Performance Analysis of a Flexible Manufacturing System under Planning and Control Strategies

Subhash Wadhwa[1], **Yves Ducq**[2], **Mohammed Ali**[3], **Anuj Prakash**[4]

[1]Principal, IGIT & Professor, Indian Institute of Technology-Delhi, India

(Corresponding author)

[2]Associate Professor, LAP-GRAI –IMS, University of Bordeaux-1, France

[3]Assistant Professor, AMU, UP, India

[4]Research scholar, Mechanical Engineering, Indian Institute of Technology-Delhi, India

Abstract: A typical Flexible Manufacturing System (FMS) has been studied under Planning, Design and Control (PDC) strategies. The chief objective is to test the impact of design strategy (routing flexibility) on system performance under given planning strategy (alternate system load condition) and control strategies (sequencing and dispatching rules). A computer simulation model is developed to evaluate the effects of aforementioned strategies on the make-span time, which is taken as the system performance measure. Shortest Processing Time (SPT), Maximum Balance Processing Time (MBPT) are the sequencing rules for selecting the part from the input buffer whereas for machine selection the dispatching rules are Minimum Number of parts in the Queue (MINQ), and Minimum queue with Minimum Waiting Time of all parts in the Queue (MQMWT). In this paper, the same manufacturing system is modeled under two different system load conditions. These load conditions are Full Balanced Load (FBL) and Unbalanced Load (UBL) with respect to machine load and processing time. The result of the simulation shows that there is continuous reduction in make-span with increase in routing flexibility when both machine load and processing times are unbalanced i.e., under UBL system condition. Modeling of FMS shows that each strategy causes a flow process for each part inside the system. The co-ordination and integration of flexible resources to guide these processes in a desirable direction (lesser conflicts) is important. An FMS can then become a platform for studying interoperability between the various potentially conflicting processes where flexibility helps to reduce these conflicts. The improved performance can then become a measure of this phenomenon.

Keywords: Flexibility, Planning strategy, Design strategy, Control strategy, Interoperability, FMS

1. Introduction

Owing to the globalization of the market, increasing demands of the customized products and rapidly changing needs of customers, the manufacturers are facing a problem of customer satisfaction and survival in the market among the various competitors. Therefore, they are 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 continue to exist in the global market. Among all the existing manufacturing system, they require a manufacturing system, which is having the flexibility to make the customized product with medium volume. Therefore, they are allured 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 prominent literature has the several definitions of the flexible manufacturing system which is given by the many a researchers like Upton (1994), Wadhwa et al. (2005) etc. 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. Thus, most real FMS have various planning, designs and control strategies to harness this flexibility when required.

In the planning strategy, the load condition of the system should be defined clearly. From the past researches, it can be easily concluded that the system should be fully balanced. The balancing of the system can be viewed as the same distribution of task among all the machines.

Raman et al. (1989) have investigated that the performance of various dispatching rules depends upon the degree of workload imbalance whereas. The routing flexibility also helps in the scheduling of jobs in very efficient manner (Sethi and Sethi 1990). Wadhwa and Bhagwat, (1998) has performed 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. In the last decade, some other researchers like Cagliano et al. (2000), Kumar and Shanker (2001) have also shown the impact of different load condition of the system. But all of these prominent researches are concentrated on the impact of balancing of the workload and not focused on the interaction among other strategies. In the present paper, the impacts of the different strategies are studied simultaneously with the different loads in the system.

