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Simulation of Manufacturing System at Different Part Mix Ratio and Routing Flexibility

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Abstract

In present market scenario, manufacturing industries need to focus towards capability to provide high product variety and availability of products at the point of demand. This situation creates pressure on manufacturing firms to be flexible and to reduce lead time to fulfill customer's demand on time. Flexible Manufacturing Systems (FMS) with appropriate Routing Flexibility (RF) in addition to different scheduling strategies is the appropriate manufacturing alternative in such a case. Such systems are capable to adjust changing product mix yet providing higher performance in dynamic business environment. This research work presents simulation analysis of a FMS with varying Routing Flexibility (RF) level at different part mix ratio to validate this. The results show that varying part mix ratio has appreciable effect on the system performance, when no routing flexibility is present in the system. Also for all product mix ratios, increase in routing flexibility levels continues to improve MST performance with diminishing return.

Keywords: Dispatching Rules, Flexible Manufacturing System, Part Mix Ratio, Routing Flexibility, Sequencing Rules

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1. Introduction

In today's rapidly changing business environment with fierce competitiveness among market players, multi-node manufacturing systems focused towards time based competition is an appropriate manufacturing alternative. While dealing with product variety, lead-time reduction becomes the primary objective to cater to the performance needs of competitive factors. To fulfill the need of product variety, the systems require various forms of flexibility. Flexibility, which is a capability that manifests in the form of greater variety of products available at shorter lead times, ensures market success although it can't be seen by the customer. High cost of resources that enable flexibility requires judicious focus on flexibility and its management through effective strategies. For a multi node manufacturing system; this offers several challenges. In the manufacturing system domain, this turns out to be the issue of deployment of Flexible Manufacturing System (FMS) with appropriate design and operational policies that can deliver customized products with shorter life cycles suitable to fulfill market demand patterns.

Flexible Manufacturing System (FMS) is a highly automated multi node manufacturing system which incorporates several Computer Numerical Controlled (CNC) machines and an automated material handling and storage system managed by a central computer through local area network. The term flexibility in FMS has been discussed widely in literature which refers to the notion of change capability with less effort and time[3,8,14,16]. Wadhwa et al.[4] has focused on automation to run the manufacturing system effectively through flexibility and information based integration. FMS research domain contains issues focused on the different design, planning, scheduling and control strategies for its management[6,10].

The changing customer demands leads towards production of continuously changing part mix ratio in production system, i.e. the FMS. This impacts the performance of the system. The identification of manufacturing flexibility levels of resources in the FMS that is capable to address the changing part mix ratio thus is a very important strategic issue which has bearing on the performance of the FMS. The present work aims to underline this as a research issue. In this paper, discrete event simulation analysis is used for analyzing the FMS performance.

The remainder of the paper contains the following: Section 2 provides the literature review. Model description is given in Section 3. In Section 4, simulation results are analyzed and concluding remarks of the study with future scope is given in section 5.

2. Literature Review

The evolving competitive environment is shifting towards time-based competition. *Now, c*ustomers demands availability of the product as soon as the need arises. Hence, time based performance

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has become the main focus area for manufacturing performance. Accordingly, published works has widely used Make Span Time (MST), Mean Flow Time, and Throughput as the performance measures for the analysis of FMS[2,5,7].

Routing flexibility among all types of manufacturing flexibility, which is one of the main contributors at the shop floor of an FMS, can be defined as the availability of alternative machines for the processing of next operation[1,4]. Caprihan and Wadhwa[1] have explored the effect of routing flexibility levels on system performance. Toni and Tonchia[13] have defined the change of product part mix in quantitative terms as the part mix flexibility. It is perceived from the published work that sufficient research have been carried out on routing flexibility but little attention is paid on the varying part mix ratio and the FMS attributes that caters to the performance needs under such a scenario. Present research deals with the study of combined effect of different part mix ratio and routing flexibility on the system performance.

In FMS management, various scheduling rules are used by the researchers as important control strategies for part and machine selection9,11. Discrete Event Simulation (DES) is found to be a suitable analysis tool to study FMS systems[4,12,15]. We use ARENA as the simulation tool for this work.

3. Problem Description

For the present simulation study an experimental FMS is considered for the performance analysis of a multi node manufacturing system. Make Span Time (MST) is considered as the performance measure of the FMS system. Experimental model details are given in following subsections.

3.1. System Description

The present experimental setup consists of eight CNC machines, a Loading Station (LS) and an Unloading Station (ULS) equipped with dedicated input buffer of unlimited capacity at each machines. The experimental setup of FMS system is shown in figure 1. This forms part of the study platform for the ongoing research by the authors.

