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Investigation on the Performance of Order Release Methods in a Flow Shop with Bottlenecks

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Abstract

The workload control (WLC) is a popular concept in manufacturing planning and control, which plays a significant role in enhancing the efficiency of manufacturing firms that have uncertainty in meeting customer orders. Owing to changes in several set of factors, such as processing time variations, fluctuation in orders, and rise in quality issues etc., would disrupt production schedules and adversely affect the shop performance. Improvements are certainly possible by integrating WLC policies in distinct stages of production that in turn help to keep a steady workflow and balanced shop floor activities. In this study, we have considered the production of a part of a windmill that poses difficulties in production due to changes in processing times. A production shop simulation model was developed by considering real-time data. The model is simulated to analyze the performance under different order release methods at process time changes. In addition, we consider the influence of downtime and capacity cushion at bottleneck station. The objective of this research is to investigate the influence of the processing time variation, downtime, and capacity cushion on the performance of the shop floor and to evaluate the best release method suitable in different situations.

Keywords: Workload control, Order release methods, Work in process, Simulation;

1. Introduction

Recently in the domain of production and operations, management workload control (WLC) has gained popularity in job- shop production systems for the multiple benefits of effectively controllingmanufacturing [1]. In job shop production systems, the level of uncertainty is extremelyhigh, as it accommodates the varieties ofgoods that are produced in different volumes.In addition to this, processing time variations,set up time changes, different job sequences,changes in resources etc., are the factors that could affect the production system and makethe scheduling work complicated. All these aspects give rise to complexities and uncertainties in taking up new orders and running currently accepted orders [2]. Hence,the impact of such factors on system performance needs to be thoroughly investigated. The likelihood of impact of uncertainty on the system's performance would be predicted and needs to be incorporated into the production planning and scheduling phase. Therefore, a new decision-making model is crucial, that could be designed through WLC concepts toovercome the uncertain production situations.

WLC aligns planning the operations by coordinating and directing shop floor-related activities by integrating complexity issues. WLC makes the manufacturing processes clearer in understanding the manufacturing situation and evades any flaws in decision- making. Design and development of WLC delivers goods at the right time along with more efficient operations by keeping a steady flow of work, controlled inventory of semi- finished goods and resource use at the best level. WLC is also recognized as input/output control, as it sets the release dates, chooses the processing sequence with effective use and effective monitoring of work progress [3]. Though there is an adequate amount of past research on WLC by Fredendall et al.[4]; Betterton and Silver [5]; Golmohammadi [6]; and Thürer et al.[7-8], an important environmental factor such as processing time variations that could affect shop performance has not been considered. Thus, in this research, we develop a realistic model of flow shop with processing time variation and analyses performance under different order release methods.

2. Literature Review

The WLC has three major phases that includes job entry, job release and job processing. Job entry shows the orders accepted, but yet to be released on the shop floor for production. The release phase decides the date when each job is to be released on the shop floor. Once released it will remain on the shop floor until all the processes have been completed. The progress of the jobs is governed by the priority dispatch rules in the form of queues. The past literature suggests that researchers have developed a variety of policies that helps to integrate all the three phases to achieve the greatest performance. The main principle of WLC is to control queues and the key decision pertains to