Within the study of design strategies, the diverse types of flexibilities are studied. According to Sethi and Sethi (1990), there are eleven flexibilities are existed in the system. To work with these all the flexibilities, a very efficient decision support system is required and effectively handling of all the flexibility is more tedious and difficult task. Therefore, Browne et.al.(1984) have comprehended it in only eight types, which are known as: machine flexibility, process flexibility, routing flexibility, operation flexibility, product flexibility, volume flexibility, expansion flexibility and production flexibility. Among all these, the routing flexibility is one possible manifestation of manufacturing flexibility at the shop floor. Browne et al. (1984) have stated that routing flexibility is potential flexibility, which is utilized only when needed, such as a part being re-routed when a machine breakdown occurs. In the late 1990's, Caprihan and Wadhwa (1997) have presented a framework based on a Taguchi experimental design for studying the impact of varying levels of routing flexibility. They concluded that an increase in routing flexibility is not always beneficial. A precious study has been done by Chan (2001) to give an idea about the effect of routing flexibility on an FMS. Another definition of the routing flexibility has been given by Barad et al. (2003), according to this the routing flexibility is the capability of processing a part through varying routes. Mohammed and Wadhwa (2005) have also explained the effectiveness of the routing flexibility in the partial flexible manufacturing system. They have shown the impact of flexibility on the three different levels of routing flexibility. The combined effects of the routing flexibility with real world situations 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 having increasing importance. In the flexible manufacturing system, the real time part priority control and routing machine priority are the two control actions, which are studied under the alternative control strategies (Wadhwa and Browne, 1990; Caprihan and Wadhwa 1997, Wadhwa and Bhagwat, 1998 etc). Choi and Malstrom (1988) have given a new thought about the combination of rules and they have also shown that the combination of SPT and MINQ (minimum queue at buffer) is dominated over all the other sets of rules. Karsiti et al. (1992) have shown that in most of the FMS systems, the combination of SPT/MINQ performs better. Chan (2003) has studied the effect of dispatching and routing decisions on the performance of an FMS with the impact of buffer capacities. In all the above-mentioned researches, the different dispatching and sequencing rules are studied, but all these is no consideration of load condition any type of flexibility.

In the present paper, a study has been accomplished with the combination of planning, design and control strategies. This paper has employed the two different load conditions in the planning strategy that is known as Full Balance Load (FBL) and Unbalanced Load (UBL). While in the design strategy, the impact of routing flexibility has been taken in to the account. The sequencing and dispatching rules are taken as the control strategies. In this study, SPT and MBPT are considered as the sequencing rule whereas the dispatching rules are MINQ and MQMWT (minimum queue with minimum waiting time). For studying all the above, the make span time is considered as the performance measure. However, this paper presents a real time simulation and the effects of 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 delineates the description of an FMS and the problem with assumptions. The working procedure of the simulator has been illustrated in the section 3. In section 4, the obtained results have been discussed. The GRAI macro reference model has been depicted in section 5. Finally, the summary and conclusions with a note about its future scope is reported in the section 6.

2. Problem Description

In the present FMS context, a system configuration has been taken into account to show the efficacy of the routing flexibility. The make-span time is considered as the performance measure in the current study. The present FMS consists 6 machines (M_1, M_2, M_3, M_4, M_5 and M_6) and all the machines are performing with their full flexibility i.e. each machine can perform each operation efficiently. There are 6 input buffers (B_1, B_2, B_3, B_4, B_5, B_6) are employed and only one buffer is dedicated to one machine. The capacity, which is 10, of each buffer is identical and pre-determined. In this system, each machine has associated with a sequencing decision point (SD) and a dispatching decision point (DD). The sequencing decision point (SD) is utilized to make decision about the selection of parts whereas dispatching decision point has made the decision for the selection of machine for the next operation. Both of these rules are called as the control strategies. Here, two sequencing rules are taken into the account: SPT (Shortest Processing Time) and MBPT (Maximum balanced processing time) and two dispatching rules are employed which are known as MINQ (Minimum length of Queue in the buffer) and MQMWT (Minimum length of queue with Minimum Waiting Time). The whole system configuration has been depicted in figure 1.

