**Proceedings of GLOGIFT 09**
November 12 – 14, 2009
National Institute of Industrial Engineering
Mumbai, India

# Performance of Flexibility Enabled Manufacturing System under Control Strategies

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## Abstract

As flexible systems become prevalent, the ability to describe the short-term future performance of the systems becomes critical. This paper reports on a simulation study aimed at understanding the impact of control strategies (static and dynamic priority rule) on the performance of a flexible system. The study is conducted at different levels of routing flexibility. The system performance considered is make-span time. The results of the experimental study shows that dynamic priority rule i.e., Modified Shortest Processing Time (MSPT) rule performed better than static Shortest Processing Time (SPT) rule for the given conditions. Moreover the maximum reduction in make-span time occurs when the level of routing flexibility is increased from 0 to 1. The results obtained from the study will help shop floor manager to take judicious decision regarding the implementation of right level of flexibility and control strategy to improve the performance of the system.

Keywords: flexibility; simulation; makespan

## Introduction

In recent years, there has been an incredible expansion towards manufacturing systems planning and control. Many manufacturing companies have realized that their manufacturing facilities can be a source of tremendous opportunity if managed in a systematic manner. According to Attaran and Bidgoli (1988), the computer based manufacturing system may play an important role in improving the performance of the manufacturing system. The current situation of flexible manufacturing system producing discrete parts is intensely competitive. The customers want products that are excellent in quality, low in cost and are delivered on time. If the production process is capable of responding to these challenges, manufacturing can be a source of real competitive advantage for the business. Hence in manufacturing, the challenges are to develop a coherent manufacturing system that are capable of meeting the cost, quality, flexibility and time pressures forced by the customers. Our primary objectives in this paper include the reduction of make-span time to the minimum possible. Flexible Manufacturing System (FMS) with its inherent flexibility helps in the realization of such objectives within reach. However advanced manufacturing technology alone is unlikely to yield an efficient shop floor strategy. Hence the focus of this paper is on operational level normally referred to as shop floor control. In this paper we concentrate on the effect of static and dynamic priority rule (control strategies) in the reduction of average make-span time. To address this problem we use simulation technique. The simulation model is built with the ARENA simulation package.

The paper is arranged as follows. We first describe the motivation of performing this study then discuss various problems in scheduling of shop floor in general and then flexible manufacturing system in particular. Next we describe the production control framework followed by the structure of the simulation model. The last section discusses the results and summarizes the conclusion of the study.

## Motivation

The role of flexibility in manufacturing is becoming most important as the pressures due to variety of products are continuously increasing coupled with declining volumes and faster response to customers. This would need large investments in flexibility, information integration and operation control. The system designer would like to invest in these key factors only to the required level. However these factors may involve dynamic interactions in the operations of discrete part manufacturing systems. As we are aware that FMS deals with mid-variety and mid-volume products, that involves complex information and material flow in the shop. To improve delivery performance there is sometime need to reschedule jobs on shop floor, expediting some urgent jobs while de-expediting others. This motivated us to study the impact of routing flexibility and priority rules on make-span performance of the flexible system.

## Shop floor scheduling and control in flexible systems

These are sequencing and dispatching decisions collectively known as scheduling decisions. Ovacik and Uzsoy (1994) explain that in practice, job shop scheduling has been approached mainly by using sequencing and dispatching rules. They are popular because they avoid the difficulty of obtaining timely shop status information beyond the work center where decisions are made. The on-line scheduling typically involves sequencing and dispatching decisions similar to those studied by Wadhwa and Browne (1990), Caprihan and Wadhwa (1997), and Daniels et al. (2002). Chen and Chung (1991) proposed three alternative sequencing models at minimizing the operation assignments and consequently the inherent FMS flexibility. The result showed the importance of utilizing an alternative routing policy in FMS environment. As we are aware that conventional job shop is the oldest kind of manufacturing systemic that deals with variety of work, hence the equipment must be flexible and general purpose to take care for this variety of work. The conventional batch manufacturing system involves the manufacturing of medium-size lots and medium size variety of items. The batch manufacturing systems almost have the same problems as in the job shops, but their control may be less demanding as the part variety is not as large as that of the job shops. A flexible manufacturing system with its inherent flexibility overcomes some of the problems of batch manufacturing system. One important factor that differentiates FMS from batch manufacturing system is high level of realizable flexibility achieved in flexible manufacturing system due to the presence of computer based control and resources. There have been many research contributions to the area of job shop scheduling in flexible system. At the operational level, the scheduling decisions in manufacturing systems are effective for virtually real time period to a few minutes to even few hours depending upon the processing times. In any manufacturing system, at the operational level, the decisions need to be taken at the start and at the end of the key activities. The part to be loaded on the machine from the queue is referred to as sequencing decisions. Similarly at the end machine activity, one needs to decide where the parts to be sent for next processing. We refer to it as the dispatching decisions. Most of the researchers who have proposed priority rules for FMS scheduling have compared their performance with SPT and FCFS rules (Montazeri and Wassenhove, 1990; Karsiti et al.1992, Wadhwa and Bhagwat (1998). Choi and Malstrom (1988) simulated six machines flexible system with physical simulators for 28 scheduling rules combinations. The SPT (Shortest Processing Rule)/WINQ (a machine was selected that had a least work in queue in terms of the process time) set dominated the other decision rules when throughput time and the actual production output were considered. Karsiti et al.1992 and Waikear et al.1995 shown that SPT/MINQ combination of rules for a flexible system performs better than other rules. In literature the loading problem has primarily been addressed by a large number of research studies and experimental investigations on FMS production planning problems (Stecke and Solberg 1981; Werra and Widmer 1990; Liang and Dutta 1993; Mohammed 2006).