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order release [2-3]. In shops the variations in processing time results in bottleneck and based on the release method adopted leads to shifting of the bottleneck [8]. Goldratt used the concept of the theory of constraints (TOC) for scheduling jobs and developed a popular bottleneck-oriented release policy that is referred to as Drum-Buffer-Rope (DBR) [9]. Implementation of the theory of constraint (TOC) led to improved delivery time, profit, and lead time reduction. Combining TOC and WLC with a change of their order acceptance/buffer management system resulted in substantial improvements in reducing the delivery time [10]. Goldratt argued that the optimum performance would be achieved by keeping an extra capacity than the actual requirements. Although, this additional capacity results in desired imbalance they would be utilized during high production requirements. However, industries without any additional capacity face capacity problems during order fluctuations. This extra capability is referred to as a protective capacity and helps absorb fluctuating workloads and stabilize the system. This DBR method incorporates protective capability and schedules the bottleneck machines by limiting the buffer size in front of the bottleneck machines [4]. Chakravorty [11] integrated dispatch rules with the order methods like DBR, immediate release and modified infinite loading (MIL) in a job shop environment and demonstrated that coupling DBR with the shortest processing time (SPT) yielded better performance than coupling DBR with first- come-first-serve (FCFS) dispatch rule. Besides, DBR performs better than other control policies such as constant work in process (CONWIP) and clockwork (CW) in the case of a single bottleneck machine. Other release methods such as pull from both bottleneck machines (PFBB) performed better than CONWIP, CW, pull from first bottleneck machine (PFB1) and pull from second bottleneck machine (PFB2) for multiple bottlenecks [12]. Furthermore, Enns and Costa [13] found that the bottleneck- oriented release performed effectively in a job shop with high routing variability and aggregate load release outperformed bottleneck-oriented release in a unidirectional flow shop. Additionally, Kim et al. [14] proposed two release methods output flow control (OFC), bottleneck flow control (BFC) and compared with dynamic flow control (DFC) under uncertain production environment. OFC and BFC outperformed DFC in an unbalanced line with work centre breakdown, bottleneck shift and time variability. Golmohammadi [6] debated that the effectiveness of DBR scheduling method in a complex job shop is determined by identifying the most influencing input parameters of scheduling such as batch size, inter-arrival time between the batches and raw material release time etc., and by fine-tuning current rules in setting these parameters. Changes in workload limits are necessary when a bottleneck shift occurs and there is a performance impact due to physical location, routing position. The effect of bottleneck position in convergent and divergent type flow shops needs to be studied as it forms a complex environment. Past research shows that the bottleneck position and workload limit are strongly associated variables, and it is important to explore dynamic solutions for linking these factors [7]. In a shop with bottlenecks, the schedule at the bottleneck determines shop performance precisely than the workload balancing and hence, release method must be chosen based on bottleneck severity. When there is a mix of jobs, routing varies and affects performance with or without bottleneck results in multiple bottlenecks and bottleneck shifting. The performance difference between WLC and DBR must be analyzed with multiple bottleneck shifting [15]. In general, with a line producing multiple products, each product will have a different constraint station. In such a condition, the influence of setups, a product mix on the location of constraints and their movements need to be investigated. Moreover, studying the relationship between the length of a production line and statistical variations of dependent events are also important [16]. The impact of direction and distance of bottleneck shift on the performance of a job shop must be investigated under the broad environmental settings such as machine failures, scrap rates and process time variability [14]. Research work conducted by Gilland [12]; Thürer et al.[7] demonstrate that DBR is superior to CONWIP, however, exploration is needed to identify the situations and contingent factors, that makes DBR dependent, when compared with CONWIP [8]. Therefore, our research sets up to bridge some of the above-found research gaps by considering an unbalanced line with two bottleneck stations. We perform relevant bottleneck-oriented order release methods in a multi-bottleneck line under a different environmental setting.

3. Conceptual Model

In the present research, we followed an approach proposed by Fernandes et al. [17], which involves developing a model of a production system based on process observation and analyzing the model. We consider a production shop, which manufactures a part of a windmill and production follows stage-by-stage processes in a fixed-line. In this flow shop production system, the arrival of jobs is assumed to be in a random fashion and hence, the inter-arrival times of jobs are considered to follow an exponential pattern [8]. The model is conceptualized through understanding processes and by closely observing the processes that are shown in figure 1.

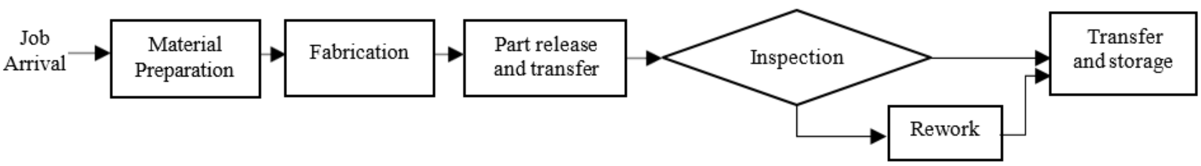

Figure 1. Conceptual model

The production of the part follows a fixed sequence, starts with material preparation, fabrication, release and transfer,an inspection of quality, rework, and finally transfer and storage. In the materialpreparation stage, raw materials required for the fabrication of parts are prepared by cutting in required dimensions and kept readyfor further processing.

Parts are fabricated inthe second stage through the required processes. Once the fabricated parts are ready to release, then the parts are transferred to theinspection bay for quality check. If the defects are observed in the product, the parts are undertaken to repair in the rework area. Finally, the reworked parts are released and deposited in the storage area. In this system, production activities begin with the job release, and flow of jobs takes place serially through the different stages from one end to the other end. If one of the stages is blocke due to any reason, the whole line undergoes disruption and lead to various problems.

In this flow shop, material preparation, part release and transfer, inspection, and storage are the non-bottleneck stations. However, disruptions are quite common in two stages such as fabrication and rework. Fabrication stage contains moulds, the glass layers are laid up, matrix is infused and allowed cure. Uncertainties in the stage are due to the following reasons: i) the process is labour oriented; ii) infusion is allowed only when the shop temperature is within the limit. Fabrication is time consuming along with these uncertainties cause bottleneck. The processing time variations in rework stage are due to technical issues of observation of defects. It is difficult to predict the processing times due to the criticality of defects in the parts produced. The type, size, location, and severity of the defects are different for each product. Hence, the rework time would vary for each product and is probabilistic in nature. In addition, station breakdowns are the issue that affects the production schedule. These aspects cause bottlenecks and our research makes an effort to understand the benefits of workload control theory in eliminating the detrimental effects of bottlenecks. In supply chain, re-processing is a main stage and it is important to decide whether it is push or pull driven [18]. This research intends to evaluate the impact of change in defect severity on the performanceof workload control strategies and determining a suitable strategy for an unbalanced flow shop. Thus, our researchintends to examine the following questions that are based on the literature review and real-time issues as observed in the flow shop:

- What are the right release methods tobe adopted when there is a variation in theprocessing time?
- How does the downtime and capacitycushion at bottleneck influence the flow shop performance?