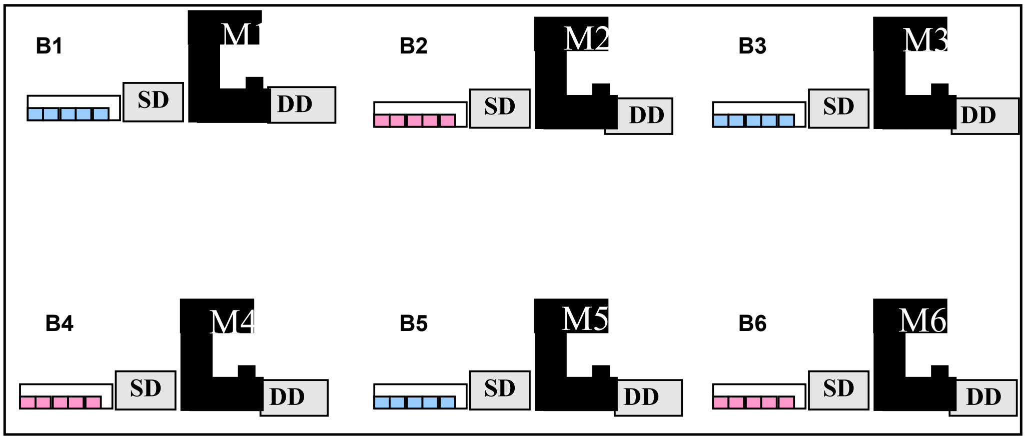

Figure 1. Configuration of the Flexible Manufacturing System

This aforementioned system configuration has been arranged for the processing of six part types (P_1, P_2, P_3, P_4, P_5 and P_6) and all the part types can track any of the alternative option for the processing routes. To show the numerical simulation of the performance, 100 parts of each part type has been taken into consideration. The processing time of every operation of each part type at each load condition has been given in table 1.

Table 1. Processing time

		FBL							UBL						
Parts	No of Operations	M1	M2	M3	M4	M5	M6	Total PT	M1	M2	M3	M4	M5	M6	Total PT
P1	4	66		64	62		68	260	40		24	12		18	94
P2	5	67	71	39	38	45		260	17	39	11	8	11		86
P3	6	50	49	22	55	39	45	260	68	49	16	94	39	70	336
P4	4		55	85		38	82	260		25	92		38	92	247
P5	5	47	50		35	93	35	260	67	20		5	94	15	201
P6	6	30	35	50	70	45	30	260	64	52	3	26	63	49	257
Total ML		260	260	260	260	260	260		256	185	146	145	245	244	

The present problem is concerned about the various level of the routing flexibility of the system. The present system consists of 5 level of routing flexibility. In the present system, 12 pallets are considered for carrying the parts into the system and all the pallets are universal i.e. they can carry each part type.

Various assumptions are taken in this research; some of them are given below:

1. There is no delay in the availability of raw material.
2. All the processing time is deterministic and pre-determined.
3. Each part type is processed by a predetermined sequence.
4. Pallets can carry only one part at a time.
5. The movements of parts among the machines are taken as negligible.
6. The set up time is included in the processing time.
7. Pre-emption is not allowed. (i.e. the operation that begins has no interruptions until completion)
8. No breakdown is allowed during the study of system.
9. No delay is allowed due the unavailability of workers, tools and other materials.
10. Each job once started must be performed up to completion (i.e. no job order cancellation)

From the prominent literature review, it is extracted that the make-span time is one of the important performance measure in the implementation of flexible manufacturing system. The make span time can be defined as follows:

Let, a set i = (1, 2,..I) shows the number of parts in a system. Each job has some operation is denoted by a set of j= (1, 2, …J). If P_{ij} is the processing time and c_{ij} is the completion time, the make-span will be

$$C_{max} = \max_{ij} c_{ij} \qquad (1)$$

Where

Cmax = Maximum completion time of all the j operations of all i jobs or Make-span

The aforementioned performance measure has been evaluated in the different planning strategies or load conditions of the flexible manufacturing system. These different load conditions are delineated as follows:

2.1 System Load Conditions

The different system load conditions are described in the following subsections.