Hence it is seen that priority sequencing for minimizing make-span time has been the subject of research investigation for several decades. The utility of any shop floor control module cannot be complete without the flexibility of rescheduling or control decisions.

## Problem Formulation

The purpose of this paper is to present the use of a simulation based decision support tool in shop floor scheduling. Priority rules or control strategies are simple heuristics used to select the order in which jobs will be processed. Identifying the best priority rule to use at a particular operation in a manufacturing process is a complex problem because the output from one operation becomes the input to another. Computer simulation models are effective tools to determine which priority rules work best in a given situation. Once the current process is modeled, the analyst can make changes to the priority rules at various operations and measure the impact on performance measures. Many simple priority rules are static in the sense that priorities are established prior to production, and remain unchanged over the life of the process. Common sequencing rules such as Shortest Processing Time (SPT), Longest Processing Time First (LPT) and First Come First Serve (FCFS) are static rules. SPT generally performs best in terms of minimizing flow time, average number of jobs in the system, and make-span. Thus, it also results in lower WIP. SPT also often provides the lowest average lateness, thus providing good customer service levels. However the major disadvantage of the SPT rule is that it tends to make long jobs wait. Various modifications are made to avoid this. To tackle this problem we have used Modified Shortest Processing Time (MSPT) rule. It is a dynamic priority rule. This rule scans the queue for jobs that have waited for a certain amount of time then, its priority is upgraded and it is moved ahead of the queue.

## Production Control Framework

The production control framework is shown in Figure 1. The proposed production control gives greater emphasizes on the lowest level i.e., queue in order to have better interaction of material and information flow. At this level the control strategies in the form of sequencing and dispatching are implemented. The second level is the workstation, which is the collection of resources. The highest level of the framework is the shop. At this level the overall production control policy is implemented. It is at this level where the manufacturing tasks are set. The company performance determines the manufacturing performance. The manufacturing performance can manifest itself in the form of variety of product produced, make-span time, productivity etc. The manufacturing flexibility at the shop level mainly routing, volume and expansion flexibility etc., responds to the manufacturing tasks set at the shop level to realize the manufacturing performance. At the workstation level decisions such as which part to be produced on which machine are taken. It helps to accomplish manufacturing task set by the higher-level i.e. shop level. In this paper we are studying the impact of static and dynamic priority rule at the lowest level.