As conducting this experiment is impossible in the real time at the real production shop, we developed a simulation model and analyze the dynamic performance.

4. Simulation Model

Overview of the simulated shop and job characteristics are outlined in section 4.1.Based on the past literature and shop characteristics, we considered bottleneck oriented order release methods such asCONWIP, immediate release, pull frombottleneck-I, pull from bottleneck-II and pullfrom both bottleneck as outlined in section 4.2, priority dispatching rule is described in section 4.3, and experimental design isdescribed in section 4.4.

4.1. Overview of the simulated shop and job characteristics

A simulation model is implemented on Arena V15 software [19-20]. The simulationmodel is a representation of pure flow shop with six workstations of dissimilar capacity. Each workstation is unique in terms of capacity and process. The process characteristics are computed through the observation of real-time production and re-entrants are not considered. Inter-arrival time follows an exponential distribution with mean 5.09 time units. Operating processing time of non-bottleneck stations follows a 2- Erlang distribution with mean 1.06 time units and a maximum of 1.63 time units. It was identified that there are two processes as bottleneck stations based on the process time requirements. In bottleneck station-II, the severity of defects is categorized into three levels based on the frequency of defects and rework time observed in the process. Operating processing time of bottleneck stations follows a 2-Erlang distribution with mean 2.4 time units and a maximum of 3.8 time units. Station downtime is measured based on the combination of mean time to repair and mean time between failures. The station downtime is set at three levels i.e., 10%, 15% and 20%. Capacity cushion is considered only at first bottleneck station at three levels i.e., 0%, 2%, 4%. These shop and job characteristics modeled in the simulation study are summarized in Table 1.

Table 1: Summary of simulated shop and jobcharacteristics

Shop Characteristics	
Shop Type	Pure flow shop; Fixed sequence
Characteristics	Real
Routing Variability	Unidirectional
Re-entrants	No
Number of workstations	6
Workstation capacity	Unequal
Job Characteristics	
Operation processing time (non-bottleneckstation)	2-Erlang distribution; (min=0.45; mean = 1.06;max = 1.63) time units
Operation processingtime (bottleneck stations)	2-Erlang distribution; (min=1; mean = 2.4; max = 3.8) time units
Inter-arrival times	Exponential distribution; mean=5.09 time units
Downtime levels	10%, 15%, 20%
Capacity cushion	0%, 2%, 4%

4.2. Order release methods (ORR)

Our research focus on the flow shop with bottleneck stations and past literature suggests the execution of bottleneck-orientedrelease methods. Hence, we considered relevant order release methods such as CONWIP, Immediate release, pull from bottleneck-I, pull from bottleneck-II, and pullfrom both bottlenecks.

4.3. CONWIP

In this release policy, the work in process inthe entire production shop is kept constant. Every new release of the job to the productionsystem is based on the completion of previously released job and work in process is kept under a specified limit.

4.4. Immediate Release (IMMD)

In the immediate release method, the jobs arereleased immediately to the shop floorwithout any prior conditions. This conservation policy follows first come first serve basis. The jobs are being released on the shop floor are immediately taken up for processing without applying any rules.

4.5. Pull from Bottleneck-1 (PFB1)

In this release policy, the quantity of jobs is held constant at the first bottleneck station. Anew job is released only when the job finishesthe first bottleneck station.

4.6. Pull from Bottleneck-2 (PFB2)

In this release method, the quantity of jobs isfixed before the second bottleneck station, and a new job is released only after the processing of the second bottleneck machine.

4.7. Pull from both Bottlenecks (PFBB)

In this release method, setting a maximum number of jobs before both the first and second bottleneck stations. A new job is released when work in process before each bottleneck is under the set limit.

4.8. Shop floor dispatching rules

Once the jobs are released to the shop floor, operations are performed in a particular sequence that depends on the type of dispatching rule used. Priority dispatchinghelps to monitor the progress of jobs waitingin the form of queues in front of machines onthe shop floor. If an order release method is effective in keeping the length of queues in a desirable limit then dispatch rules become unproductive and, in such cases, use of conservative rule like first-come-first-serve (FCFS) would be beneficial [3]. In this research, we have considered a flow shop thatprocesses only one type of product adopting a FCFS basis.

4.9. Experimental Design

We have conducted three distinct set of experiments for three variables such a processing time variation, station downtime, and capacity cushion. In each experiment, a full 5x3 factorial experimental design was used. Five release methods have been applied at three levels of each variable, which results in 15 experiments. In each combination strategy, five replications are used with initial 1000 hours discarded (warm-up period) to reach steady-state conditions. Each experiment is run for 10000 hours. We consider one factor at a time for experimentation.