(a) Full Balanced Load:

In this condition, both the machine load and total processing time is identical i.e. that the total load on each machine and total processing time of each part type, is the same or balanced. It is an ideal condition of the system on shop floor and we always crave for achieving this condition. It is denoted as SL_1.

(b) Unbalanced Load:

In this condition, both the machine load on each machine and total processing time of each part types are not balanced i.e. both are unequal. This condition exactly maps the real world FMS condition. It is denoted by SL_2.

2.2 Sequencing Rules

To make decision about the part selection, two sequencing rules are considered.

(a) Shortest Processing Time (SPT):

It illustrates the minimum processing time of the coming up jobs within a queue in an input buffer. This time should be calculated for each machine individually. The job, which is having shortest processing time, is selected for the processing.

$$\mathrm{SPT} = \min_{i \in SJ_q}\left(P_{ij}\right) \tag{2}$$

Here, P_{ij} = Process time of the operation of ith job, i = Job index,

SJ_q = Set of jobs in a queue

(b) Maximum Balanced Processing Time (MBPT):

It is another rule for selection of jobs for processing. According to it, the job, which is having maximum remaining or balanced processing time, will be selected for the processing of next operation. It is articulated by the following mathematical expression:

$$\mathrm{MBPT} = \max_{i \in SJ_q}\left(\Sigma_{j \in SR_i} P_{ij}\right) \tag{3}$$

Where :P_{ij} = Processing time of the operation of ith job, i = Job index

SJ_q = Set of jobs in a queue

SR_i = Set of remaining operations of ith jobs in a queue at an input buffer

2.3 Dispatching Rules

The decision about the machine selection is influenced by the dispatching rules. In the present study, two dispatching rules are taken into the consideration.

(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. The mathematical formulation can be given as:

$$\mathrm{MINQ} = \min_{k \in SM_a}\left(N_k\right) \tag{4}$$

Where, k= Machine index, SM_a = Set of alternative machines for a operation

N_k = Number of jobs in the queue at the buffer of k^{th} machine

(b) Minimum Queue with Minimum Waiting Time (MQMWT):

In this machine selection scheme, the job decides about the machine on the basis of the minimum length of queue and minimum waiting time in a queue at the buffer of all alternative machines. The expression in the mathematical form is given below:

$$\mathrm{MQMWT} = \min_{k \in SM_a} \left(WT_k\right) \qquad \text{if } N_i = N_j \tag{5}$$

Where $WT = \sum_{i \in SJ_q} P_{ij}$

Where, WT_k = Waiting time at machine k

N_i = Number of jobs in queue at i^{th} alternative machine

N_j = Number of jobs in queue at j^{th} alternative machine

3. Methodology

To highlight the impacts of routing flexibility, a simulation model has been created. On the basis of this simulation model, the results are taken. The model is depicted in figure 2. The description about the figure is given below.

