EFFECT OF BUFFER CAPACITY ON MANUFACTURING LEAD TIME IN FLEXIBLE MANUFACTURING SYSTEMS

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ABSTRACT

Local buffers at workstations in most flexible manufacturing systems have very limited storage capacity and, consequently, parts attempting to enter the workstations may be blocked. The implication of machine-blocking due to queue size is that a machine will not be allowed to process an available job. If the subsequent buffer storage is full, it means that the job, upon its process completion, can not be accommodated in the buffer storage. And hence, the machine can not take up the job for processing, in spite of the availability of the job. In the current study, the effect of buffer capacity on manufacturing lead time (MLT) in flexible manufacturing systems will be studied under some dispatching policies. The experimental results show that the reduction of MLT continues as the storage capacity increases till it reaches a certain buffer capacity at which the reduction becomes insignificant.

Keywords: Flexible manufacturing systems, Dispatching policies, Constrained buffers

INTRODUCTION

A flowshop is a conventional manufacturing system where the machines are arranged in the order of job processing, and all jobs undergo processing on all machines in the same sequence. In the case of flexible flow manufacturing cell (FFMC), parts that require similar operations are grouped together into a cell such that there is no (or minimum) intercell movement. All jobs in a part family need not be processed on all machines in a cell, i.e. jobs can have missing operations on some machines. Implementing a FFMC involves three phases, namely, cell formation, cell layout, and scheduling of jobs in the cell. The first two phases are design problems, while the other one is a production planning problem. The configuration of the cell could be two types, viz, flowline layout and jobshop layout. A flowline layout has definite advantages over the jobshop layout such as simplified flows, easier conveyance between cells, and greater control over cell activities [1]. Flowshop scheduling problem has been a keen area of research for over the last three decades. Most researchers have considered the flowshop problem with infinite in-process inventory or storage buffers [2-4]. Three levels are applied to the constraint of a storage buffer. Zero capacity means that there is no buffer at that place in the system. Limited capacity indicates that the buffer can only accommodate a restricted number of parts at any time interval. When the buffer size is large enough such that no delay will be caused by the waiting of a part for a place in the buffer, then infinite capacity may be assumed. Intuitively, the more restrictive the buffer capacities are, the more difficult it is to find a schedule. Such a buffer-constraint aims to reduce in-process inventory and enhances floor-space utilization in the system. With the advent of Just-in-Time manufacturing, the scheduling problem with the limited buffer capacity assumes greater significance and needs to be intensively studied [5]. Only a few researchers have tackled the scheduling problem in a buffer constrained statement. Leisten [6] derived a mathematical formulation for buffer constrained flowshop problem. He assumed that every job requires a unit in-process storage space (or buffer space). Good achievements have been obtained but the mathematical formulation is found to be restrictive. Sharadapriyadarshini *et al.* [7,8] developed a procedure for scheduling permutation flowshop and a flowline-based manufacturing system. The results of the simulated experiments reveal that the proposed heuristic and its variant emerge to be better than the existing heuristics. A Drum-buffer-robe (DBR) procedure has been presented as an extremely robust method for scheduling by Guide [9]. The use of DBR leads to consistency in throughput rates and fairly level amounts of work-in-process and a larger buffer size is required to cope with the variability in a remanufacturing environment when performance to schedule is the primary management concern. A set of models has been developed to accommodate flexible manufacturing systems with limited local buffers by Yao *et al.* [10]. The models have easily computable solutions, and with small local buffers are robust to various processing time distributions. For systems with large local buffers, they can readily incorporate the exponentialization approach to yield accurate results. A two level distributed production control system (DPCS) is developed for on-line scheduling in a multi-cell flexible manufacturing system in case of operating in a produce-to-order environment by Arzi [11]. The DPCS allows autonomous and simultaneous operation of each cell-controller, utilizing only local short term information as well as heuristic rules. Simulation experiments show that DPCS achieves good results in throughput, tardiness of orders, and WIP inventory level and it is robust to machine and handling device failures. As it is highlighted from the aforementioned review of literature, the constrained buffer capacity is an important parameter that affecting the system performance. The buffer-constrained manufacturing systems are characterized by machine blocking due to the limitation on total queue size. Also, the manufacturing lead time (MLT) is considered as a one of the vital criteria for measuring system performance. The main objective of the current work is to study the effect of buffer storage capacity on manufacturing lead time when some dispatching policies are under consideration.

