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Comparison of SCONWIP, DCONWIP, TOC and CWIPL II in Job Shop

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Abstract Critical WIP Loop II (CWIPL II) is a control mechanism previously proposed for unbalance flow line. The purpose of this paper is show how to apply CWIPL II in job shop and then comparing it with Theory of Constraint (TOC), Dedicated CONWIP (DCONWIP) and Shared CONWIP (SCONWIP). The Performance measures considered are average throughput, average lead time, average tardiness time and percent of tardy. Two set of examples are simulated. At First set, each job has a bottleneck that is not bottleneck for other jobs. Simulation results and statistical tests demonstrates that CWIPL II has better lead time and throughput compared to TOC and CWIPL II has better or the same due date compared to TOC. TOC works better than DCONWIP for all performance measures and DCONWIP is better than SCONWIP for average throughput lead time and tardiness time while DCONWIP and SCONWIP are the same for percent of tardy. At second set, single machine is bottleneck for all jobs. So the Job shop has one bottleneck. In this set, TOC has better lead time, tardiness and percent of tardy compared to CWIPLII, DCONWIP and SCONWIP with the same throughput.

Keywords Job Shop, CONWIP, TOC, CWIPL II, Throughput, Due Date Performance

1. Introduction

Increasing competitiveness in the global market has led firms to place greater emphasis on their performance. The material flow control (MFC) mechanism of a firm has a major role on the firm's performance. The main objective of MFC mechanism is to manage the flow of material to minimize work-In–Process, minimize lead time, maximize throughput and maximize customer responsiveness.

Because of MFC mechanism influences the performance measures of a manufacturing line, many MFC mechanisms have been developed. These are including Base Stock System (BSS), Material Requirements Planning (MRP), Line Requirements Planning (LRP) , Just in Time (JIT), Constant Work in Process (CONWIP), Optimized Production Technology (OPT), Workload Control (WC), Starvation Avoidance (SA), Queue Management Release Policy (QMRP), Load Oriented order release (LOOR), Theory of constraints (TOC), Waiting time heuristic , Decentralized WIP oriented (DEWIP), Gated MaxWIP, Critical WIP Loops (CWIPL), CWIPL II, Cobacabana and WIPLCtrl (Graves et al. 1995, Graves and Milne 1997, Lodding et al. 2003, Grosfeld Nir and Magazine 2002, Sepehri and Nahavandi 2007, Nahavandi 2009, Land 2009, Gonzalez-R et al. 2011, Qi et al. 2009).

This study focuses on the previously proposed material flow control mechanism in flow shop named CWIPL II and compares it with CONWIP and TOC. So the literature review focuses on research related to that topic.

The mechanism of maintaining a constant level of WIP in the line is "constant work in process". Spearman et al. (1990) refer to their mechanism as CONWIP. Under CONWIP, the first machine visited by a job is only authorized to begin production if the total number of WIP is less than the specified target WIP level. No WIP target level is set for individual buffers between machines. Rather, CONWIP seeks to maintain a constant total WIP level in the line, with the objective of keeping the bottleneck busy (Kim et al. 2003). So under CONWIP, when a part has left the system, another part is triggered to start instantaneously. The control policy is to push materials to downstream machines as quickly as possible.

In the case of multiple products, CONWIP can be applied in two approaches, Dedicated CONWIP (DCONWIP) and Shared CONWIP (SCONWIP). In DCONWIP the target WIP level is defined for each product type so individual product WIP levels are controlled. So when a job has completed processing, it is replaced by a new job of the same type (Ryan et al. 2003). In SCONWIP the target level of WIP is defined for all product types so when a job has completed processing, a new job is released into the system whose type is determined probabilistically according to the product mix. So In this approach the WIP mix is not controlled directly and is not fix (Ryan et al. 2003).

Theory of constraints (TOC) was developed in 1986 by Goldratt and Fox. Goldratt (1992) defines a constraint as anything that limits a system from achieving a higher performance versus its goal. Hence in an unbalanced flow line, the constraint is the slowest machine in the line which is named "bottleneck". Goldratt and Cox (1986) recognized that the bottleneck often governs the production rate of the entire manufacturing line. Thus they propose a mechanism which called it "drum-buffer- rope" (DBR). The first machine is only authorized to begin production if the WIP upstream the bottleneck machine is less than the target level. The DBR method is used to control production. As Chakravorty et al. states a "drum" is the exploitation of the constraint of the system, the constraint dictates the overall beat or pace of the system. A "buffer" is protection time buffers are used to protect the drum from disruptions on the adjacent operations. Two time buffer is used: one time buffer referred to as the constraint buffer and is placed between material release and primary bottleneck. It provides sufficient processing time at the non-constraint resources preceding the bottleneck operation to ensure that any disruptions in order's flow do not prevent it from arriving at the constraint in time to meet the drum schedule. The second time buffer, called the shipping buffer, allows sufficient time for orders to flow across non-constraint operations after leaving the primary bottleneck so they arrive in shipping in time to meet their due dates (Chakravorty et al. 1996). A "rope" is a mechanism to force all the parts of the system to work up to the pace dictated by the drum and no more (Shrangheim et al. 1990).