5. Simulation Results and analysis

We discuss the shop performance under threelevels of process time variation, station downtime, and capacity cushion. In addition, we conduct an analysis of variance (ANOVA) for critical variable process time variation. The results are described in thesubsequent sections.

5.1. Process time variation

We statistically analyzed the simulation results by conducting ANOVA toinvestigate the comparative effect of experimental factors. The ANOVA results help to understand the relationship between various release methods under each level of processing time variation (PTV). In this test,PTV is taken as the blocking factor for different processing time levels, are considered as the different systems. The maineffects and interaction effects of PTV and ORR are captured and presented in the ANOVA Table 2.

The dependent variables in the study are production time, work in process inventory, fabrication waiting time, rework waiting time, and resource utilization. The independent variables are the PTV and ORR. At 5% significance level, the main effects of PTV, ORR and interaction effects of (PTV*ORR) are discussed. When the main effects are considered, with respect to p- values less than 0.05, first factor, PTV has significant influence on all the performance factors except fabrication time and resource-I utilization. Second factor, ORR has significant influence on fabrication waiting time and rework waiting time.

When the interaction effects of (PTV*ORR) are considered, the factors withp-values less than 0.05, i.e., p-value=0.028 for fabrication waiting time and p-value=0.00 for rework waiting time, shows the significant influence on the performance. This identifies that the relationship between order release methods and waiting times depends on process time variation. Hence, it is critical to identify the bottleneck stations toimprove the performance of the shop. When the main effects are considered, process time variation has considerable influence on production time, work in process inventory, rework-waiting time and resource-II utilization and the results are insignificant with fabrication waiting time and resource-I utilization. Second factor, ORR significantlyinfluence only fabrication waiting time and rework waiting time. Some significant facts have been observed from the results and graphs. Performance is measured based on the production time, work in process level, waiting time at two operations and resource utilization. The experimental results are plotted to understand the performance of various ORR. The performance is shown in the graphs, (Figure 2 to Figure 5) with the X-axis representing PTV from low to high.

Table 2. ANOVA Results

Performance Measure	Sources of variance	Degrees of freedom	Sum ofsquares	Mean squares	F-ratio	*p*- value
ProductionTime	Process time variation (PTV)	2	137633	68816.7	223.54	0.00
	Order release rules (ORR)	4	278	69.6	0.23	0.923
	PTV*ORR	8	1114	139.3	0.45	0.884
	Error	60	18471	307.9		
Work InProcess	Process time variation (PTV)	2	839.11	419.555	29.45	0.00
	Order release rules (ORR)	4	30.49	7.622	0.53	0.711
	PTV*ORR	8	95.63	11.953	0.84	0.572
	Error	60	854.8	14.247		
Fabrication Waiting time	Process time variation (PTV)	2	109885	54942	1.24	0.296
	Order release rules (ORR)	4	18739725	4684931	106.03	0.00
	PTV*ORR	8	834796	104349	2.36	0.028
	Error	60	2651107	44185		
Rework waiting time	Process time variation (PTV)	2	5591171	2795586	39.33	0.00
	Order release rules (ORR)	4	6798285	1699571	23.91	0.00
	PTV*ORR	8	3449631	431204	6.07	0.00
	Error	60	4265105	71085		
Resource-I Utilization	Process time variation (PTV)	2	0.000889	0.000445	0.46	0.634
	Order release rules (ORR)	4	0.002957	0.000739	0.76	0.554
	PTV*ORR	8	0.006621	0.000828	0.85	0.56
	Error	60	0.058156	0.000969		
Resource-II Utilization	Process time variation (PTV)	2	0.421736	0.210868	237.99	0.00
	Order release rules (ORR)	4	0.002332	0.000583	0.66	0.624
	PTV*ORR	8	0.005999	0.00075	0.85	0.566
	Error	60	0.053162	0.000886		

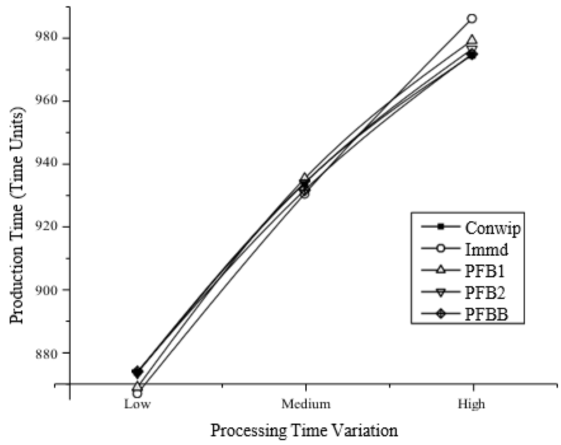

Figure 2. Production time (Time Units)

