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Analysis of a manufacturing system using sequencing flexibility in a SFMS

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Abstract

This work is performed to reveal the effect of sequencing flexibility in a flexible manufacturing system working under different load condition and sequencing rules in the stochastic environment. The manufacturing system is comprises of six machining centers along with variable capacity dedicated buffers with each machining center. In the study four sequencing flexibility are considered with four different system capacity, system load and sequencing rule are considered with four levels of each factor. Make-span time is taken as performance measure.It is found that the load condition has an impact on all the performance measures. The LFB is found the best among the four selected load conditions. Further, it is found from the results that the sequencing rules at the queue also has some impact on the performance of the system this impact is more at lower level of sequencing flexibility because the formation of queue is more likely at lower level of sequencing flexibility. Hence, it is evident that the sequencing rule FCFS has the best performance among the four selected sequencing rules.

Key Words: Sequencing flexibility, make-span, load balancing.

1. Introduction

To cater a dynamic market, the manufacturing system requires flexibility in various forms. So, flexibility in manufacturing system is the most sought after property to take in account the stochastic condition in the manufacturing system. Hence an attempt is being made in this research work towards the analysis of the effect of sequencing flexibility in FMS under stochastic environment.

Our initial motivation is based on different decisions related to design, planning and control of flexible manufacturing system operating under stochastic environment. Since the parts are operated at various operational conditions, the flexible manufacturing system due to its inherent flexibility will take care of the variation in operational conditions to give the desired output (Browne et al. 1984). Despite number of works done in the area of flexibility in manufacturing system still more work is to be done in this domain. This includes different planning and control of various FMS parameters.

2. Literature Review

Implementation of FMS or any sub-system of FMS, in a stochastic environment is one of the expensive and complex problems of an organization. While reviewing the papers in the concerned area, efforts were made to highlight not only the researcher's viewpoint but also to find out how it relates to our work. This will help us to obtain important research issues and objectives for this work.

Flexibility was first introduced by George Stigler in 1939 as reported by Carlsson in 1989. Koste et al., (2004) has compared a subset of firms in respect to their flexibility types, and observed that adding more flexibility features in a flexible manufacturing system increases the complexity as well as cost. Implementation of different flexibilities in an uncertain manufacturing environment is an expensive affair as well as difficult to understand and quantify (Chauhan et al. 2007). Chauhan and Singh (2011) further stated that flexibility is the ability of a system to accommodate the changes in the system and react according to the situation in a complex and uncertain environment. Joseph and Sridharan (2012) studied the effect of sequencing flexibility, routing flexibility and part sequencing rules of a typical flexible manufacturing system on different performance measures i.e. flow time and tardiness of parts. They revealed that the system performance can be improved by incorporating either routing flexibility or sequencing flexibility or both. Recently Singh and Singh (2013) also advocated that flexibility in manufacturing management plays a vital role in today's most changing and turbulent environment of the market.Safitra et al. (2014) studied flexible manufacturing systems in stochastic environment and stated that the successful implementation of the flexible system will increase the capital utilization and competitiveness.

To improve the system performance there is need to minimize the make-span time. Ali and Wadhwa (2010) considered make-span as the performance measure to study an FMS with variation in routing flexibility. Al-Kahtani et al. (2014) concluded that the make-span decrease whereas machine utilization.So that in this work make-span is considered as performance measure for the SFMS.

3. Objective

To study the sequencing flexibility enabled make-span reduction in SFMS operating under planning and control decisions.

3.1 Key features of the manufacturing system

In this work we developed sequencing flexibility enabled conceptual framework of the Stochastic Flexible Manufacturing System (SFMS). The system is comprises of six machines with dedicated input buffer of variable size. For simulation 600 parts are manufactured with 6 parts type of equal ratio i.e. 100 of each type. Five operations were considered for each part. The operation time is taken from the real manufacturing system under four different load conditions i.e. LFB, LBMUPT, LUMBPT and LUB.

3.2 Modeling sequencing flexibility

The parts were sequenced according to the sequencing flexibility. The measure of sequencing flexibility was considered as proposed by Rachamadugu et al. (1993). Illustration of sequencing flexibility is shown in Figure 3.1. The make-span, work-in-process and resource utilization for processing a product-mix of 600 parts are considered as performance measures.

