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Evaluating the Effect of Part-mix and Routing Flexibility on FMS Performance

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Abstract

The flexibility in manufacturing environment is implemented to respond proactively and cost effectively towards dynamic production requirements. Previous literature has explored eight common types of flexibility in manufacturing. This paper presents a simulation study based on Part-mix and Routing Flexibility and their impact on system performance of a typical Flexible Manufacturing System (FMS). ARENA based computer simulation models have been developed to investigate the effect of flexibility on the performance under various control strategies (sequencing and dispatching rules). The performance measure used in this paper is make-span time. Unbalanced type job shop FMS consist of four CNC general purpose machining centers and one loading/unloading station is considered for the illustration of simulation models. These demo simulation models are intended for deterministic environment, and the use of discrete event simulation approach is adopted to offer a focus on dynamic behavior of FMS operating under different manufacturing strategies and flexibility types. This simulation study, under dynamic environment, may be very useful for practitioners. Management can obtain better insight and guidelines for determining various decisions relating to process and operations improvement and investment in new facility.

Keywords: *Flexible manufacturing system, Control strategy, Sequencing and Dispatching Rules, Simulation Modeling.*

1. Introduction

The globalization of the market, increasing demands of the customized products and rapidly changing needs of customers, are forcing the manufacturers for searching such a manufacturing system, which fulfill the demand of the market within due dates and it should be available on lower cost. Thus, they can survive in the market among the various competitors of global market. They require a manufacturing system, which is having the flexibility to make the customized product with medium volume. Therefore, they are fascinated to the flexible manufacturing system (FMS), which is a compromise between job shop manufacturing system and batch manufacturing system. Flexible manufacturing system is the system, which is equipped with the several computer-controlled machines, having the facility of automatic changing of tools and parts. The machines are interconnected by Automatic Guided Vehicles (AGVs), pallets and several storage buffers. These components are connected and governed by computer using the local area network. The exquisiteness of this system is that it gleaned the ideas both from the flow shop and batch shop manufacturing system. The major literature has the several definitions of the flexible manufacturing system which is given by the many a researchers like Carlson (1989), Upton (1994), Wadhwa and Aggarwal (2000) Wadhwa et al. (2005) etc. In the dynamic business scenario at present, organizations must change continuously in adaptation to changes in the environment. Consequently, flexibility has become a holy grail to be sought. However, the term “flexibility” is often used for various meanings, and its essence is not always clear. Wadhwa and Rao (2000) have defined the flexibility as the ability to deal with change by judiciously providing and exploiting controllable options dynamically. Due to this flexibility, some decision-making problems have occurred in the system. Therefore to run the system efficiently, the judicious combination of flexibility and information based integration and automation (Wadhwa et al. 1997). Thus, most real world manufacturing systems have various planning, designs and control strategies to exploit this flexibility whenever desired.

The paper presents a simulation study with the combination of various design and control strategies. In the design strategy, the impact of part mix and routing flexibility has been taken in to the account. The sequencing and dispatching rules have been selected as the control strategies. In this study, SPT and FCFS are considered as the sequencing rule whereas the dispatching rules are MINQ (minimum number in queue) and MWTQ (minimum waiting time in queue). The make span time is considered as the performance measure for the FMS. The different combinations of various strategies are studied with the help of ARENA simulator. However, the real time simulation study presents the effects of part mix and routing flexibility with the different sets of sequencing and dispatching rules.

The remainder of the present paper has been organized in the following manner; section 2 briefly reviews the literature on the domain of paper whereas section 3 delineates the description of sample FMS and the problem with assumptions. Section 4 reveals the simulation modeling and results obtained under various design and control strategies. Finally, the summary and conclusions with a note about its future scope is reported in the section 5.