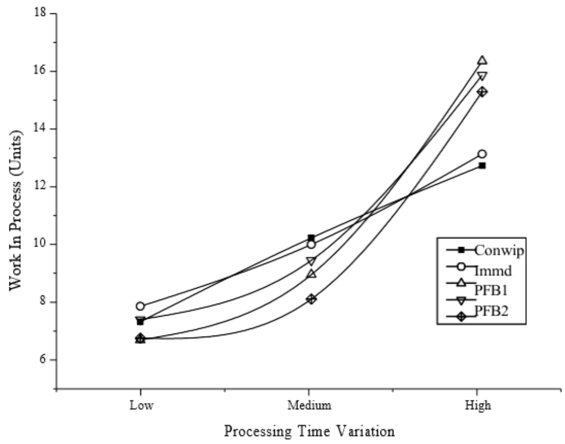

Figure 3. Work in process (Units)

It is observed that the performances of individual order release rules are vary withthe defect criticalities. Hence, a single order release method may not be suitable at a different level of settings.

Figure 2 demonstrates that when production time is considered withimmediate-release, it shows better results in lower and medium levels of bottleneck severity, but shows poor results at a high levelof bottleneck severity. CONWIP does not perform well at a lower level of bottlenecks, performs moderately at a medium level, and works out to be better at high levels of bottleneck severity. PFB1 and PFB2 perform moderately at all levels of bottleneck severity. PFBB shows better results only at high levels of bottleneck severity.

The Work in process inventory resultsis shown in figure 3. When work in process inventory is concerned, CONWIP followed by immediate release yields better results at high levels of PTV. PFBB performed better in low and medium levels of PTV. PFB1 andPFB2 were not suitable in any levels of PTVdue to its poor results.

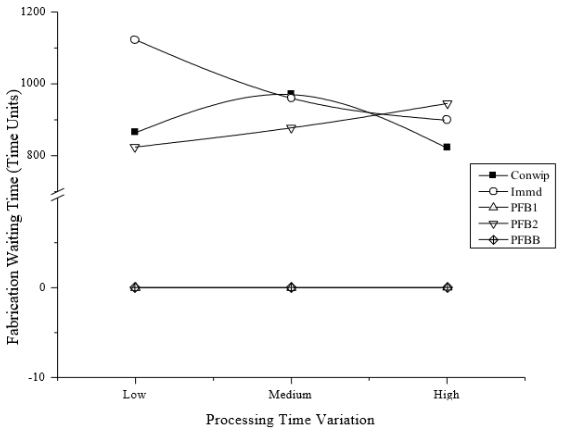

Figure 4. Fabrication waiting time (TimeUnits)

The fabrication-waiting time is shown in Figure 4. PFB1 and PFBB yielded better results irrespective of levels of PTV asthese release methods have closer control over the bottleneck station-1. When we compare the other three ORRs such as CONWIP, IMMD, and PFB2, PFB2 works better at lower and medium levels of PTV, CONWIP performs better only in the high level of PTV. IMMD works satisfactorily at higher levels of PTV and showed poor resultsat low and medium levels of PTV.

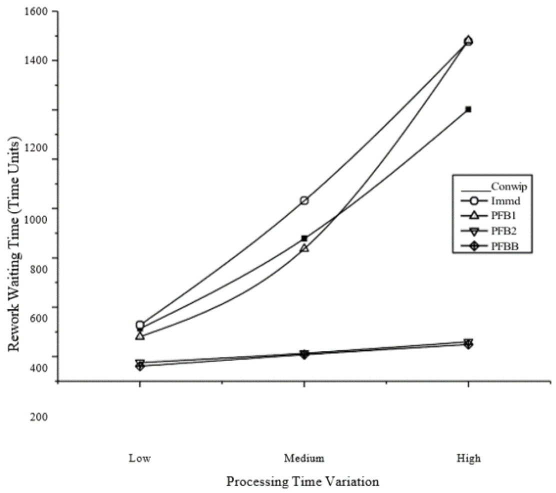

Figure 5. Rework waiting time (Time Units)

Figure 5 shows the results for reworkwaiting time, PFB1 and PFBB are highlyeffective in reducing the waiting times at bothbottleneck stations at all levels of severity. When CONWIP, immediate release andPFB1 are concerned, at a low level the resultsare same, but as the severity increases, CONWIP works better than other release policies. PFB1 shows better results at low and medium levels of severity but itsperformances diminish at the higher level of severity. PFB1 limits only the bottleneck station-I and parts passed the first bottleneckwill wait at the second bottleneck, which results in work in process, hence performancedeclines.

Figure 6 shows the resource utilization of the first bottleneck station during PTV. Resource-I is utilized approximately from 83 to 85 per cent of the times irrespective of the level of PTV. This indicates the utilization of resource-I is uninterrupted due to the changes in processing time. The variance observed in the bottleneck station-I is quite less compared tothe bottleneck station-II.