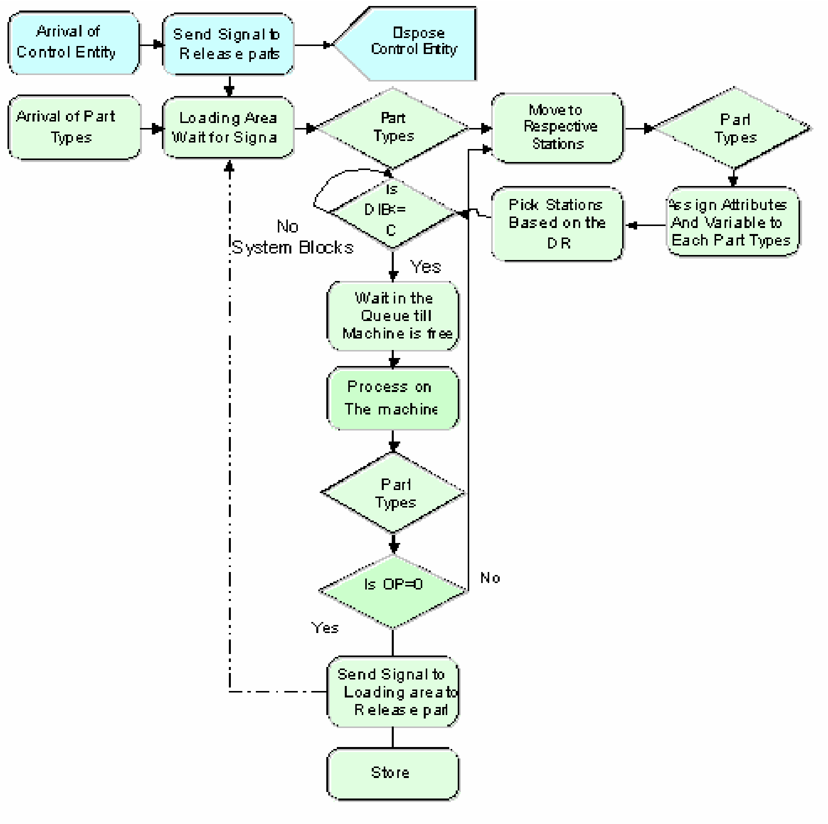

Figure 2. Flowchart showing materials and information flow in the system

In this figure, the flow of information and material has been clearly described through flow chart. At the initial stage, different part types move toward the system. The order of the proceeding of the part types in the system is decided on the basis of the incoming signal at the loading area where the part types are held up for waiting. For the first run of the simulation, some control entities are utilized for sending the signal at the loading area to release the part type 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 other runs of simulation the releasing of the parts and pallets are governed by the signal arriving from the system. On reaching in the system, the parts types are identified by a decision module. After assigning the attributes like processing time, operation sequence etc., and the part will go to the pick station module and it will decide the machine on the basis of dispatching rules. It will also check the availability of the space in the input buffer of the machine. After the operation on one machine, a decision module checks the status of the part. This decision module verifies that any operation is remaining on the part or not. If there is any remaining operation, it will further go to the decision module to select the next machine and attributes are updated, otherwise it will be sent to the store. The completed part also sends a signal to the loading area to load a new part on the pallet. Thus, the number of pallets or parts in the system becomes constant and the constant number of the parts will be entered in the system and it will be repeated in the cyclic manner until all the operations of parts are finished.

4. Results and Discussion

In the present paper, the impact of the routing flexibility has been shown with some different strategies like as planning strategy, design strategy and control strategy. These impacts have been tested on the different load conditions of the system, with different dispatching rule and sequencing rules. The dispatching rules, which are taken into consideration for study, are minimum queue at buffer (MINQ) and minimum queue with minimum waiting time (MQMWT) whereas, shortest processing time (SPT) and maximum balanced processing time (MBPT) are chosen as the sequencing rule for the present study. The simulation results of the present system with different routing flexibility are depicted as following.

In the first case, the system is in full balanced condition. This type of system has been studied under two different sequencing rules and dispatching rules, which has been also described in sections 2.2 and 2.3. Now the sequencing rule is shortest processing time in the buffer (SPT) and the dispatching rule is minimum queue at the buffer. At RF=0, the make span time is maximum and its value is 26821 time units whereas at RF=1, the value of performance measure is 26564 units. The total reduction is 2.88% from RF=0 to RF=1. In another condition, the sequencing rule is same as the previous one but minimum queue with minimum waiting time (MQMWT) is taken as dispatching rule. From the experimental results, it is concluded that at RF=0, the make span time is 26271 units while at next level, the reduction in make-span time is 0.97% and the value is 26463 units. The results for SPT rule has been given in table 2 and graphically represented in figure 3. For another test, the sequencing rule is maximum balanced processing time (MBPT) and the dispatching rule is minimum queue in the buffer (MINQ). The make span time is 26271 units at RF=0 while at next level, the reduction in make-span time is 0.97%. From RF=0 to RF=1, the total reduction in make-span is 2.46%. For the further study, the sequencing rule is same as previous one and the dispatching rule is minimum queue with minimum waiting time (MQMWT). The value of make-span time is 27049 units at the initial level while the make-span time is 26070 units at RF=5. Therefore, the total reduction is 3.76% in the make-span time. In the addition, it is also valuable thing that the maximum reduction occurs at RF=1 and RF=2, which is 1.22% and 1.38% whereas, at the higher level, the reduction is only 0.24%. The percentage reduction in the make-span time and their values has been shown for both cases in the fig 4 and table 3.