PROBLEM TREATMENT

To study the effects of the dispatching rules on the performance of FMSs, we consider a flexible flow manufacturing cell (FFMC). In FFMC a set of medium sized batches are to be processed. Each batch requires processing on each station without skipping any station. Figure 1 shows a schematic diagram of the FFMC. The cell has a receiving area, a load/unload station, and four work stations. Each work station has three identical machines. Each machine has a tool magazine that holds all the tools required for each operation that is assigned to a machine. Machines are equipped with automatic tool changer for processing of different part types. Between each two successive workstations there is a local buffer with finite capacity. The workstations are integrated by a material handling system. Three AGVs are used in the system with specified speed, capacity, and direction. The parts received at the receiving area and handled to load station for clamping onto pallets. The AGVs move the parts between load station and the local buffer of the first station, from the last buffer (B4) to the unload station, and from the stations to their output buffers(for example, from station 1 to buffer two). The buffer serve as a float between station by reducing the effect of the differences in the processing times of the part types on the performance of the system. Parts wait for processing at the workstations in the buffers if all the machines of the stations are busy. Otherwise parts enter to the station. Each workstation is equipped with a robot to load and unload the machines in the station. However, the model is treated based on the following assumptions:

1. The load/unload storage area have unlimited capacity.
2. Each workstation consists of m identical machines and each machine can process one operation at a time.
3. The processing time of the part types are deterministic.
4. Setup times, teardown times are assumed to be negligible.
5. Both the machines, and the material handling equipments are assumed to be reliable.
6. Tool-change over time is included in the processing time.
7. The time the AGV takes to transport the parts between workstations is included in the unit processing time.
8. Tool magazine capacities are not binding constraints.
9. The flow of parts from the buffer to the machines in any station is controlled by the dispatching rules.
10. The initial conditions of the system at the beginning of each production period is empty and idle.
11. No allowances is made for scrapping and rework.
12. A set of part types is known for processing at the beginning of production period.
13. The loading order of the part types and the production mix will be maintained on every workstation.

PERFORMANCE MEASURE UNDER CONSIDERATION

Many performance measures can be used to evaluate the system performance. The manufacturing lead time is considered as a measuring performance criterion in the current study. The reason of this is due to the fact that, the other measures can be evaluated if the lead time is known. Considering the manufacturing lead time is L, as the total time required to produce a set of batches of the given set of part types. Thus, L can be written as the sum of the processing time and the delay time, as follows:

$$L = \sum_{\forall p}\sum_{\forall J}(Q_p.O_{PJ} + D_{PJ}) \qquad (1)$$

where :

Q_p is the batch size of part type p (p=1, 2, 3, ... , p)

O_{pj} is the unit processing time of part type p on a machine at station j .

D_{pj} is the delay time due to starving and blocking that part type p encountered at station j.

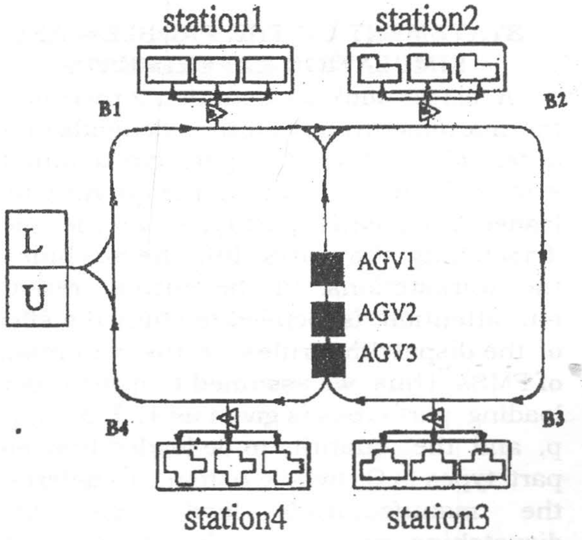

Figure 1 Schematic diagram of the flexible flow manufacturing cell

The delay time due to blocking and starving can be separated and the lead time will take the form

$$L = \sum_{\forall p}\sum_{\forall J}(D^{s}_{pj} + Q_p.O_{pj} + D^{b}_{pj}) \qquad (2)$$