2. Literature Review

Many researchers have illustrated the role of flexibility in the manufacturing strategy of organizations. Early work presented by Skinner (1969) identifies manufacturing flexibility as one of four objectives of a manufacturing organization; other objectives are costs, delivery, and quality (Davies and Kochhar, 2002). New researchers consider flexibility as a “competitive parameter” that must be considered along-with other parameters, specifically production and other costs, product quality, delivery, and delivery speed (Dangayach and Deshmukh, 2001), By aligning these parameters with the market demands, researchers suggest that manufacturing objectives can be fulfilled (Lloréns-Montes *et al.*, 2004, Davies and Kochhar, 2002, Cox, 1989, Schroeder *et al.*, 1989, Gerwin, 1987, Wheelwright, 1984). Owing to the flexibility, decision-making problems require the judicious combination of flexibility and information based integration and automation (Wadhwa et al. 1997). Thus, most real world manufacturing systems utilize various planning, designs and control strategies whenever required. Loading pattern of the system is defined clearly in the planning strategy, in literature; it can be drawn that the system should be fully or partially balanced. The balancing can be defined as the equal distribution of jobs among all the machines. Raman et al. (1989) have explored that the performance of different dispatching rules highly depends upon the degree of workload imbalance whereas Shanker and Tzen (1985) have concentrated on the machine loading problem and part sequencing in a typical FMS by considering two objectives i.e., balancing the workload and meeting due dates and they have stated that sustaining a balance of workload on each machine reduces the work in process inventory and SPT (shortest processing time) rule performed better than other sequencing rules. The routing flexibility helps in the scheduling of jobs in very efficient manner (Sethi and Sethi 1990). Wadhwa and Bhagwat, (1998) has presented simulation experiments under various conditions of machine load and processing times balance. They have considered the impact of decision and information delays under various conditions of machine load and processing time balance. But all of these researches are focused on the effect of balancing of the workload and not concentrated on the interaction among other strategies. In the present paper, system is considered to be working in unbalanced load conditions.

In design strategies, various researchers described different types of flexibility types like Sethi and Sethi (1990) gave the concept of eleven flexibility types, Browne et.al. (1984) illustrated only eight types, which are known as: machine flexibility, process flexibility, routing flexibility, operation flexibility, product flexibility, volume flexibility, part mix flexibility and production flexibility. Among all types, the routing flexibility is one probable demonstration of manufacturing flexibility at the shop floor. Sinha and Wei (1992) have described that the number of alternative routes available for processing each part as a measure of routing flexibility. Browne et al. (1984) have confirmed that routing flexibility is possible flexibility, which is exploited only when required, such as a part being re-routed when a machine breakdown occurs. Caprihan and Wadhwa (1997) have presented a framework based on a Taguchi experimental design for studying the impact of varying levels of routing flexibility. Toni, D, Tonchia S. (1998) described part mix flexibility as the ability to vary the part mix of products in quantitative terms without further costs. In the abovementioned approaches, the effect of the routing flexibility has been studied on the different performance measures but there is no major consideration was given to the part mix flexibility. The collective effects of the routing flexibility and mix flexibility are not studied in the previous researches while the present paper has provided a new insight to get the combined effect of both. The impact of these is also combined with another strategy known as control strategies.

The controlling action in any manufacturing system is an important aspect. In the FMS, the real time control of part movement has been studied under the alternative control strategies (Wadhwa and Browne, 1989; Caprihan and Wadhwa, 1997), Wadhwa and Bhagwat, 1998) etc). Elmaraghy (1982) has studied different sequencing rule and concluded that the SPT (Shortest Processing Time) yields the highest production rate. Blackstone et al. (1984) have also given the similar results about the performance of SPT. Choi and Malstrom (1988) have introduced a new concept about the combination of rules and shown that the combination of SPT and MINQ (minimum numbers in queue) is dominated over all the other sets of rules. For the machine routing, the most of the previous researchers have employed the MINQ and MWTQ (minimum waiting time in queue). Hutchison et al. (1991) have utilized the SPT and MWTQ combination and the results shows the great reduce in make span. The main objective of various studies was to minimize total cost of production consisting of tooling, operational and delay costs. In all the above mentioned studies, the different dispatching and sequencing rules are presented and are compared at the same condition of the system and at the same time there is no consideration of any type of flexibility.

3. Problem Description

In the present FMS environment, a sample system configuration has been considered to show the effect of the routing and mix flexibility. The make-span time is considered as the performance measure in the current study. The present FMS consists of 4 general machines (M_1, M_2, M_3, and M_4) along with 4 dedicated input buffers (B_1, B_2, B_3, B_4). The buffer capacity of all machines is taken as 10. The machine selection is done by the dispatching rule while sequencing rules contribute in the selection of next parts. Here, two sequencing rules are taken into the account: SPT (Shortest Processing Time) and FIFO (First In First Out) and two dispatching rules are employed which are known as MINQ (Minimum length of Queue in the buffer) and MWTQ (Minimum Waiting Time in Queue). The whole system is governed by a Local Area Network (LAN) through information flow. The whole system configuration has been depicted in figure 1.