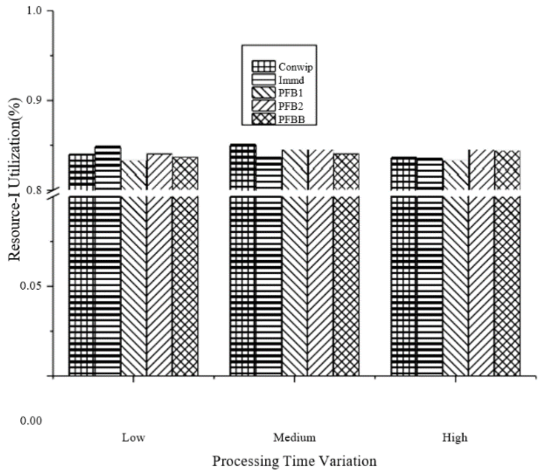

Figure 6. Resource-I Utilization (Percent)

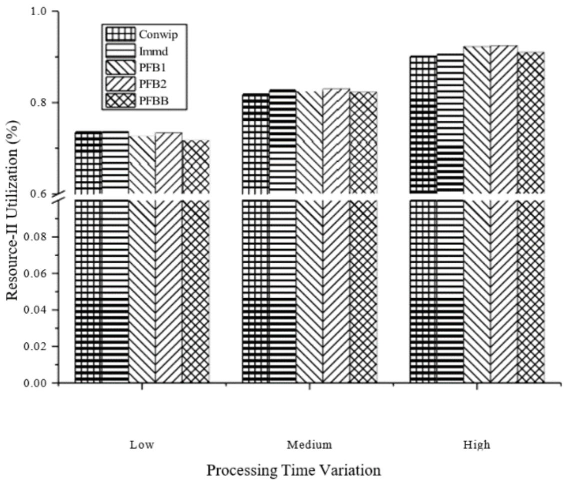

Figure 7. Resource-II Utilization (Percent)

From the graph, it is clear that utilization of resource-II increases from 71 to92 per cent with the increases in process time variability. As the rework increases the resource requirements also increase which in turn improves the utilization. An extra 8 per cent of capacity cushion still is available to accommodate any variation in orders. Resource utilization of bottleneck station-II is shown in figure 7.

5.2. Downtime levels

The influence of different levels of downtime on performance of flow shop was also investigated. Consideration of downtimelevels is based on factors that give rise to downtime such as unexpected machine breakdowns, tool failures and supply chain failures. We investigate the influence of threelevels of down time on the work-in-process inventory and throughput under different release methods. The performance in terms of work in process and throughput of is shown in the graphs, (Figure 8 to Figure 9) with the X-axis representing downtime level from 10% to 20%.

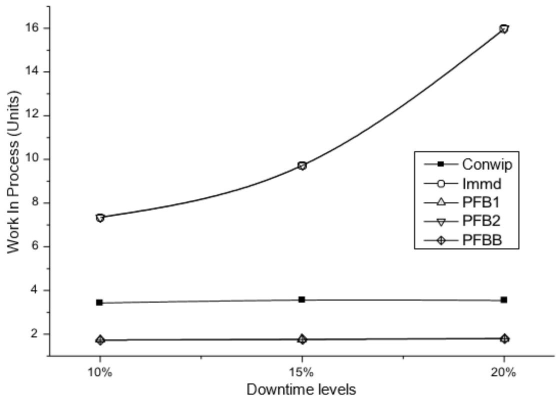

Figure 8. Work in process at downtime levels (Units)

The fluctuations in work-in-process under different down time level is shown in Figure 8. PFB1 and PFBB generated better results regardless of levels of downtime. CONWIP performed moderately but performance is same at all levels. IMMD and PFB2 are not influenced by the downtimelevel.

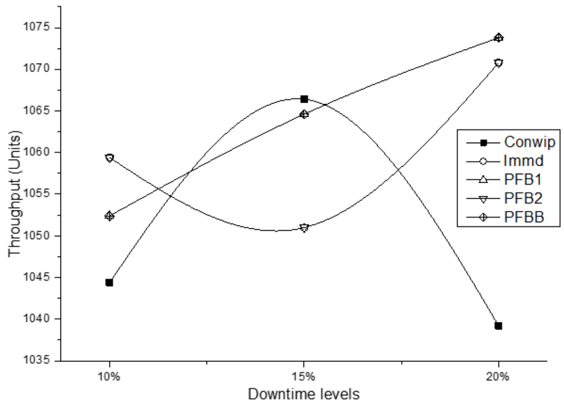

Figure 9. Throughput at downtime levels(Units)

Figure 9. Shows the throughput at various levels of downtime. We observed thatrelease methods IMMD and PFB2 are suitable at lower downtime, CONWIP is bestwhen downtime is moderate and PFB1 and PFBB which works better when downtime level is high.

5.3. Capacity cushion at bottleneck-I

Literature shows that provision of protectivecapacity at non-constraints will improve the shop performance [18]. We consider the capacity cushion at constraint station in termsof improving skill level. We assume that skilllevel improvement will bring down the bottleneck process time. We examine the shop performance like work-in-process and throughput at different levels of capacity cushion. The performance in terms of work in process and throughput of is shown in the graphs, (Figure 10 to Figure 11) with the X-axis representing downtime level from 0% to 4%.