where D^{s}_{pj} is the delay time due to starving and D^{b}_{pj} is the delay time due to blocking that Q_p units will encounter at station j. Given the manufacturing lead time, we can use it to calculate any other performance measure. The average production rate can be written as:

$$\overline{R}_p = \sum_{\forall p} Q_p / L \qquad (3)$$

The average unit production time equals $1/R_p$ and the system utilization U can be written as:

$$U = (\sum_{\forall p}\sum_{\forall j} Q_p.O_{pj}) / L \qquad (4)$$

The proportion of delay can be written as follows:

$$D = (L - \sum_{\forall p} \sum_{\forall J} Q_p . O_{pj}) / L \qquad (5)$$

The utilization of any workstation can also be evaluated. The above discussion clarify that the manufacturing lead time can be used to find any other performance measure of the system.

STATEMENT OF THE PROBLEM AND SIMULATION EXPERIMENTS

A closer look at Equation 2 reveals that the manufacturing lead time depends on the order of loading the part types into the system from L/U station, the quantity to be loaded from each part type, and the rule of dispatching the parts into the machines in the workstations. In the current research our attention is focused to study the effects of the dispatching rules on the performance of FMSs. Thus, we assumed that the order of loading part types is given as 1, 2, 3, ..., p-1, p, and the quantity to be loaded from each part types is Q_p (whole batch). To determine the manufacturing lead time of a dispatching rule for a given loading order, and production mix, Equation 2 has to be solved. Mathematical solution of that equation is unavailable . Thus, it is intended to use discrete event simulation to evaluate the lead time. SIMIFACTORY II.5 is used as a software to run the simulation experiments. Eight dispatching rules are under consideration for the simulation experiments in the current study. These dispatching rules are RANDOM, BY TURN, LOW USAGE, HIGH USAGE, CLOSEST, FARTHEST, SHORTEST IDLE, and LONGEST IDLE. Each rule is used to dispatch the parts among the machines in the workstations for a set of experiments. In each experiment the number of part type P, the production mix Q_p, the load and unload time t_L, t_u the unit processing times O_{pj} are generated at random. Table 1 displays the data for set of simulation experiments. For each experiment the simulator is run for buffer capacities starting with two units up to 16 units and of two units as stepwise. In each experiment the lead time is taken simulator output.

Table 1 Set of data for simulation experiments

P	O_{pj}				Q_P	$t_{,L,P}$	$t_{u,P}$
	1	2	3	4			
1	7	3	0	2	250	3	1
2	4	0	1	5	120	1	2
3	3	6	3	4	175	6	2
4	0	3	3	2	200	3	1
1	9	3	1	0	100	1	3
2	6	4	4	4	200	5	3
3	8	8	0	9	300	9	3
4	5	4	8	0	150	5	3
5	5	5	5	5	500	3	3
6	1	3	1	1	100	6	3
1	6	0	3	6	120	2	3
2	9	2	5	4	150	6	3
3	6	2	0	9	300	5	3
4	5	0	3	1	250	2	3
5	5	3	5	2	200	4	3
6	2	3	1	5	150	3	3
7	11	8	5	0	800	6	8
8	15	3	8	6	350	5	7
1	4	5	5	2	200	3	3
2	5	5	0	3	730	5	3
3	4	5	2	0	100	7	3
4	8	8	4	4	425	6	3
5	2	5	0	1	75	2	3
6	6	3	6	2	175	6	3
7	15	5	2	4	550	3	8
8	15	3	8	6	225	3	7
9	6	8	12	0	300	5	2
10	9	0	6	4	125	3	6
1	9	0	2	8	745	3	1
2	0	5	5	7	829	0	1
3	8	8	1	8	313	2	1
4	7	9	6	0	171	4	0
5	5	6	1	2	758	4	1
6	1	9	5	5	144	0	2
7	5	0	5	4	312	3	2
8	6	3	6	0	268	3	0
9	5	2	8	9	755	4	4
10	9	9	5	2	880	2	1
11	6	2	4	8	71	4	5
12	9	10	5	3	200	5	2

RESULTS AND DISCUSSION

For each dispatching rule the simulator runs at each level of storage capacity. The results are summarized in Table 2. The table exhibits the manufacturing lead time of each dispatching rule at each buffer capacity (B) of the set of part types. For four part types problem, it is clear that all the dispatching rules give the same lead time at a given buffer capacity. Also, it is observed that the MLT decreases as the storage capacity increases, the reason is that as the buffer capacity increases the delay time due to starving and blocking decreases. For the 6 part types problem it is noted that rules 2, 4, 6, and 8 are the best rules because they result in the smallest value for MLT. For the 8 part types problem it is clear that at storage capacity of 3 units, rules 2, 4, 5, and 7 result in the smallest value of MLT

Table 2 MLT at various buffer capacities and dispatching rules.