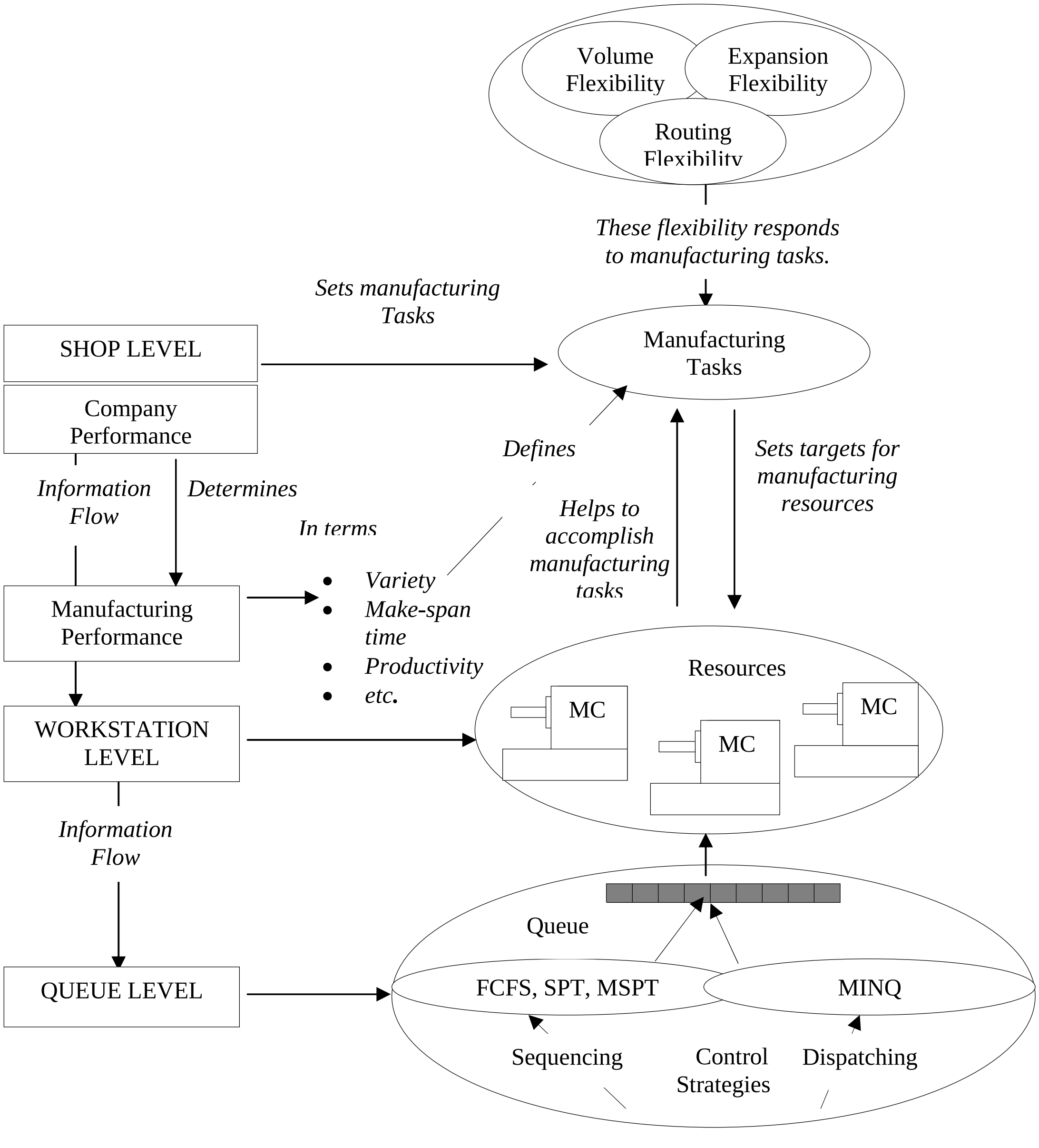


**Figure 1: Production control framework**

## A simulation study

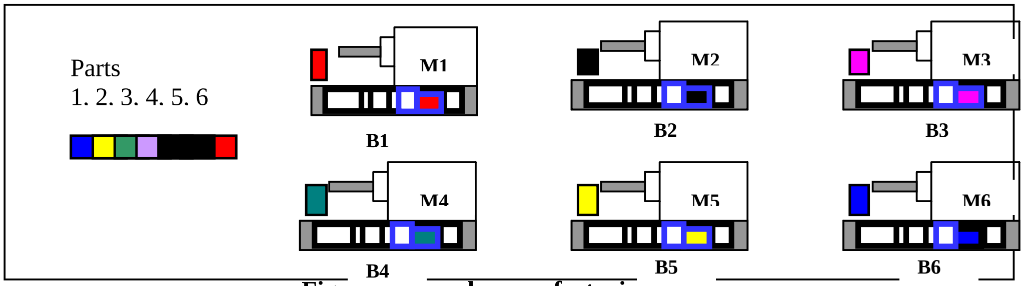
Simulation technique is widely used for the purpose of scheduling and control of manufacturing system. In contrast to the mathematical models, they are suitable for representing complex system to get the feeling for the real system. We found several papers following this approach. In our study we model the manufacturing system as discrete event dynamic systems. The role of flexibility within such systems can be viewed as one that provides alternative decisions choices at certain discrete events through which the system evolves. Wadhwa and Browne (1990) refer to these events as decision points. Depending on the type of flexibility (Buzacott and Gupta (1986) present in a manufacturing system, decision point provide an opportunity for controlling the direction in which the decisions should evolve. Decision choices are typically exercised using control strategies, which manifest themselves as sequencing, dispatching and/or queue selection rules. In order to compare the various priority rules, a computer simulation model of a simple queuing system was constructed. Next we describe the structure of the simulation model.