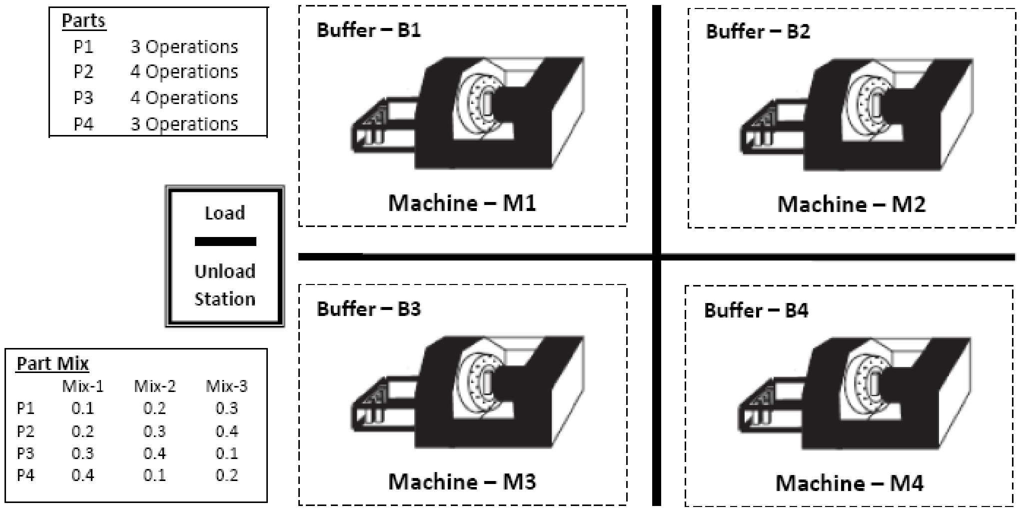

Figure – 1 Configuration of the FMS modeled for simulation with Part Mix and Operations

This abovementioned system configuration has been arranged for the processing of four part types (P_1, P_2, P_3, and P_4) and all the part types have number of operations ranging from 3 to 4. The system is designed to consider part mix flexibility by introducing three part-mixes i.e. (PM-1, PM-2, and PM-3). The present configuration is also employed with four level of the routing flexibility. The processing time of every operation of each part type and part-mix values are given in table 1a, 1b respectively.

Table – 1a, FMS operating under UBL condition (Unbalance Load)

Part Types	M1	M2	M3	M4	Total PT
P1	14		10	11	**35**
P2	17	10	6	9	**42**
P3	6	12	17	13	**48**
P4		18	5	8	**31**
Total ML	**37**	**40**	**38**	**41**	

Table 1b, <u>Part - Mix values considered</u>

Part Mix - 1	Part Mix - 2	Part Mix - 3
0.1	0.2	0.3
0.2	0.3	0.4
0.3	0.4	0.1
0.4	0.1	0.2

The study is made under certain assumptions including; the delay of any kind is not allowed either of raw material or from other resources, the transfer time of parts is negligible, the set up time is included in the processing time, and finally no breakdown is allowed.

3.1 Sequencing Rules:

(a) *Shortest Processing Time (SPT):* In a buffer, a part with shortest processing time will be processed first.

(b) *First In First Out (FIFO):* A part which first enters the buffer will be processed first.

3.2 Dispatching Rules:

(a) Minimum Queue at the buffer (MINQ): It is a machine selection scheme for the next operation. The job selects the machine which is having the minimum number of parts or minimum length of queue at its buffer among all the alternative machines.

(b) Minimum Waiting Time in Queue (MWTQ): The job selects the machine which is having the minimum total time of parts waiting in a queue.

4. Results and Discussion

To predict the effects of part mix and routing flexibility, a simulation model has been created using Rockwell's ARENA v.10.0 which is an industrial simulator. ARENA is based on the general purpose simulation language called SIMAN. On the basis of this simulation model, the results are taken. For the initial run of the simulation, some control signal entities are created for sending the signal at the loading queue to release the initial parts in the system. These control entities settle on the required number of part or pallets to go on the system and after the initial run, it will be disposed off automatically.