Capacity cushion versus work in process graph is shown in Figure 10. The work-in-process slightly decreases if capacity cushion is introduced but there is nosignificant improvement. PFBB, PFB1 and CONWIP were not much influenced by the variation of capacity. However, influence was observed in PFB2 and IMMD release methods.

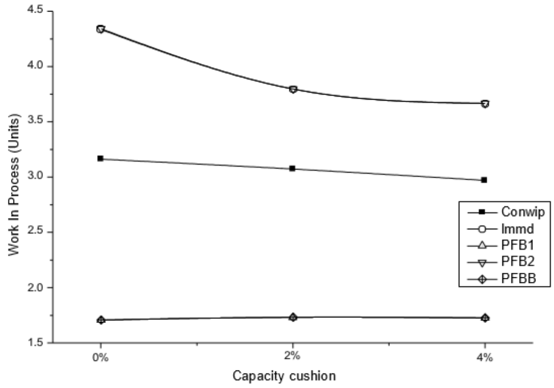

Figure 10. Work in process under capacity cushion (Units)

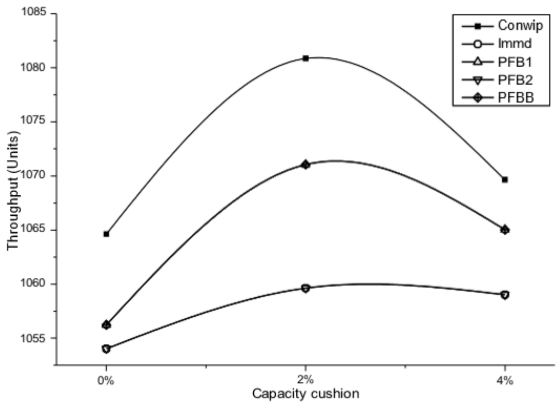

Figure 11. Throughput under capacity cushion (Units)

In Figure 11, we see that throughput improves at 2% improvement of skill level but decreases at 4% improvement. The trendof graph looks same with respect to all releasemethods. Further improvement of skill level may have adverse effect on the performance. Based on the throughput outcome CONWIP outperformed over other release methods.

5.4. Discussion of results

Gilland [12] argues that in case of dual bottlenecks PFBB dominates other policies like COWIP, PFB1 and PFB2. In thiscase it may be certainly true but when process time variability is introduced in a shop with dual bottlenecks CONWIP outperforms otherrelease methods. Gilland [12] demonstrates that if the limit for work in process is set maximum at second bottleneck machine PFBB works exactly like PFB1. We observe similar behavior in our model and it is due to the shift in control point from second bottleneck to first bottleneck. Betterton and Cox [9] argued that release method can be chosen as to help overcome variability. Additionally, releasing jobs by assessing bottleneck capacity and stop release during unexpected downtimes as it might cause bottlenecks. We use similar approach in our model and observe that performance is not much influenced by the downtime level. It ismight be due to availability of buffer level infront of bottleneck machine which absorbfluctuations during long run. Research studies [21-22] focused on the influence of protective capacity towards reducing the bottleneck shifts. Research outcomes state that protective capacity at non-constraint stations helps to overcome bottleneck shifting and improve flow time.

Fredendall et al. [4] found that the bottleneck and the protective capacity important parameter to judge the shop performance. Thürer et al. [7] describes that protective capacity can be changed either by redistributing capacity or by manipulating the flow shop work. Weredistribute work in flow shop by placing capacity cushion at bottleneck station in terms of improvement in skill level. We found that improvements are certainly possible with optimum level of capacity cushion.

6. Conclusion

This research has investigated the performance of a flow shop with different release methods under distinct levels of uncertainty. Simulation model of aproduction system was developed which hassix workstations with two bottleneck stations.The performance of the production is measured in terms of production time, work in process inventory, throughput, resource utilization and waiting time at bottleneck machines. Simulation results show that CONWIP is best ORR in terms of all performance measures, at higher process time variability. However, when the performance is measured based on waiting time and work in process level, PFB1performed better at the medium level of process time variability and PFBB is best at lower levels of process time variability. The improvement in resource utilization is observed, as there is an increase in the process time variation. The ANOVA results showed that PTV has a significant effect on performance. However, the main effects of ORR and the interaction effects of ORR*PTV are statistically significant only with respect to fabrication waiting time and rework waiting time. It is insignificant on other factors, which may be due to two following reasons: i) the process that considered has machines with less process time difference between the machines. ii) The bottleneck release methods exercised in this study are similar type. When downtime is introduced at bottleneck station, PFBB and PFB1 outperformed. CONWIP worked well when a capacity cushion placed at bottleneck station, results show that any further addition of capacity may lead to loss of performance. The release methods applied in the study used work in process as control criteria, i.e., the work in process level is varied in each release methods. Hence, the release methods are not significant for the considered scenario. However, as other studies this study too have limitation, we have not considered the aspect of due date which could be incorporated into future research and analyzed. Literatures suggest that six sigma practices would help to improve quality of product and reduce production time by concentrating on process parameters [23]. Further studies are also possible that focus on reducing quality problems by incorporating six sigma methodologies.