Critical WIP Loops (CWIPL) was developed by Sepehri and Nahavandi (2007) for balanced flow shop. It is shown that every line, even balanced line has critical machine that demonstrate the performance of the line. The WIP of the critical machine works as the crystal ball. It means that careful observation of the WIP of the critical machine can tell us a great deal about the way that the line operates and then decide whether to release or not the material to the line. The main goal of CWIPL control mechanism is to set a WIP at the critical machine to a predefined level. It is shown that last machine is critical machine in balanced line. So WIP control loops design in such a way that utilization of the last machine is high and at the same time prevents the release of more parts than the last machine can process. In CWIPL the raw material is released to the balanced line if the 'total WIP of the line' or 'the WIP of the last machine' is less than the limit. Besides the aformentioned condition, the necessary condition for releasing the raw material to the line is idleness of the first machine.

CWIPL II was developed by Nahavandi (2009) for unbalanced flow shop. CWIPL II proposed a new classification for unbalanced flow line which is "near unbalanced flow line" and "perfect unbalanced flow line". This classification helps to propose the appropriate material flow control mechanism in which it offers better controls.

In unbalanced flow line the mean or variance of the processing time of machines are not the same. Assume that pi is the mean processing time of machine i. If the mean processing time of machines is sorted increasingly as {P[1], P[2], …, P[k-1], P[k]}where P[1] = Min {P1, P2, …, Pk-1, Pk} and P[k]= Max {P1, P2, …, Pk-1, Pk}. It means that P[1] is the mean processing time of fast machine and P[k] is the mean processing time of slowest machine. Then M[1] is the machine with smallest mean processing time (fast machine) and M[k] is the machine with largest mean processing time (slowest machine)[6]. If P[k]-P[k-1] is large enough, then the line is called "near unbalanced line". The experimental examples show that approximately if P[k]-P[k-1] is larger than (P[k]- P[1]) / 2 then P[k]- P[k-1] is large enough. If P[k]- P[k-1] is small enough, then the line is called "perfect unbalanced line.

In "near unbalanced flow line", there is one bottleneck (M[k]) and a raw material release to the line if "WIP of the bottleneck (exactly in front of M[k]) "or "WIP upstream the bottleneck (WIP accumulated between the first machine M1 and M[k] "is less than defined level. The necessary condition for releasing raw material to the line is idleness of the first machine (M1) (Nahavandi 2009).

In "perfect unbalanced flow line" there are multiple bottleneck and a raw material release to the line if "WIP upstream the slowest machine (M[k])" or "WIP between two primary bottlenecks (M[k]and M[k-1])" is less than defined level. As before, the necessary condition for releasing raw material to the line is idleness of the first machine (M1) (Nahavandi 2009).

Shop floor configuration is a major factor determining the performance measures of MFC mechanisms. In general there are two configurations, Flow shop and job shop. A flow shop is a manufacturing system consisting of work centers separated by storage areas in which material flows in a fixed sequence, to produce a product in a high volume so the material flow in one direction. A job shop is a manufacturing system producing a wide variety of products at relatively low volumes. A job shop consisting of work centers which material flows in a different sequences to produce different products. So job shop environment is more complex than flow line because the shop try to meet orders of different products with different quantity and different due date for different customers.

Research on CONWIP, TOC and CWIPL has primarily focused on flow shop that produces one or more similar products. For examples Kim et al. (2003) compared CONWIP, TOC and dynamic flow control mechanism. They showed that both CONWIP and TOC perform favorably under different scenarios. Fargher (1997), Miltenburg (1997) and Chakravorty and Atwater (1995, 1996) also used simulation to compare MFC mechanisms, while Sale and Inman (2003) used a survey approach to compare JIT and TOC. They concluded that TOC has significantly higher performance than JIT. Gilland (2002) evaluate the performance of a manufacturing system under CONWIP and bottleneck based release rule in flow line with single and multiple bottleneck. He showed that bottleneck based release rule is superior that the other. In 2004, Koh and Bulfin compared DBR with CONWIP in an unbalanced line with three stations. They found that DBR is better than CONWIP.