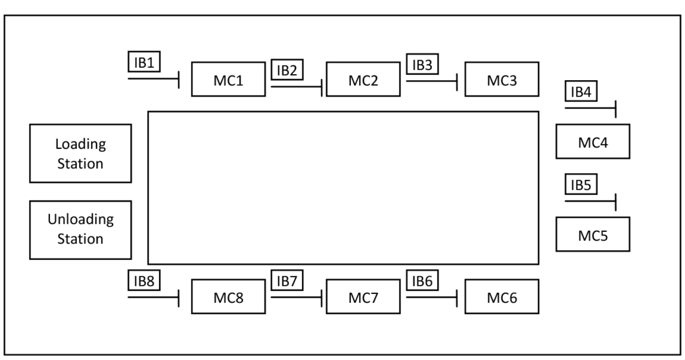

Figure 1. FMS Configuration.

The part family consists of eight part types (P1, P2, …… P7, P8); four to eight operations were required for processing each part types in the present experimental setup. A product mix of 800 parts is considered to be available at the start of the production run. Based on previous literature[1], a similar data set is adopted for the study as given in Table 1.

3.2. Design Strategies

Different manufacturing flexibilities, FMS system load and part variety spectrum etc. are some of the main constituents of FMS system design. We have considered five levels of Routing Flexibility (RF), and eight numbers of pallets, each one dedicated to one part at a time; as part of design strategy for the proposed experimental FMS. Routing flexibility level zero means that there is no alternate machine available for processing of parts in the system. RF3 means that three alternative machines are available for parts processing. Data set for the alternative machines and operation sequence requires large space and hence it could not be included here.

For the present experimental setup four types of Unequal Part Mix Ratio (UPMR) are considered to represent the customers demand variations as UPMR1, UPMR2, UPMR3 and UPMR4. The part ratio in percentage and number of parts for each part mix ratio is given in Table 2.

3.3. Scheduling Rules

Scheduling rules are used for part selection and machine loading in the FMS system. While, sequencing rules are used for selection of the next part from the machine queue, dispatching rules are used for the machine selection for next operation step. Here, Shortest Operation Processing Time (SOPT) and Maximum Balanced Processing Time (MBPT) rules are used as sequencing rules for parts selection and Minimum Number in Next Queue (NINQ) rule is used as dispatching rule for machine selection.

4. Result and Discussion

To explore the effects of unequal part mix ratio and routing flexibility on the performance of the FMS system, an experimental model has been created using ARENA simulation software, which is based on SIMAN language. We have considered four cases of unequal part mix ratios with total 800 parts for our analysis as mentioned in Table 2. The simulation results for different part mix ratios (UPMR1 to UPMR4) with different scheduling rule combinations are given in Tables 3 - 6 and presented graphically in Figures 2 to 5.

Simulation results for the first case of unequal part mix ratio (UPMR1) are given in Table 3. From results, we can conclude that Make Span Time (MST) is maximum at RF0 for both scheduling

Table 1. Details of part type, operation sequence and processing time

S. No.	Part Type	Operation Sequence							
		1	2	3	4	5	6	7	8
1	P1	MC7	MC5	MC4	MC1	MC3	MC6	MC2	-
		53	**60**	**73**	**12**	**52**	**35**	**44**	-
2	P2	MC5	MC3	MC6	MC2	MC7	-	-	-
		60	**18**	**85**	**5**	**14**	-	-	-
3	P3	MC3	MC1	MC8	MC4	-	-	-	-
		83	**33**	**42**	**34**	-	-	-	-
4	P4	MC1	MC2	MC3	MC6	MC4	MC8	-	-
		58	**47**	**9**	**77**	**23**	**44**	-	-
5	P5	MC2	MC4	MC5	MC8	-	-	-	-
		36	**22**	**11**	**16**	-	-	-	-
6	P6	MC4	MC6	MC7	MC3	MC1	-	-	-
		10	**10**	**7**	**35**	**35**	-	-	-
7	P7	MC6	MC8	MC1	MC7	MC5	MC2	-	-
		35	**51**	**85**	**73**	**14**	**28**	-	-
8	P8	MC8	MC7	MC2	MC5	MC6	MC4	MC3	MC1
		44	**16**	**47**	**32**	**65**	**23**	**9**	88