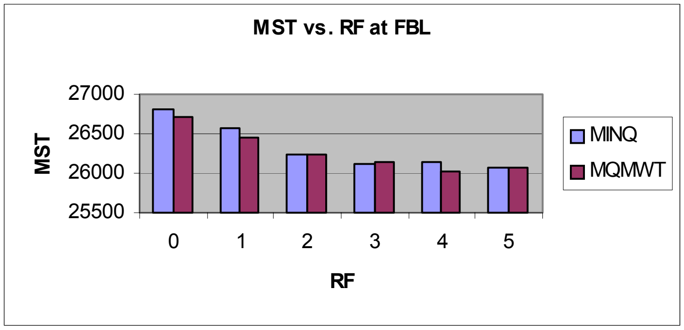

Figure 3. Variation of MST under various levels of RF at FBL with SPT

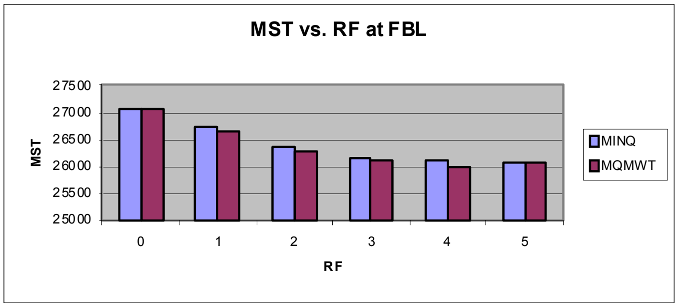

Figure 4. Variation of MST under various levels of RF at FBL with MBPT

Table 2. Percentage MST variation at different levels of RF at FBL with SPT

	MINQ			MQMWT		
RF Levels	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	26821	-	-	26721	-	-
1	26564	0.97%	0.97%	26463	0.97	0.97
2	26231	1.27%	2.25%	26239	0.85	1.84
3	26115	0.44%	2.70%	26135	0.40	2.24
4	26140	-0.10%	2.61%	26030	0.40	2.65
5	26070	0.27%	2.88%	26079	-0.19	2.46

Table 3. Percentage MST variation at different levels of RF at FBL with MBPT

	MINQ			MQMWT		
RF Levels	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	27049			27049		
1	26723	1.22%	1.22%	26649	1.50%	1.50%
2	26358	1.38%	2.62%	26295	1.35%	2.87%
3	26149	0.79%	3.44%	26107	0.72%	3.61%
4	26135	0.05%	3.50%	26000	0.41%	4.03%
5	26070	0.24%	3.76%	26081	-0.31%	3.71%

From the aforementioned results, it can be concluded that at the full balanced load condition of an FMS, the routing flexibility has a great impact on the performance. Besides this ideal condition, the study has been also done in the real FMS load condition, which is known as unbalanced load condition (UBL).