P	B	Dispatching rule							
		1	2	3	4	5	6	7	8
4	2	2615	2615	2615	2615	2615	2615	2615	2615
	4	2595	2595	2595	2595	2595	2595	2595	2595
	6	2575	2575	2575	2575	2575	2575	2575	2575
	8	2560	2560	2560	2560	2560	2560	2560	2560
	10	2557	2557	2557	2557	2557	2557	2557	2557
	12	2554	2554	2554	2554	2554	2554	2554	2554
	14	2552	2552	2552	2552	2552	2552	2552	2552
	16	2549	2549	2549	2549	2549	2549	2549	2549
6	2	6866	*6849	6866	*6849	6866	*6849	6866	*6849
	4	6860	*6844	6860	*6844	6860	*6844	6860	*6844
	6	6856	*6839	6856	*6839	6856	*6839	6856	*6839
	8	6848	*6831	6848	*6831	6848	*6831	6848	*6831
	10	6842	*6826	6842	*6826	6842	*6826	6842	*6826
	12	6838	*6821	6838	*6821	6838	*6821	6838	*6821
	14	6830	*6813	6830	*6813	6830	*6813	6830	*6813
	16	6824	*6808	6824	*6808	6824	*6808	6824	*6808
8	2	13598	13575	13598	*13575	*13575	13581	13575	13598
	4	13545	13545	13545	*13542	*13542	13545	13547	13545
	6	13538	13538	13538	*13515	*13515	13521	13515	13538
	8	13507	13507	13507	*13482	*13482	13507	13487	13507
	10	13507	13507	13478	*13452	*13452	13507	13457	13507
	12	13507	13507	13448	*13422	*13422	13507	13427	13507
	14	13507	13507	13418	*13392	*13392	13507	13397	13507
	16	13507	13507	13388	*13362	*13362	13507	13367	13507
10	2	16767	*16751	16769	16878	16757	16877	16755	16883
	4	16626	*16614	16634	16805	16623	16805	16620	16811
	6	16520	*16504	16526	16755	16510	16756	16510	16761
	8	16403	*16394	16414	16706	16402	16705	16400	16711
	10	16300	*16284	16304	16655	16293	16655	16290	16661
	12	16189	*16174	16194	16605	16180	16606	16180	16611
	14	16103	*16087	16101	16579	16095	16579	16093	16579
	16	16037	*16027	16043	16579	16035	16579	16033	16579
12	2	17839	17835	17841	17833	17835	17837	17834	17841
	4	17782	17780	17785	17778	17780	17782	17781	17785
	6	17723	17723	17723	17723	17723	17723	17723	17723
	8	17710	17710	17710	17710	17710	17710	17710	17710
	10	17679	17679	17679	17679	17679	17679	17679	17679
	12	17647	17647	17647	17647	17647	17647	17647	17647
	14	17614	17614	17614	17614	17614	17614	17614	17614
	16	17583	17583	17583	17583	17583	17583	17583	17583

At storage capacity of 4 units, rules 4 and 5 result in the smallest value of MLT. At storage capacity of 6 units, rules 4, 5, and 7 result in the smallest value of MLT. At storage capacity greater than 6 units, rule 4 and 5 results in the smallest value of MLT. For 10 part types problem it can be seen that rule 2 results in the smallest value of MLT at all storage capacities, where MLT decreases as the storage capacity increases. For 12 part types problem it is exhibited that rule 4 results in the smallest value for MLT at buffer capacity of 2, and 4 units. At buffer capacity more than 4 all the rules result in the same MLT. However, the above cited trend of variation between the buffer capacity and MLT at different dispatching rules has been exhibited in Figure 2 to Figure 4.