Table 2. Description of Part Mix Ratio of different Part Types

S. No.	Part Types	Un-equal Part Mix Ratios							
		UPMR-1		UPMR-2		UPMR-3		UPMR-4	
		Part Ratio (%)	No. of Parts	Part Ratio (%)	No. of Parts	Part Ratio (%)	No. of Parts	Part Ratio (%)	No. of Parts
1	P_1	10	80	4	32	14	112	23	184
2	P_2	15	120	9	72	6	48	17	136
3	P_3	20	160	16	128	6	48	12	96
4	P_4	15	120	11	88	21	168	7	56
5	P_5	5	40	21	168	14	112	9	72
6	P_6	10	80	7	56	19	152	13	104
7	P_7	5	40	19	152	14	112	8	64
8	P_8	20	160	13	104	6	48	11	88
Total		100	800	100	800	100	800	100	800

rule combinations (NINQ/SOPT and NINQ/MBPT). When we increase the RF level from zero to one, the percentage reduction in MST is maximum, which is 14.17% and 16.10% for NINQ/SOPT and NINQ/MBPT rule combinations respectively. This is due to shifting of workloads from highly loaded machining centers towards machining centers with lower load. On further increase in RF levels, the results show the diminishing effect on MST reduction. At higher level of routing flexibility, the change in MST is negligible or in certain cases it even shows negative impact i.e. increase in MST.

The experimental model is tested out for other three part mix ratios (UPMR2, UPMR3 and UPMR4) with same experimental

Table 3. Percentage MST variation at different levels of RF for Unequal Part Mix Ratio (UPMR-1)

RF Levels	NINQ/SOPT			NINQ/MBPT		
	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	38361.376	--	--	39491.26	--	--
1	32925.626	14.17	14.17	33134.001	16.10	16.10
2	32594.626	1.01	15.03	32622.626	1.54	17.39
3	32437.626	0.48	15.44	32437.626	0.57	17.86
4	32437.626	0.00	15.44	32437.626	0.00	17.86

Table 4. Percentage MST variation at different levels of RF for Unequal Part Mix Ratio (UPMR-2)

RF Levels	NINQ/SOPT			NINQ/MBPT		
	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	35160.376	-	-	35643.26	-	-
1	29817.626	15.20	15.20	30066.001	15.65	15.65
2	29375.626	1.48	16.45	29386.626	2.26	17.55
3	29467.626	-0.31	16.19	29467.626	-0.28	17.33
4	29467.626	0.00	16.19	29467.626	0.00	17.33

Table 5. Percentage MST variation at different levels of RF for Unequal Part Mix Ratio (UPMR-3)

RF Levels	NINQ/SOPT			NINQ/MBPT		
	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	33970.376	-	-	35106.26	-	-
1	30462.626	10.33	10.33	30558.001	12.96	12.96
2	29909.626	1.82	11.95	29831.626	2.38	15.02
3	30026.626	-0.39	11.61	30026.626	-0.65	14.47
4	30026.626	0.00	11.61	30026.626	0.00	14.47

Table 6. Percentage MST variation at different levels of RF for Unequal Part Mix Ratio (UPMR-4)

RF Levels	NINQ/SOPT			NINQ/MBPT		
	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	MST (Minutes)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	36198.376	-	-	37332.26	-	-
1	32449.626	10.36	10.36	32734.001	12.32	12.32
2	32237.626	0.65	10.94	32227.626	1.55	13.67
3	32075.626	0.50	11.39	32075.626	0.47	14.08
4	32075.626	0.00	11.39	32075.626	0.00	14.08

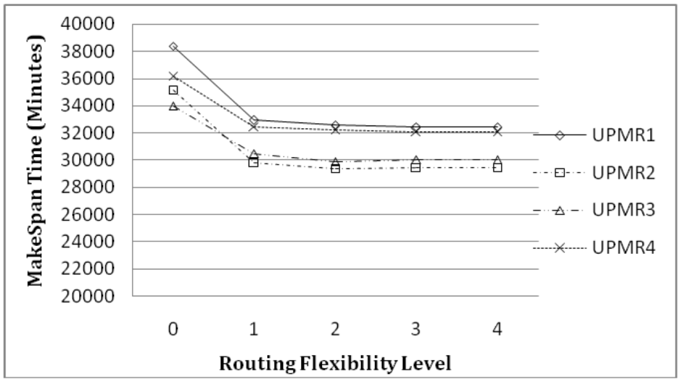

Figure 2. MST vs. RF (DR/SR = NINQ/SOPT).

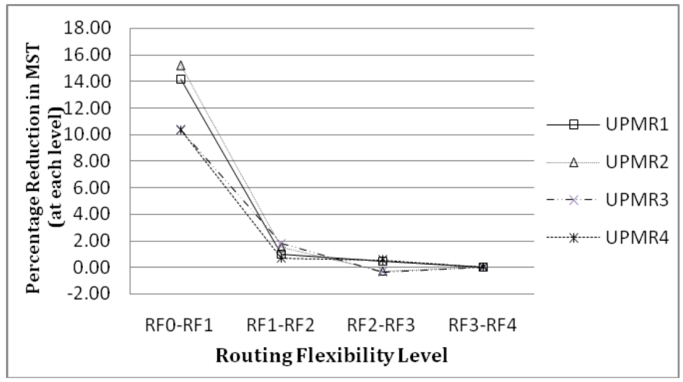

Figure 4. Percentage Reduction in MST at each level of RF with SOPT for UPMR.