As stated above, much research has studied the MFC mechanisms in flow line. But little has been done in job shop environment. For example, Ryan and Choobineh (2003) identify the total WIP, WIP mix and minimum total WIP to achieve maximum throughput in a job shop environment operating CONWIP. Newman and Maffei (1999) simulate the effect of routing flexibility, order release mechanism and sequencing rules in job shop. Atwater and Chakravorty (2002) evaluate DBR mechanism compared to Immediate release (IMM) in a 13- station job shop producing 10 products. They conclude that DBR has less mean flow time than IMM and IMM has better due date performance than DBR. Santoro and Mesquita (2008) study the effect of the work-in-process control on due date performance in job shop environment. The due date performance is measured by both the number of tardy jobs and the total tardiness. They concluded that due date performance is highly dependent on the work-in-process, particularly after the system reaches saturation.

It must be noted that implementing MFC mechanism in job shop is significantly more complicated than flow line. On the other hand the growth and importance of job shop make it necessary to undertake more research on it. The purpose of this paper is to compare SCONWIP, DCONWIP, TOC and CWIPL II mechanisms in job shop environment.

2. Applying CWIPL II in Job Shop

A job shop is a manufacturing system producing different types of products by using different process plans on machines. So each product type has its routing on machines and its processing time on it. In CWIPL II, each product is considered individually and has its own bottleneck. So for each product determine that the line is "near unbalance" or "perfect unbalance" and then release order based on these rules for each product.

2.1. Near Unbalance Line

Rule 1: Protect the WIP upstream the bottleneck machine (WIP accumulated between the first operation and bottleneck of that product).

An order is released if the WIP upstream bottleneck machine is less than the "WIP target level". If the first operation is not bottleneck for any products, then the necessary condition for releasing the order is idleness of the first machine.

Rule 2: Protect the WIP of the bottleneck (exactly in front of bottleneck).

The WIP of bottleneck increases one unit at the time of entering a part to the bottleneck and decreases one unit when leaving a part from the bottleneck.

So an order is released to the line if the WIP is less than the specified "WIP parameter". If the first operation is not bottleneck for any products, then the necessary condition for releasing the order is idleness of the first machine.

Therefore, one can release order into the line if rule 1 or 2 is satisfied.

2.2. Perfect Unbalance Line

Rule 1: Protect the WIP upstream the bottleneck machine (WIP accumulated between the first operation and bottleneck of that product).

An order is released if the WIP upstream bottleneck machine is less than the "WIP target level". If the first operation is not bottleneck for any products, then the necessary condition for releasing the order is idleness of the first machine.

Rule 2: Protect the WIP between two primary bottlenecks (M[k] and M[k-1]).

If the above WIP is less than the "WIP parameter" then a raw material release to the line. If the first operation is not bottleneck for any products, then the necessary condition for releasing the order is idleness of the first machine.

Like near unbalanced line, one can release the raw material into the line if rule 1 or 2 is satisfied.

3. Comparison of SCONWIP, DCONWIP, TOC and CWIPL II

The success of mechanisms depends on how it can improve performance measures compare to other mechanisms. A framework is used to compare SCONWIP, DCONWIP, TOC and CWIPLII in the same condition. According to the framework, “Maximum WIP” is the same for all mechanisms.

Four different examples are used in the comparison analysis. The product mix is the same for all examples (33% for each type of product) and Maximum WIP is 48 for all examples. The processing time distribution for each machine in all examples is Exponential. The mean processing time of each machine for each product and routing of product through the shop are provided in tables 1- 4. The routing sequence for each product specifies how a product moves through the shop. In the considered examples, the processing time of each machine for each type of product is different.

When the order arrive to the system, it waits in a pre-shop file where the routing, processing times, due date and release time are assigned. A due date is assigned using constant allowance method (Baker 1984). The constant time allowance is 200 time units which are used for all type of products in all examples.