With the first combination (SPT and MINQ), the make span time at zero level is also less than the previous condition and it is reduced 20.20% at the next level whereas the total decreasing in time is 26.50%. According to this declining of the time, it can be stated that in the real problems, the routing flexibility is performed well. At the higher levels the reduction will be lower than the prior levels. It shows the limitation of applying the flexibility. During the experiment with combination of SPT and MQMWT as sequencing and dispatching rule respectively, it has been seen that the maximum reduction always occur at the first level and at the higher level it may be negative otherwise it will be very less. In the present scenario, the percentage reduction at the highest level is negative which indicates that routing flexibility should be only up to for the level. The experimental results are given in table 4 and graphically represented in figure 5. For the next arrangement of the sequencing and dispatching rules, which are MBPT and MINQ, the results show the same fashion of the declination in the percentage reduction of performance measure (make-span time). At the first level, it is very high as 18.80% while at the highest level; it is only 0.40%, which is almost negligible in the comparison of previous one. In another testing within the same loads condition has been accomplished with the help of MBPT as sequencing rule and MQMWT as dispatching rule. The results depicted the well-known fact that the major time is reduced at the first level of flexibility and after a certain level, it tends to be increased. The description of all the results at each level has been given in table 5 which is shown in figure 6. Now, in this real world condition, it can be stated that the impact of routing flexibility is deeply affect the performance of the system.

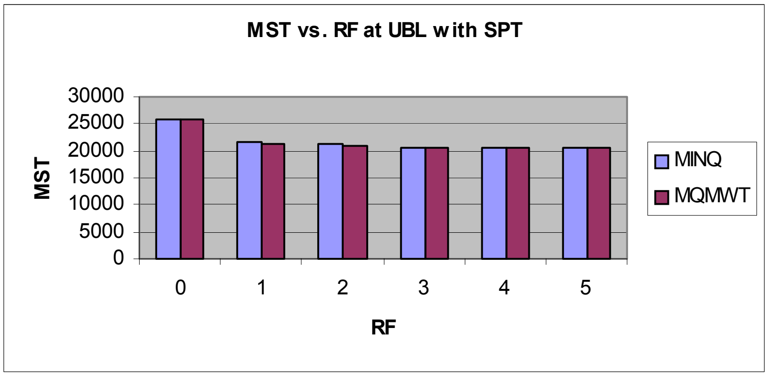

Figure 5. Variation of MST under various levels of RF at UBL with SPT

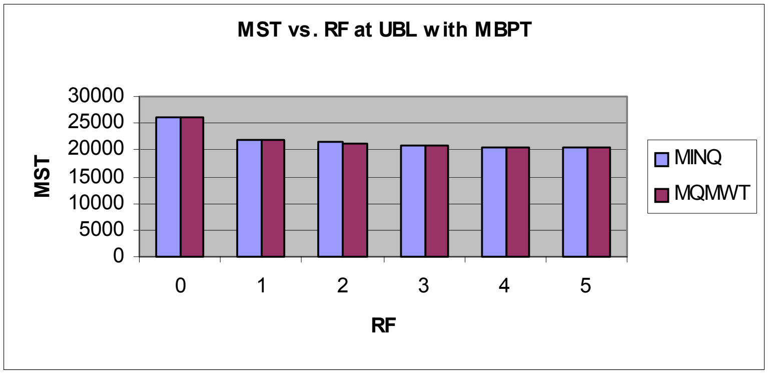

Figure 6. Variation of MST under various levels of RF at UBL with MBPT

Table 4. Percentage MST variation at different levels of RF with UBL (MINQ/SPT)

	MINQ			MQMWT		
RF Levels	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	25862			25862		
1	21514	20.20%	20.20%	21248	21.7	21.7%
2	21188	1.50%	22.10%	20840	2%	24.1%
3	20681	2.50%	25.10%	20653	0.9%	25.2%
4	20559	0.60%	25.80%	20408	1.2%	26.7%
5	20452	0.50%	26.50%	20473	-0.3%	26.3%