Sequencing flexibility depends on the type of product to be produced. It is exploited if there is no dependency of operations on each other.The maximum flexibility can be achieved when all the operations are independent that is none of the operation has any precedence. Hence the sequencing flexibility is measured on the bases of number of possible operation sequences in a job (Sethi and Sathi 1990). Rachamadugu et al. (1993) proposed sequencing flexibility measure that is defined as:

$$SFM_i = 1.0 - \frac{2 * TPA_i}{n_i(n_i - 1)} \qquad (3.1)$$

Where

n_i = number of operations for part i,

TPA_i = number of transitive precedence arcs in the operation graph for part i

The transitive precedence arc represents the precedence relationship between the pair of all operations, both explicit and implicit of a part. Figure 3.1 shows the operation graph of sequencing flexibility level 2.

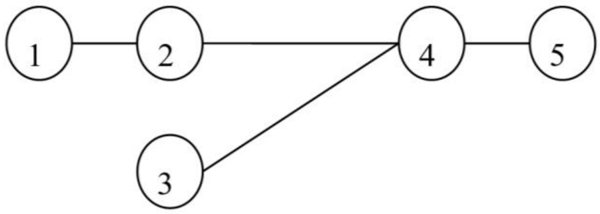

Figure 3.1: Operation graph of sequencing flexibility level 2.

3.3 Assumptions

The aim of this study was to determine the effect of planning and control decisions on the performance of SFMS. It is assumed that the processing time of the parts is considered as normally distributed with four different system load conditions that are mentioned in the above section and four sequencing rules. The system capacity (SC) is controlled by maintaining the input buffer size of each machine. Sequencing rules are employed over each queue of the machine individually. The make-spanis considered as the performance measure. One operation is performed on a machine at a time. Processing time also includes the set-time. All the decision factors with their levels are shown in Tables 3.1.

Table 3.1: Factor-level details

Factor	Level	ID
Sequencing flexibility (SF)	0	1
	1	2
	2	3
	3	4
System Capacity (SC)	30	1
	60	2
	90	3
	120	4
System load (SL)	LFB	1
	LUB	2
	LUMBPT	3
	LBMUPT	4
Sequencing rules (SR)	FCFS	1
	SPT	2
	HPT	3
	LCFS	4

The simulation model of SFMS has been developed in ARENA simulation. The proposed SFMSis run at different system load conditions. These areLoad Fully Balanced (LFB), Load Balanced on Machine and Unbalanced Processing Time (LBMUPT), Load Unbalanced on Machine and Balanced Processing Time (LUMBPT) and Load Fully Unbalanced (LUB). The sequencing rules helps to select the parts on the basis of priority from the buffer of the machine. The sequencing rules are modeled as FCFS, SPT, HPT and LCFS.

4. Performance under Sequencing Flexibility

Simulation model for SFMS was developed in Arena simulation software. The developed models are used to conduct a series of experiments to investigate the effects of sequencing flexibility, system capacity, system load conditions and part sequencing rules. The impact of sequencing flexibility on the performance of SFMS is evaluated under different planning and control decisions.

4.1. Effect of sequencing flexibility on MST at different system load conditions

In this section we find the effect of sequencing flexibility on make-span time (MST) at different system load conditions. The figures 4.1 to 4.4 are drawn between MST and sequencing flexibility at all four system load conditions. Tables 4.1 to 4.4 shows the MST value at four levels of sequencing flexibility under four system load conditions and four sequencing rules i.e. FCFS, SPT, HPT and LCFS respectively.

Figure 4.1 shows the impact of sequencing flexibility under different load conditions at sequencing rule FCFS for 600 parts at a system capacity of 120 on the MST performance of the system. It is seen from the figure that at SF0, MST is maximum for LUB and minimum for LUMBPT. At SF1, again MST is maximum for LUB and minimum for LBMUPT. At SF2, MST is maximum for LUB and minimum for LFB. Similarly at SF3 it is observed that MST is maximum for LUB and minimum for LFB. As one adopts different levels of sequencing flexibility, MST decreases from SF0 to SF3 for LUB system load condition. Almost similar trend is observed for other system load conditions.