The order waits in the pre-shop file until release time. Release time of jobs determined for each mechanisms. When DCONWIP is applied, a job release to the shop when a job of the same type has completed processing so that the total level of WIP of that job is constant. In SCONWIP, the target level of WIP is defined for all product types so when a job has completed processing, a job is released into the system whose type is determined probabilistically according to the product mix. When TOC is applied, two buffer named "constraint buffer" and "shipping buffer" are established. Constraint buffer is a time buffer placed between material release and bottleneck to ensure that disruptions in order's flow preceding the bottleneck don't prevent it from arriving at the constraint in time (Atwater et al. 2002). Shipping buffer allows sufficient time for orders after leaving the primary bottleneck to arrive in shipping in time (Atwater et al. 2002). The size of two buffers is defined by dividing the constant time allowance in half. Then a detailed schedule is developed for bottleneck as follows. The shipping buffer is added to the order's processing time at the bottleneck. The resulting sum is subtracted from the order's due date to establish the start time at the bottleneck. It must be noted that shipping buffer is used for scheduling the bottleneck and it is not included in lead time.

The order's release time is determined by subtracting the constraint buffer from the order's start time at the bottleneck (Atwater et al. 2002). The release time of CWIPL II is determined based on the rules explain in section 2. For rule 1 the time buffer is considered as TOC and for rule 2 number of WIP is checked.

The examples are as follows:

Example 1

Three products are produced by four machines which the sequences of operations on machines are not the same and the processing time of machines is Exponential with mean shown in table 1.

Table 1. Routing and mean processing time for example 1

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 1	Machine 2	Machine 3	Machine 4
	2	3	7	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	2	1	9	4
Product 3	Machine 1	Machine 2	Machine 4	Machine 3
	2	12	3	3

As it can be seen, in table 1, machine 3 has largest mean processing time for product 1, so machine 3 is bottleneck for product 1. Machine 4 has largest mean processing time for product 2 so machine 4 is bottleneck for product 2. Machine 2 has largest mean processing time for product 3. So machine 2 is bottleneck for product 3. The process line for all product of this example is "near unbalance". These are used for CWIPL II.

With regard to the same product mix for all products, machine 2 has the largest load for three products (3+2+12). So machine 2 is primary bottleneck which are used in TOC.

Example 2

Three products are produced by four machines which the sequences of operations on machines are not the same and the processing time of machines is Exponential with mean shown in table 2. It can be seen that the mean processing time is the same as example 1 except for time of product 3 on machine 4 that is 9. So the process line for products 1 and 2 is "near unbalance" while the line of product 3 is "perfect unbalance".

It can be calculated that machine 4 has the largest load for three products (1+9+9). So machine 4 is primary bottleneck which are used in TOC.

Table 2. Routing and mean processing time for example 2

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 1	Machine 2	Machine 3	Machine 4
	2	3	7	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	2	1	9	4
Product 3	Machine 1	Machine 2	Machine 4	Machine 3
	2	12	**9**	3

Example 3

In this example, machine 3 is bottleneck for product 1, machine 4 is bottleneck for product 2 and machine 2 is bottleneck for product 3. The process line for all product of this example is "near unbalance" that are used for CWIPL II.

It can be calculated that machine 2 has the largest load for three products. So machine 2 is primary bottleneck which are used in TOC.

Table 3. Routing and mean processing time for example 3

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 3	Machine 2	Machine 1	Machine 4
	9	3	1	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	2	1	9	4
Product 3	Machine 4	Machine 2	Machine 1	Machine 3
	3	12	2	3

Example 4

In this example, machine 3 is bottleneck for product 1, machine 4 is bottleneck for product 2 and machine 2 is bottleneck for product 3. The process line for all product of this example is "perfect unbalance".

It can be calculated that machine 2 has the largest load for three products. So machine 2 is primary bottleneck which are used in TOC.

Table 4. Routing and mean processing time for example 4

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 3	Machine 2	Machine 1	Machine 4
	7	5	1	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	2	7	8	4
Product 3	Machine 4	Machine 2	Machine 1	Machine 3
	9	12	2	3

Example 5

As it can be seen in table 5, machine 2 has largest mean processing time for all products; so machine 2 is bottleneck for all products. The process line for all product of this example is "near unbalance". These are used for CWIPL II. With regard to the same product mix for all products, machine 2 has the largest load for three products (7+9+12). So machine 2 is primary bottleneck which are used in TOC.

Table 5. Routing and mean processing time for example 5

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 1	Machine 2	Machine 3	Machine 4
	2	7	3	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	9	1	2	4
Product 3	Machine 1	Machine 2	Machine 4	Machine 3
	2	12	3	3

Example 6

As it can be seen in table 6, machine 2 is bottleneck for all products. The process line for all product of this example is "near unbalance". With regard to the same product mix for all products, machine 2 has the largest load for three products (9+9+12). So machine 2 is primary bottleneck which are used in TOC.