In the present paper, the effect of part mix and the routing flexibility is shown with different strategies like design strategy and control strategy (different dispatching rule and sequencing rules). The system is modeled and studies in unbalanced system load condition. This type of system has been studied under various part mixes and at different levels of routing flexibilities. Various model test conditions and their results have been discussed as follow:

In the first case, the system model is tested for Part Mix 1 (PM-1) and the sequencing rule is shortest processing time in the buffer (SPT) and the dispatching rule is MINQ, At the initial level of routing flexibility or when RF=0, the make span time is maximum and its value is 1106.45 time units whereas at RF=1, the value of performance measure is 938.27 units. It is clear that the reduction in MST is huge i.e.15.2%. Similarly, it is reduced by further increasing the routing flexibility levels and the total reduction is up to 19.8%. In next test condition, the sequencing rule is same but dispatching rule is MWTQ (Minimum Waiting Time in Queue) From the experimental results, it is concluded that at the zero level of routing flexibility, the make span time is 1106.45 units while at next level, the reduction in make-span time is 15.7%. Further for the same Part Mix (i.e. PM-1) the model is tested with initial combination of FIFO (First in First Out) and MINQ and the result shows that from increasing the RF level from 0 to 1 the reduction is again huge i.e. 15% and further increasing. Finally the test is done for FIFO and MWTQ and the same pattern is still following. These results for Part Mix 1 (PM-1) with different control rule combinations are given table 2a and graphically represented in figure 3.

Table 2a - Make Span Time (MST) for Part-Mix 1 (PM-1) under various control rules

PM-1				
	SPT + MINQ	**SPT + MWTQ**	**FIFO + MINQ**	**FIFO + MWTQ**
RF=0	1106.45	1106.45	1106.45	1106.45
RF=1	938.27	932.64	938.27	932.64
RF=2	910.13	912.11	910.13	912.11
RF=3	887.46	891.07	887.46	891.07

The same simulation model has also been tested with other Part Mixes (i.e. PM-2 and PM-3) and with different combinations of sequencing and dispatching rules (i.e. SPT + MINQ, SPT + MWTQ, FIFO + MINQ and FIFO + MWTQ). The result pattern is almost similar as in the previous case, and is shown in table 2b and 2c for part mix 1 and part mix 2 respectively.

From the simulation results, it can be concluded that for a Flexible Manufacturing System (FMS) running under the unbalanced load conditions, the part mix flexibility has less effect as compared to the routing flexibility on the system performance (Make Span Time), which is also evident from the figure 2 and figure 3.

Table 2b - Make Span Time (MST) for Part-Mix 2 (PM-2) under various control rules

PM-2				
	SPT + MINQ	**SPT + MWTQ**	**FIFO + MINQ**	**FIFO + MWTQ**
RF=0	1120.35	1120.35	1182.81	1182.81
RF=1	951.16	948.89	973.11	968.52
RF=2	918.65	917.24	957.38	954.97
RF=3	897.28	896.52	932.65	944.31

Table 2c - Make Span Time (MST) for Part-Mix 3 (PM-3) under various control rules

PM-3				
	SPT + MINQ	**SPT + MWTQ**	**FIFO + MINQ**	**FIFO + MWTQ**
RF=0	1059.4	1059.4	1112.53	1112.53
RF=1	847.52	844.37	944.75	940.89
RF=2	825.63	827.26	930.18	934.62
RF=3	811.19	818.43	921.38	923.06

Further it is also explored that for initial level of routing flexibility i.e.RF-0, the part mix variation also effect the make span performance of the system and the variation in MST is from 2 to 5%, but at next level of routing flexibility i.e. RF-1 the effect of part mix variation is not at all seen in almost all cases. Therefore it can be illustrated that for routing flexibility level one, the variation in part mix does not really bother to the system. In other words, for a real situation when sudden demand of a particular part mix increases the system should be designed to operate on routing flexibility level one so that overall make span of the production will not be effected. This is an important revelation of the study and can also be utilized in a productive manner in manufacturing industries.