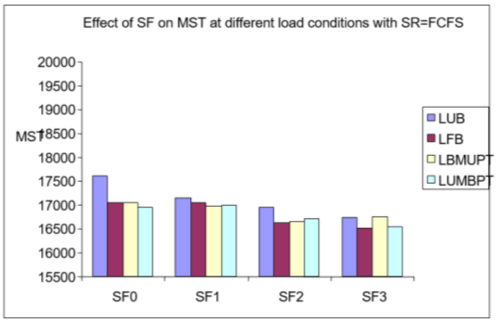

Figure 4.1: MST performance at four levels of SF (V=600, N=24, SC=120, SR=FCFS)

Table 4.1: Effect of SF on MST at different system load conditions

V=600, N=24, SC=120, SR=FCFS				
	SF0	**SF1**	**SF2**	**SF3**
LUB	17609.79	17149.99	16961.18	16734.68
LFB	17038.06	17043.15	16622.29	16530.82
LBMUPT	17054.12	16971.6	16661.07	16760
LUMBPT	16957.57	17001.96	16715.99	16534.93

Next we change the sequencing rule to SPT and perform the experiment with all other decision parameters keeping same. Figure 4.2 shows the relationship between MST and sequencing flexibility at different load conditions. It is seen from the figure that at SF0, MST is maximum for LBMUPT and minimum for LUMBPT. At SF1, again MST is maximum for LUB and minimum for LBMUPT. At SF2, MST is maximum for LUB and minimum for LUMBPT. Similarly at SF3 it is observed that MST is maximum for LBMUPT and minimum for LUMBPT. With increase in sequencing flexibility level MST decreases for all the system load conditions. The improvement in the MST is much visible in the figure with system load LBMUPT and LFB from SF0 to SF1 and SF2 to SF3 respectively.

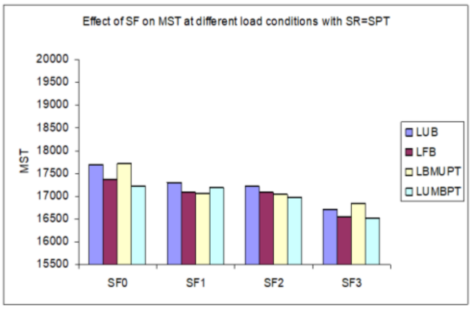

Figure 4.2: MST performance at four levels of SF (V=600, N=24, SC=120, SR=SPT)

Table 4.2: Effect of SF on MST at different system load conditions

V=600, N=24, SC=120, SR=SPT				
	SF0	**SF1**	**SF2**	**SF3**
LUB	17701.78	17296.56	17224.59	16709.62
LFB	17367.37	17095.47	17086.98	16542.01
LBMUPT	17727.18	17061.2	17042.23	16848.97
LUMBPT	17216	17202.41	16976.59	16526.67

Now we change the sequencing rule to HPT and observe its impact on the performance of the system. From Figure 4.3 it is seen that at SF0, MST is maximum for LUB and minimum for LUMBPT. At SF1, again MST is maximum for LUB and minimum for LUMBPT. At SF2, MST is maximum for LUB and minimum for LBMUPT. Similarly at SF3 it is observed that MST is maximum for LUB and minimum for LUMBPT. The MST is improved with the increase of sequencing flexibility at all load conditions but it is seen it has a counterproductive when the system moves from SF2 to SF3 with the load condition LBMUPT.

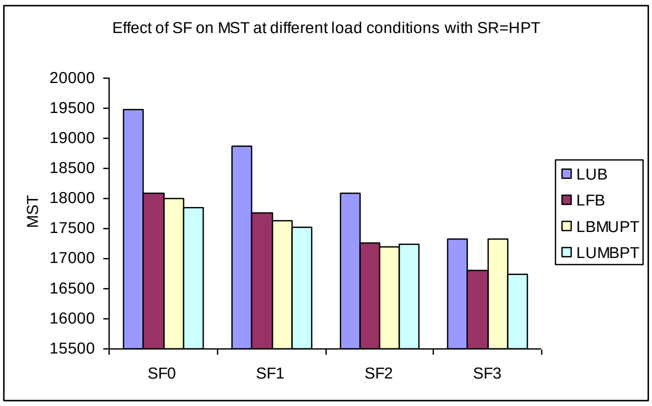

Figure 4.3: MST performance at four levels of SF (V=600, N=24, SC=120, SR=HPT)

