candidate to receive help (Helped). The extent to which workers in Ω help is equal to the load contribution of job k. While, the extent to which stations in Ω can provide help is defined according to the difference between their ExpWl and the workload norm.

7.Compute all possible permutations of elements in φ to the number of elements contained in Ω. Every permutation of the resulting set represents a couple Helper (Jer) –Helped (Jed).

8.Eliminate all couples of the set of permutations which combine stations in φ to stations in Ω where the idleness of stations in Ω is not enough to fulfil the extra load of job k of stations in φ. Whether all couples Jer-Jed result unfeasible, job k is retained in the PSP and ORROCI moves to the evaluation of the next job k.

9.In case there are couples Jer-Jed feasible, it assigns a score to each couple. The score is assigned in accordance to the following formula:

$$Score(p) = \sum_j Extratime(Jed) * WS(Jer, Jed)$$

where

- p is the permutation
- Jed is the station that receives help
- Jer is the station that helps
- WS (Jer, Jed) is the proficiency of worker w (with w=Jer) at station Jed

- Extratime is the number of time units that stations Jed needs to be helped (it derives from the extra load of job k)

The Couple Jer-Jed that minimize the score is chosen.
10.The couple found out in previous step determines the stations that need help and the station that receives help. In this way, the allocations Jer-Jed are determined.

3.2. WORKER'S ALLOCATION

Each worker w is assigned to its station j (with w=j). In the case worker w assigned to station j (with w=j) is idle (there no jobs in the queue of station j), the worker w defines a set of stations where he/she can go to work. Two constraints have to be met in order to define the next station where to work:
a.External stations (for j different from w) have workload to process (i.e. number of orders in their queue > 0).
b.Stations have to be part of the set of couples Helper(j)-Helped(i) defined by ORROCI (step 9 in Section 3.1).
The worker is transferred to its next station and he/she is locked there for a minimum of 30 times units (equal to the average processing time of a job). For this period of time, two workers are working together at the same station until one of the following events trigger the evaluation of the next station's choice for each worker w:

1. Worker ends processing his/her current job
2. A new order enters the queue of his/her station
3. End of Help Required defined by ORROCI (Step 5 in Section 3.1).

In this paper, we assume that there are no constraints in terms of worker's transfers: each worker can work on all the five stations with the maximum of efficiency with a transfer time equal to zero.

4.PRELIMINARY RESULTS

Results were collected over 4000 time units following a warm-up period of 2000 time units. The five main system performance measures considered in this study are the following: Gross Throughput Time (GTT), the time period between the order entry in the PSP and the exit from the last processing station; Shop Floor Time (SFT), the time period between the order release from the PSP and the exit from the last processing station; the Lateness for each job i (i.e. the actual delivery date minus the due date of job i); Percentage of tardy orders – The percentage of tardy orders is determined as the percentage of orders with a lateness value exceeding zero; Tardiness – the maximum number between 0 and the difference between the completion date of a job i and the due date of the job i. In the table below we present the five main system performance measures for the five workload norms tested. The results are collected both for workload limiting and for the ORROCI model (values in bold).
From the table below we see that the integration of the OC along with the ORR brings improvements for what concerns all the five system performance measures. The improvement is bigger when WLC norms are lower (i.e. 2700, 3000 and 3600 time units) and it decreases when WLC norms increase. In fact, with lower WLC norms, ORROCI brings a reduction between 7% and 2% for GTT, between 4% and 3% for SFT, between 16% and 6% for Tardiness, between 5% and 2% for Tardy Orders and between 45% and 16% for Lateness.

WLC norms (tu)	GTT (tu)	SFT (tu)	Tardiness (tu)	Tardy jobs	Lateness (tu)
2700	2325,88	1952,90	707,42	0,57	318,01
3000	2302,59	1983,71	688,57	0,57	294,71
3600	2297,37	2038,41	685,38	0,57	289,49
4800	2296,16	2078,17	684,74	0,56	288,28
6600	2296,46	2088,11	685,03	0,56	288,58
2700	**2181,21**	**1876,31**	**594,71**	**0,54**	**173,34**
3000	**2208,63**	**1929,41**	**613,75**	**0,55**	**200,79**
3600	**2251,94**	**2011,43**	**646,79**	**0,56**	**244,08**
4800	**2291,11**	**2076,76**	**680,05**	**0,57**	**283,24**
6600	**2296,39**	**2088,34**	**684,97**	**0,57**	**288,51**

To better highlight the impact of OC integration together with the ORR, we report values of PSP load and station load from 1 (S1) to 5 (S5). Results have been reported for each WLC norms for both the ORR and for the ORROCI model (values in bold for the latter).

WLC norms (tu)	PSP load (tu)	S1 load (tu)	S2 load (tu)	S3 load (tu)	S4 load (tu)	S5 load (tu)
2700	2400	1657	1600	1603	1584	1631
3000	2154	1695	1626	1622	1602	1654
3600	1822	1755	1680	1676	1671	1709
4800	1608	1774	1708	1702	1691	1735
6600	1459	1805	1744	1737	1725	1767
2700	**2014**	**1582**	**1500**	**1505**	**1496**	**1535**
3000	**1931**	**1616**	**1550**	**1545**	**1528**	**1580**
3600	**1660**	**1685**	**1619**	**1624**	**1607**	**1655**
4800	**1533**	**1768**	**1713**	**1695**	**1687**	**1731**
6600	**1442**	**1807**	**1745**	**1739**	**1726**	**1768**

Values highlight that the integration of the OC in ORR decreases the average load in the PSP and in each station. This is particularly true when WLC norms are lower; in fact, as well as for the five system performance measures, with higher WLC norms the decrease of the load for PSP and for the five stations is negligible, when ORROCI is applied.

5. CONCLUSIONS AND FURTHER DEVELOPMENTS

This research presents preliminary results deriving from the integration of a specific OC strategy - Worker's allocation – with an ORR- workload limiting approach. The results are referred to a pure flow shop system. There are very few research studies that address the integration of ORR with OC. Moreover, none of them focused on a specific OC strategy. In addition, all considered a job shop as system configuration. The main element of novelty is, not only the integration of OC decision at the ORR phase, but also the consideration of a specific OC strategy, that is, in our case, worker's allocation. Then, the allocation of the workers is realized within the five stations of the flow shop, meaning that idleness time of periods are exploited and no extra capacity/extra workers are needed. In this way, flow shop performances improved without considering investment in extra capacity (overtime-subcontracting-extra-workers). Preliminary results show that the integration of the OC at the ORR phase increases the benefits already brought by the use of the ORR. In fact, lead time performances and due date adherence performances improved because idle times are shifted. Moreover, where to move the worker and which worker to transfer have been decided at the release phase considering the expected workload of each worker; in this way, just the right workers are transferred (workers whose stations will be under-loaded) and where it is more needed (stations that will be over-loaded). In this way, the number of transfers is constrained just to the needed and most beneficial ones. The evaluation of the expected workload leads to the release of additional orders thanks to the possibility of worker's transfer: idles times of worker are shifted to over-loaded stations. The results here presented are preliminary results and further developments emerge. The consideration of worker's allocation as OC mechanism brings the consideration of different parameters concerning labor allocation as for example, different flexibility and efficiency levels for workers. Then, different Who, Where and Who rules can be considered when dealing with worker's transfer and they refer to which worker should be transferred, when and where (in which stations). DRC literature investigated different worker's transfer matrices derived from the combination of different Who, Where and When rules.

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