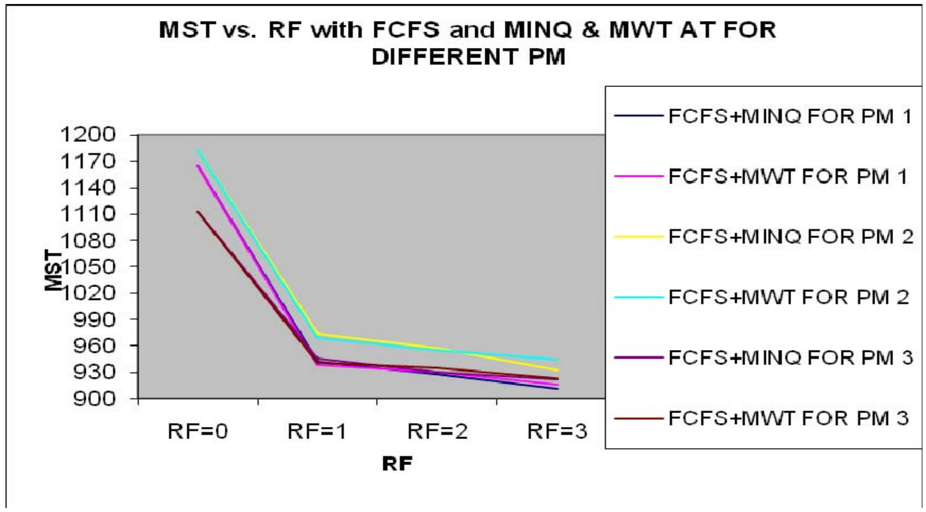

Figure – 2 MST performance under FCFS (FIFO)+MINQ & MWTQ, diff. Part Mixes

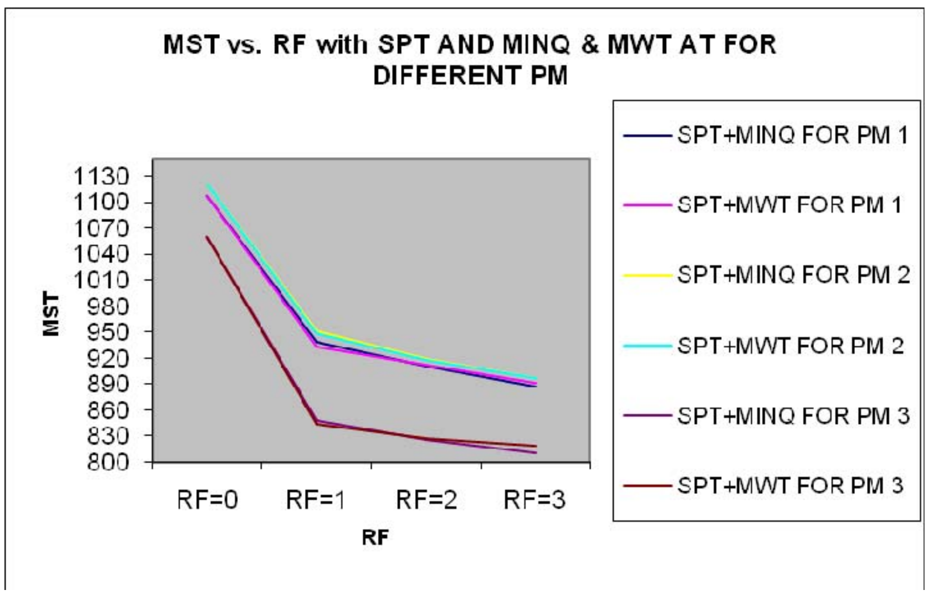

Figure – 3 MST performance under SPT + MINQ & MWTQ for different Part Mixes

6. Conclusion

The main contribution of this paper is to know the effect of various design strategies along with the different combinations of control rules on a typical FMS. In the proposed simulation model, it has been clearly shown that part mix and routing flexibility together can improve the make-span performance of an FMS. It is concluded that for initial level of routing flexibility the part mix variation also effect the make span performance but at next level of routing flexibility i.e. RF-1 the effect of part mix is almost negligible. Therefore it can be demonstrated that for RF-1, the part mix variation does not really bother to the system. In other words, for real situations when the demand of a particular part mix increases suddenly the system should operate on RF-1 so that overall performance of the system will not be affected. This is a vital exposure of the study and can also be exploited in a productive manner in manufacturing industries. Through this research an attempt has been made towards developing a theory of flexibility enabled performance improvement in flexible manufacturing systems. It will help practitioners and researchers in tactfully deploying and exploiting flexibility in various systems.

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