Table 4.3: MST of different load conditions with SR=HPT at 4 levels of SF

V=600, N=24, SC=120, SR=HPT				
	SF0	**SF1**	**SF2**	**SF3**
LUB	19477.89	18877.21	18092.54	17320.53
LFB	18084.99	17764.31	17269.86	16801.26
LBMUPT	17991.9	17638.6	17198.23	17327.01
LUMBPT	17839.49	17528.91	17240.88	16738.34

Finally we changed the sequencing rule to LCFS and observe the performance of the system. Figure 4.4 shows the relationship between MST and sequencing flexibility for different system load conditions.

It is seen that at SF0, MST is maximum for LUB and minimum for LBMUPT. At SF1, again MST is maximum for LUB and minimum for LFB. At SF2, MST is maximum for LUB and minimum for LFB. Similarly at SF3 it is observed that MST is maximum for LUB and minimum for LFB. It is also seen that MST increases when system shifts from SF0 to SF1 with the load condition LBMUPT and then it improves by further increase in the level of flexibility. The system load condition LFB gives best response among all four load conditions at sequencing flexibility levels of SF1, SF2 and SF3 respectively. In all four studies carried above it is seen that with LUB system load condition MST is maximum. This is because standard deviation of processing time is highest among all load conditions.

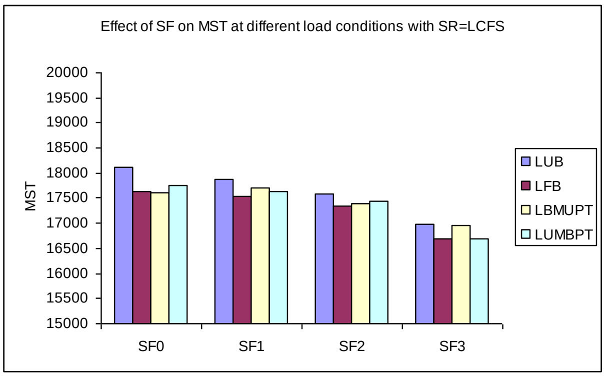

Figure 4.4: MST performance at four levels of SF (V=600, N=24, SC=120, SR=LCFS)

Table 4.4: MST of different load conditions with SR=LCFS at 4 levels of SF

V=600, N=24, SC=120, SR=LCFS				
	SF0	**SF1**	**SF2**	**SF3**
LUB	18124.17	17863.11	17576.52	16980.05
LFB	17639.96	17527.01	17347.08	16681.56
LBMUPT	17596.87	17695.9	17384.13	16952.22
LUMBPT	17742.04	17637.27	17447.54	16689.44

5. Conclusion

In this study, the simulation experiments are carried out with four load conditions (i.e. LUB, LFB, LBMUPT, and LUMBPT) and four sequencing rules (i.e. FCFS, SPT, HPT, and LCFS) at four levels of sequencing flexibility. The performance of the system is considered as makespan. In the result it is found that the performance improves with the increase of sequencing flexibility in most of the combinations. It is concluded from the above results that the load condition has an impact on all the performance measures. The LFB is found the best among the four selected load conditions. Further, it is concluded that the sequencing rules at the queue also has some impact on the performance of the system. It is found that this impact is more at lower level of sequencing flexibility because the formation of queue is more likely at lower level of sequencing flexibility. Hence, from the above discussion the sequencing rule FCFS has the best performance among the four selected sequencing rules.

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Abbreviations

SFMS	Stochastic Flexible Manufacturing System
SR	Sequencing rule
SC	System capacity
SF	Sequencing flexibility
SL	System load
MST	Make-span time
LFB	Load fully balanced
LBMUPT	Load balance on machine unbalanced process time
LUMBPT	Load unbalanced on machine balanced process time
LUB	Load unbalanced
FCFS	First come first serve
SPT	Shortest process time
HPT	Highest process time
LCFS	Last come first serve