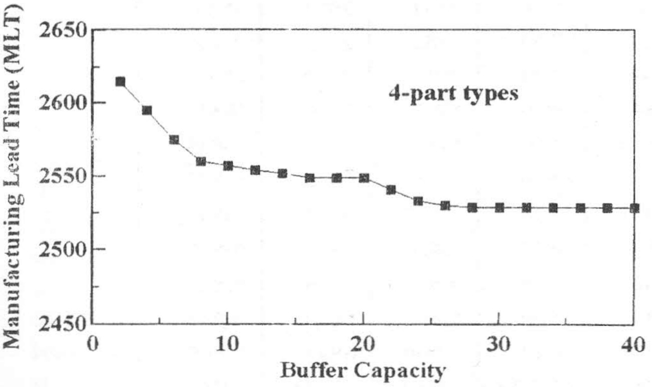

Figure 2 Buffer capacity and MLT for the best and worst rule

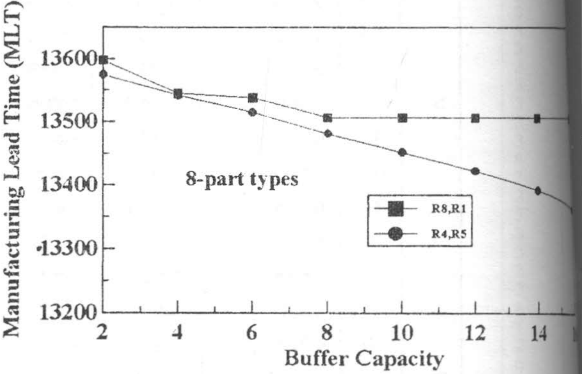

Figure 3 Buffer capacity and MLT for the best and worst rule

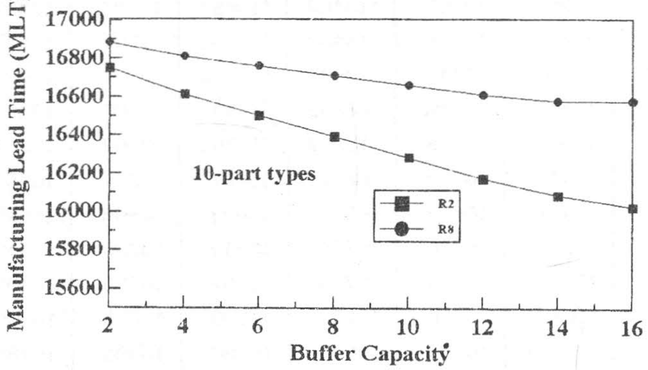

Figure 4 Buffer capacity and MLT for the best and worst rule.

CONCLUSION

The main results and observations lead to the following conclusions:

The storage capacity has significant and vital impact on the manufacturing lead time in flexible manufacturing system. Increasing the storage capacity results in decreasing the MLT. The reduction in MLT continues as the storage capacity increases until the reduction becomes insignificant at a certain specified buffer capacity. This storage capacity is the best for the production mix under consideration. Hence, it is recommended to study MLT at different storage capacities to achieve the best performance within the system configuration under consideration. Also, no specific dispatching rule can be considered as the best rule of other rules, where the best rule depends on the system configuration, number of part types, and production mix.

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تاثير سعة التخزين المؤقت على زمن التصنيع الإرشادى فى نظم التصنيع المرنة

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ملخص البحث

ان سبل التخزين الموضعى المؤقت أمام محطات ومراكز العمل فى معظم نظم التصنيع المرنة لها طاقة تخزينية محدودة مما قد يؤدى فى كثير من الأحيان الى توقف أو تعطيل دخول الأجزاء المراد تصنيعها الى مراكز التصنيع ذاتها. وهذا يؤدى بدوره الى عدم تحميل الأجزاء المراد تصنيعها على ماكينات التشغيل فى مراكز ومحطات التصنيع ذاتها فى أزمنة مناسبة وملائمة وبالتالى تأخير أزمنة الانتهاء من التصنيع. فى هذا البحث تم دراسة تأثير سعة التخزين الموضعى المؤقت على زمن التصنيع الارشادى فى نظم التصنيع المرنة وذلك عند استخدام العديد من قواعد الدفع بالمنتجات بين مواضع التخزين المؤقت وماكينات التصنيع. وقد خلصت الدراسة الى أن زمن التصنيع الارشادى يمكن انقاصه بزيادة سعة التخزين الموضعى المؤقت ولكن هذه العلاقة ليست مطلقة حيث انه عند حد معين لسعة التخزين بعده يكون الانقاص فى زمن التصنيع الارشادى غير مؤثر.