## A Sample Manufacturing System

Many researchers have used different configurations for studying different aspects of the manufacturing system, in particular the control strategy and flexibility. A six-machine system with eight parts types was used by Choi and Malstrom (1988) to evaluate traditional scheduling rules in a FMS system. Shnilovici and Maimon (1992) simulated a four machine system for testing heuristics for dynamic selection and routing of parts in an FMS. Huq and Huq (1995) considered a hypothetical system of six machines and six parts for testing the sensitivity of rule combinations for scheduling. In this paper six machines and six parts configuration is used for the study, as this configuration will be complex enough to incorporate the complexities related to scheduling in a manufacturing system.

## Key Features of the Sample Flexible System

The manufacturing system consist of six flexible machines M1, M2, M3, M4, M5, and M6 with input buffers B1, B2, B3, B4, B5 and B6 respectively as shown in the Figure 2. There are six part types (P1, P2, P3, P4, P5 and P6) which follow alternative processing routes in the system. The number of operations required for processing the part type have been varied from four to six such as P1=P2=4 operations, P3=P4=5 operations and P5=P6=six operations. Table 1 summarizes the key operating parameters of this system. The parts can be routed through the different machines for processing depending on the level of routing flexibility available in the system. Table 1 shows the details of alternative machines available at the highest level of routing flexibility i.e., 4. It can be observed from the table that the processing time on all the alternative machines is same for a given part and operation. This implies that all alternative machines are equally efficient for processing the same operation.



**Figu mple manufacturin n**

**Table 1: Routing for sequence of operation and processing time for routing flexibility (RF=4)**

| Parts | O1 | O2 | O3 | O4 | O5 | O6 |
|---|---|---|---|---|---|---|
| P1 | M1M2 M4M5 M3 (40) | M3M5 M2M1 M4 (50) | M4M1 M5M2 M6 (60) | M6M3 M1M2 M5 (70) | * | * |
| P2 | M4M3 M5M6 M1(40) | M2M1 M3M4 M5 (55) | M6M4 M2M1 M3 (54) | M5M2 M4M3 M6 (95) | * | * |
| P3 | M5M6 M2M1 M4 (60) | M1M4 M6M5 M2 (45) | M3M5 M4M6 M1(48) | M2M1 M6M5 M4 (65) | M4M6 M1M2 M3 (75) | * |
| P4 | M2M1 M3M4 M6 (40) | M5M3 M4M6 M1 (50) | M6M2 M1M3 M4 (50) | M3M6 M5M4 M1 (45) | M1M5 M2M4 M6 (85) | * |
| P5 | M6M5 M1M3 M2 (40) | M4M6 M5M2 M3 (45) | M2M3 M6M4 M5 (45) | M5M4 M3M1 M2 (40) | M1M2 M3M6 M5 (55) | M3M1 M6M5 M3 (100) |
| P6 | M3M4 M6M2 M5 (35) | M5M2 M1M3 M6 (45) | M4M6 M3M5 M2 (55) | M1M5 M2M6 M3 (50) | M6M3 M4M1 M2 (52) | M2M4 M5M3 M1(75) |

** operations are not performed*

## Sequencing Decision

When any machine finishes the present operation and becomes idle, the sequencing decision module collects the available information of the parts waiting for processing in the input buffer, evaluates all the alternatives amongst waiting parts based on the available information about these parts and selects the next part for processing from the queue of parts in the input buffer. The sequencing decision modules select the next part according to an operating control strategy. In our study first we have selected SPT and FCFS as static priority rule and MSPT as dynamic priority rule to sent part to idle machines from the input buffer. Figure 3 shows the information flow for these control strategies. When SPT priority rule is used the parts are arranged in the queue according to the shortest processing time. Whenever new part comes in the input buffer of the machine it s placed ahead of part having processing time more than the incoming part. When MSPT rule in invoked the part that has been waiting for some specified period of time is given higher priority and moved ahead in the buffer.