Table 5. Percentage MST variation at different levels of RF at UBL with MBPT

	MINQ			MQMWT		
RF Levels	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)	Make-Span Time (Mins.)	Percentage Reduction (At each level)	Percentage Reduction (From zero level)
0	26178			26178		
1	22034	18.80%	18.80%	22046	18.74%	18.74%
2	21363	3.10%	22.50%	21048	4.74%	24.37%
3	20662	3.40%	27.70%	20652	1.92%	26.76%
4	20539	0.60%	27.50%	20412	1.18%	28.25%
5	20461	0.40%	27.90%	20517	-0.51%	27.59%

The above mentioned all the analysis has been carried out with the help of ARENA 7.0 simulator, which is used for the industrial system. It can be concluded that routing flexibility is important to improve the system performance. The first level of routing flexibility offers maximum benefits. The investment in flexibility needs to be carefully analyzed by simulation.

An important challenge to model the decision system and its impact on the flexible system performance is related to the sub-system based structuring of the problem.

5. Importance of the GRAI Macro Reference Model: Interoperability Direction

It is useful to structure the flexibility and control decision problems in Flexible systems (CIM systems and FMS etc) in the GRAI macro reference framework. The GRAI methodology (Doumeingts et. al., 1995) and DIS framework (Wadhwa and Bhagwat, 1999) can show the relationship between control decisions and availability of the information in these systems. There are four types of sub-systems in the macro reference model e.g. physical subsystem, operating subsystem, information subsystem and decision subsystem. It is useful to study these four subsystems and their integration to appreciate the need for interoperability among different subsystems. The knowledge obtained can be applied to other flexible systems such as flexible supply chains and virtual enterprise models. Interoperability in the context of an enterprise is the ability to work with other systems, processes etc (Gonclaves, Muller, Mertins and Zelm, 2007). In our model the process involved the flow of entities through the various subsystems. For instance the material flows from one flexible machine to another (i.e. the physical subsystem) only when the decision system directs the flow process. The decision system does this on the basis of information flow process that indicate the part routing information, end of the last event (finished operation at a machine), next operation machine and status of the machine etc. The operating system uses the information system and decision system knowledge to move the material handling devices to transfer the part to the right machine and to put it in a queue at the buffer if the machine is in busy status. Thus it can be seen that using an appropriate structure of subsystems and by defining the underlying rules, the interoperability between the processes can be improved. As part of future research, efforts should be put in the direction of developing generic models of domain knowledge that can be translated into reference models based on operating scenarios. These can be further detailed into specific models. Specific requirements of a domain should be kept in mind to develop the generic models. For instance where synchronization between decision and information is important, it is useful to have DIS and DKS framework based models (Wadhwa and Saxena (2006)). These frameworks can benefit/extend the challenges and approaches on interoperability as compiled by Doumeingts et al (2006). It is proposed as an important direction for future research to use flexible systems and decision system models as a base to expand to domain of interoperability required amongst constantly changing enterprise systems. Flexibility (as in FMS) and the strategies used can help improve the performance.

6. Conclusion

The main aim of this paper is for knowing the impact of the design strategy and different combinations of planning and control strategies and on the whole FMS. In the proposed model, it has been clearly shown routing flexibility as a design option can reduce the make-span effectively. It is seen that improvement from no flexibility to first flexibility level is most productive. With two different conditions of the system and different sets of sequencing rules, the make span is seen to be reduced. One of the valuable implications is that judicious level of flexibility depends on planning and control strategies. Further flexibility helps to change the flow processes for each part in a desirable direction. Such studies offer a good platform to study interoperability issues between two flexible subsystems in any enterprise. The aim of system design and control is to integrate the flexible flow processes to minimize detrimental process flow conflicts. Make-span can act as a measure for interoperability potential between two or more flow processes in flexible systems. A future research direction is the development of generic models that focus on the synchronization between knowledge, objectives, decisions and information systems to create minimal conflicts between different flow processes. It appears useful to develop these generic models with capabilities to model the multiple entity flows using suitable simulation primitives.

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