Table 6. Routing and mean processing time for example 6

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 3	Machine 2	Machine 1	Machine 4
	3	9	1	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	9	1	2	4
Product 3	Machine 4	Machine 2	Machine 1	Machine 3
	3	12	2	3

Example 7

In this example, machine 2 is bottleneck for all products. The process line for all product of this example is "perfect unbalance". It can be calculated that machine 2 is primary bottleneck which are used in TOC.

Table 7. Routing and mean processing time for example 7

	Operation 1	Operation 2	Operation 3	Operation 4
Product 1	Machine 3	Machine 2	Machine 1	Machine 4
	5	7	1	1
Product 2	Machine 2	Machine 1	Machine 4	Machine 3
	8	7	2	4
Product 3	Machine 4	Machine 2	Machine 1	Machine 3
	9	12	2	3

As it is known in the literature, simulation modeling is very useful and probably the most widely used modeling technique for manufacturing system design. Due to the fact that in the mentioned mechanisms, some of the control decision rules being used require the real time information about the state of the system, computer simulation is the best methodology for measuring performance measures. Visual Slam II is used for simulating the different mechanisms.

In order to obtain an approximated sample size for the experiment, several pilot runs of simulation were made. The necessary sample size required for the desired degree of accuracy is estimated using a relation derived from the formulae for the confidence interval for the population mean: $x\text{-}d =<\mu<= x+d$ where d is $z(1-\alpha/2)s/n$ and is the half width of the confidence interval, n is the sample size, z is the standard normal deviation, s is the estimated standard deviation of measure which is obtain from the pilot runs. So the sample size required is $n= (zs)2/d2$. In this way, the z value is 1.96 for a 95% confidence interval and n is equal to 30.

Each example was simulated for a total of 15000 time units. The first 5000 time units were used as a warm-up period to achieve steady state. So data were collected and analyzed for the next 10000 time units. The end of the transient period was found by plotting the cumulative moving average and the time when this average approaches a level, value was taken as the end of the initial transient period.

The performance measures of CWIPL II (C), TOC (T), Shared CONWIP (S) and Dedicated CONWIP (D) are measured by conducting 30 simulation runs in the case of Maximum WIP is 48. The performance measures considered in this paper, Average lead time, Average throughput, Average Tardiness time and Average percent of Tardy

are evaluated using a statistical hypothesis test. A statistical hypothesis test is consisting of null and alternative hypothesis tests. The null hypothesis (H0) states that there are no differences in the performance measure levels that can be attributed to the MFC mechanisms. The alternative hypothesis (H1) is that the average levels of performance measure are not equal. Scheffe and Knew-Man tests are done by SPSS and the hypothesis were evaluated at the 0.01 significance level.

4. Comparing Results

The results of simulation and statistical analysis are shown in table 8 and table 9. The last columns of tables show the significance of differences in performance measures. For example S<D means that there is statistically significant differences among the mechanisms SCONWIP and DCONWIP and also DCONWIP has larger average than SCONWIP in related performance measure. D-T means that there is not statistically significant difference between DCONWIP and TOC. The * sign is used to show the best mechanism between mechanisms in related performance measure.

In examples 1-4 the bottleneck for each product is different. It is observed that there is statistically significant difference between average throughput of CWIPL II and TOC. CWIPL II has better throughput than TOC. It can be seen that TOC has better throughput than DCONWIP and DCONWIP has better throughput than SCONWIP. The results are the same for lead time. CWIPL II has better lead time than TOC and TOC has better lead time than DCONWIP and DCONWIP has better lead time than SCONWIP.

It is observed that CWIPL II works better or the same as TOC with respect to measures related to responsiveness to the customer. CWIPL II has better or the same average tardy time and percent of tardy compared to TOC. TOC has better average tardy time and percent of tardy compared to DCONWIP and DCONWIP has better or the same performance compared to SCONWIP.

In examples 5-7 that single machine is bottleneck for all jobs, it can be seen that there is not significant difference between average throughput of TOC and CWIPLII but there is significant difference between average lead time, average tardiness time and average percent of tardy of TOC and CWIPL so that TOC works better than CWIPLII, DCONWIP and SCONWIP. So with the same throughput, TOC has better lead time, tardiness time and percent of tardy compared to other mechanisms.