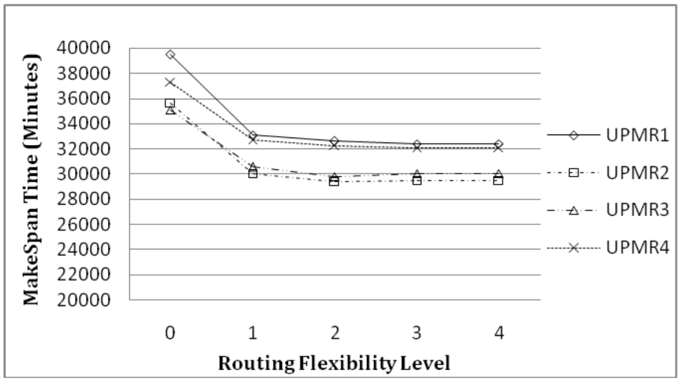

Figure 3. MST vs. RF (DR/SR = NINQ/MBPT).

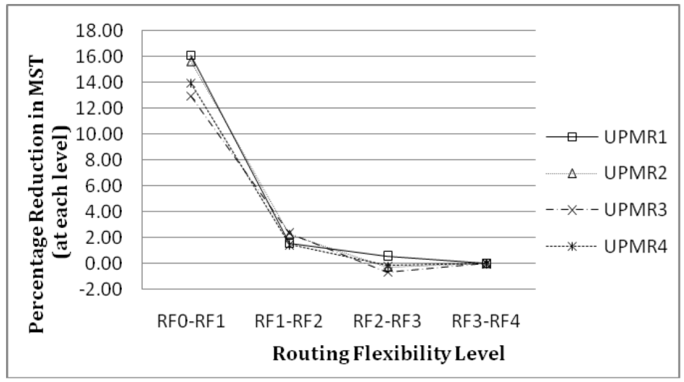

Figure 5. Percentage Reduction in MST at each level of RF with MBPT for UPMR.

set up and scheduling rule combinations. The results indicating percentage MST variations at different levels of routing flexibility for these cases are given in Tables 4 to Table 6 respectively. The results indicate that when FMS is at no routing flexibility (RF0) level, changes in part mix ratio effect the system performance appreciably (Figures 2 and 3). However, in all cases of product mix ratios, the effect of increase in RF levels has the same pattern of reduction in MST. The maximum reduction in MST is at RF level RF1. Further increase in RF levels has diminishing effect on system performance as discussed earlier.

Variations in MST at different levels of RF for different part mix ratio are depicted in Figure 2 and 3 for NINQ/SOPT and NINQ/MBPT scheduling rule combinations respectively.

The percentage reduction at each levels of RF in MST for all four cases of unequal part mix ratio is presented in Figure 4 and 5 for NINQ/SOPT and NINQ/MBPT scheduling rule combinations. From figure, we can find out that maximum percentage reduction in MST is for increase at first level of RF (RF0 to RF1) as compare to other flexibility level changes for all four cases. Percentage reduction is maximum for UPMR1 i.e. 16.12% with NINQ/MBPT rule combination and minimum for UPMR3 i.e. 10.33% with NINQ/SOPT scheduling rule combination when RF level changes from zero to one. The values of percentage reduction at each level of RF for different part mix ratio are given in Table 1 to 4.

From the experimental results discussed above, it can be concluded that change in part mix ratio has appreciable effect on system performance when no routing flexibility is employed on the system (Figures 2 and 3). This is also observed that the profile of system performance at different RF levels for all product mix ratio are similar (Figures 4 and 5).

5. Conclusion

The present research work shows the effect of varying part mix ratio and routing flexibility on the performance of a multi-node manufacturing system. The present study shows that varying part mix ratio has appreciable effect on the system performance, when no routing flexibility is present in the system. Moving from RF0 to RF level one, there is huge reduction in make-span due to proper balancing of workloads among machining centre's which improves system performance. These set of experiments suggest that for all product mix ratios, increase in routing flexibility levels continues to improve MST performance albeit with diminishing return, but routing flexibility does not seem to provide stability of MST performance against variation in part mix ratio. These observations can be used in the design of FMS system. Analysis of industrial FMS system with different design strategies and scheduling rules combinations considering different performance parameters can be considered in future study.

6. Acknowledgement

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Conflict of Interest:

Author of a paper had no conflict neither financially nor academically.