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REFERENCES

[1] Thürer, M., Stevenson, M., and Land, M.J., “On the integration of input and output control: Workload Control order release”. International Journal of Production Economics, Vol. 174, 2016, 43–53.

[2] Sabuncuoglu, I., and Karapinar, H.Y., “A Load-based and Due-date-oriented Approach to Order Review/Release in Job Shops”. Decision Sciences, Vol. 31 (2), 2000, 413–447.

[3] Land, M.J., and Gaalman, G.J.C., “The Performance of Workload Control Concepts in Job Shops: Improving the Release Method”. International Journal of Production Economics, Vol. 56–57, 1998, 347–364.

[4] Fredendall, L.D., Ojha, D, and Patterson, J.W., “Concerning the theory of workload control.” European Journal of Operational Research, Vol. 201, 2010, 99–111.

[5] Betterton, C.E. and Silver, S.J., “Detecting bottlenecks in serial production lines – a focus on interdeparture time variance”. International Journal of Production Research, Vol. 50 (15), 2012, 4158- 4174.

[6] Golmohammadi, D., “A study of scheduling under the theory of constraints”. International Journal of Production Economics, Vol. 165, 2015, 38–50.

[7] Thürer, M., Qu, T., Stevenson, M., Li, C.D., and Huang, and G.Q., “Deconstructing bottleneck shiftiness: the impact of bottleneck position on order release control in pure flow shops”. Production Planning and Control, Vol. 28 (15), 2017, 1223-1235.

[8] Thürer, M., and Stevenson, M., “Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation”, International Journal of Production Economics, Vol. 197, 2018, 275-282.

[9] Betterton, C.E., and Cox III, J.F., “Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models”. International Journal of Production Economics, Vol. 117, 2009, 66–79.

[10] ebos, J., Korte, G. J., and Land, M.J., “Improving a practical DBR buffering approach using Workload Control”. International Journal of Production Research, Vol. 41 (4), 2003, 699-712.

[11] Chakravorty, S.S., “An evaluation of the DBR control mechanism in a job shop environment”. OMEGA, Vol. 29, 2001, 335–342.

[12] Gilland, W.G., “A simulation study comparing performance of CONWIP and bottleneck-based release rules”. Production Planning Control, Vol. 13 (2), 2000, 211–219.

[13] Enns, S.T., and Prongue Costa, M., “The Effectiveness of Input Control Based on Aggregate versus Bottleneck Work Loads”. Production Planning and Control, Vol. 13 (7), 2002, 614– 624.

[14] Kim, S., Davis, R.K., and Cox III, J.F., “An investigation of output flow control, bottleneck flow control and dynamic flow control mechanisms in various simple lines scenarios. Production Planning and Control: The Management of Operations”, Vol. 14 (1), 2003, 15-32.

[15] Thürer, M., Stevenson, M., Silva, C., and Qu, T., “Drum-Buffer-Rope and workload control in high variety flow and job shops with bottlenecks: an assessment by simulation”. International Journal of Production Economics, Vol. 188, 2017, 116–127.

[16] Betterton, C.E., and Cox III, J.F. “Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models”. International Journal of Production Economics, 117, 2009, 66–79.

[17] Fernandes, N.O., Silva, C., and Carmo-Silva, S., “Order release in the hybrid MTO–FTO production”. International Journal of Production Economics, Vol. 170, 2015, 513–520.

[18] Jayanth, A, Gupta, P and Garg, S.K., “Perspectives in Reverse Supply Chain Management(R-SCM): A State-of-the-Art Literature Review”. Jordan Journal of Mechanical and Industrial Engineering, 2012, 87-102.

[19] Renna, P. "Dynamic Control Card in a Production System Controlled by CONWIP Approach". Jordan Journal of Mechanical and Industrial Engineering, 2010. 425 – 432.

[20] Kelton, W.D., Sadowski, R.P., and Swets, N.B. "Simulation with ARENA". McGrawHill Eduction. 2017.

[21] Craighead, C.W., Patterson, J.W., and Fredendall, L.D. "Protective capacity positioning: Impact on manufacturing cell performance". European Journal of Operational Research, 134, 425-438.

[22] Kadipasaoglu, S.N., Xiang, W., Hurley, S.F., and Khumawala, B.M. "A study on the effect of the extent and location of protective capacity in flow systems". International Journal of Production Economics, 63, 2000, 217-228.

[23] Mandahawi, N., Fouad, R. H., Obeidat, S."An Application of Customized Lean Six Sigma to Enhance Productivity at a Paper Manufacturing Company". Jordan Journal of Mechanical and Industrial Engineering, 2012, 103 – 109.