Table 8. Comparison of throughput and lead time of SCONWIP, DCONWIP, TOC and CWIPLII mechanisms

Example	Max. WIP	Avg. Throughput				Avg. Lead time				Significant difference in	
		SCONWIP (S)	DCONWIP (D)	TOC {T)	CWIPL (C)	SCONWIP (S)	DCONWIP (D)	TOC (T)	CWIPL (C)	Avg. Throughput	Avg. Leadtime
1	48	0.1500	0.1614	0.1765	0.1797	315.6	287.8	127.59	108.8	S<D<T<C*	S>T>D>C*
2	48	0.1309	0.1433	0.1505	0.1695	362.8	325.8	171.39	114.2	S<D<T<C*	S>T>D>C*
3	48	0.1450	0.1533	0.1618	0.1705	327.2	305	131.98	122.2	S<D<T<C*	S>T>D>C*
4	48	0.1264	0.1370	0.1465	0.1712	376.4	341.5	170.59	112.96	S<D<T<C*	S>T>D>C*
5	48	0.1009	0.1034	0.1058	0.1030	472.9	442.9	78.27	113.9	S<D-C-T	S>D>C>T*
6	48	0.0955	0.0980	0.0988	0.0985	499.9	480.9	81.9	118.18	S<D-C-T	S>D>C>T*
7	48	0.1040	0.1108	0.1100	0.1090	457.3	426.04	92.8	124.5	S<D-C-T	S>D>C>T*

Table 9. Comparison of tardiness time and percent of tardy of SCONWIP, DCONWIP, TOC and CWIPLII mechanisms

Example	Max. WIP	Avg. Tardiness time				Avg. percent of tardy				Significant difference in	
		SCONWIP (S)	DCONWIP (D)	TOC {T)	CWIPL (C)	SCONWIP (S)	DCONWIP (D)	TOC (T)	CWIPL (C)	Avg. Tardiness time	Avg. percent of tardy
1	48	115.9	89.03	19.57	23.17	93	62	4	1	S>D>T-C*	S>D>T-C*
2	48	162.8	126.14	60.94	21.57	100	94	34	3	S>D>T>C*	S-D>T>C*
3	48	127.3	105.3	37.94	24.45	97	91	14	4	S>D>T>C*	S-D>T>C*
4	48	176	141.5	61.13	16.31	99	99	33	1.4	S>D>T>C*	S-D>T>C*
5	48	272.9	242.9	8.816	16.58	100	100	0.1	1.7	S>D>C>T*	S-D>C>T*
6	48	299.9	280	5.68	20.05	100	100	0.1	2.2	S>D>C>T*	S-D>C>T*
7	48	257.3	226.04	15.69	18.31	100	100	0.6	2.6	S>D>C>T*	S-D>C>T*

5. Summary and Conclusion

CWIPL II is a control mechanism previously proposed for unbalance flow line. The basic idea of CWIPL II is classifying the unbalance flow line to "near unbalance" and "perfect unbalance" line. CWIPL II determined critical operations for each class and control the WIP of critical loops. This paper shows how to apply CWIPL II in job shop.

For applying CWIPL II in job shop consider each product individually. So each product has its own bottleneck. So for each product determine that the line is "near unbalance" or "perfect unbalance" and then release order based on rules.

In this paper, the rules of CWIPL II for releasing material to the shop are revised. In unbalanced flow line, the necessary condition to release the material to the shop is idleness of first machine (operation). While in job shop, if the first operation is not bottleneck for any products then this necessary condition must be met, otherwise it is relaxed.

CWIPL II is compared with TOC, DCONWIP and SCONWIP. Two set of examples are simulated. At First set, each job has a bottleneck that is not bottleneck for other jobs. So single machine is not bottleneck and there is more than one bottleneck in the job shop. Simulation results and statistical tests demonstrates that CWIPL II has better lead time and throughput compared to TOC, while it works better or the same as TOC with respect to tardiness and percent of tardy. TOC works better than DCONWIP for all performance measures and DCONWIP is better than SCONWIP for average throughput lead time and tardiness time while DCONWIP and SCONWIP are the same for percent of tardy. At second set, single machine is bottleneck for all jobs. So the Job shop has one bottleneck. In this set, TOC has better lead time, tardiness and percent of tardy compared to CWIPLII, DCONWIP and SCONWIP with the same throughput. So TOC works better than CWIPLII, DCONWIP and SCONWIP.

Future research will focus on considering line with different number of products, different number of machines, different processing time distribution, different Maximum WIP and different bottlenecks for each product.

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