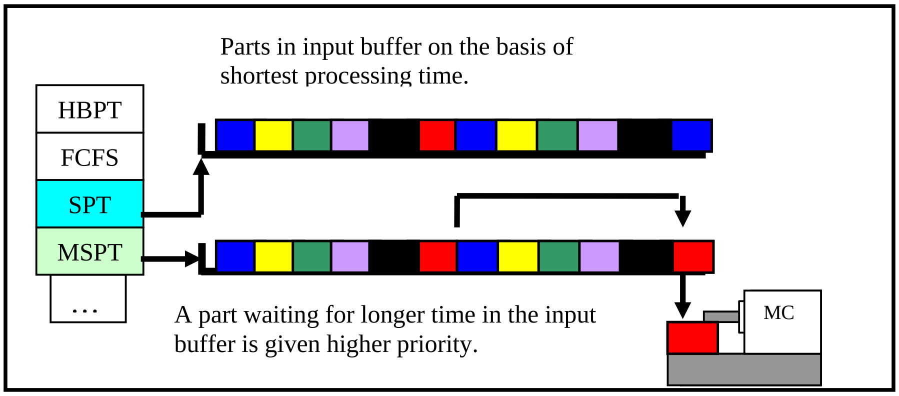


Figure 3: Logical information flow in SPT and MSPT priority rules

## Routing Flexibility

Figure 4 shows the routing flexibility concept.

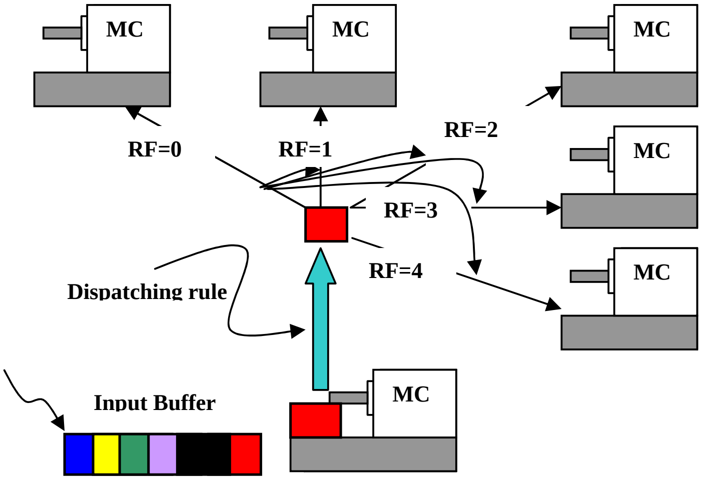


Figure 4: Illustrating different levels of routing flexibility

The routing flexibility measures the ability to perform operations by more than one machining center in order to alleviate bottleneck machines or to handle machine breakdowns. Exploiting the routing flexibility in the discrete part manufacturing systems involving variety production towards the make-span performance by using on line control strategies is represented by key works of, Wadhwa and Browne (1990), Lin and Solberg (1991), Caprihan and Wadhwa (1997), Wadhwa and Rao (2002), Mohammed and Wadhwa (2005). The manufacturing system considered have a capability of routing flexibility i.e., the parts can be processed on the alternative machines. The number of alternative machines depends on the level of routing flexibility present in the system. RF=0 means exactly one machine available for an operation on a given part. RF=1 implies that there are two possible machines for processing the same operation. RF=2 implies that there are in all three possible machines for processing the same operation. Similarly RF=3 and RF=4 imply that there are four and five alternative machines available respectively for any operation.

Figure 4, also illustrates that as a machine finishes the job currently being processed, the part next to be processed is selected on the basis of priority rule. When the machine unloads a job into output buffer, the dispatching rule uses routing flexibility to select the next machine for the next operation. The dispatching rule used in our study selects the machine having minimum number in its input buffer (MINQ).

## Development of manufacturing system simulator

The simulation model has been developed in the ARENA simulation package. For modeling various control strategies a built in feature of the package have been used. For sequencing decision such as SPT, FCFS and MSPT the built in feature selects the next part from the input buffer. For dispatching decision again the in built feature of ARENA i.e., the (PICKSTATION MODULE) scans the available machines depending on the level of routing flexibility and sends the parts to the input buffer of the machines having the minimum number in its queue (MINQ). To implement the MSPT we have used the following module of ARENA. First the control part is created every minute by CREATE module. A variable TNOW is attached with this control part. TNOW records the simulation clock time as the model progresses. After all activities at a particular simulation time have been processed, TNOW is updated to the time of the next activity. Then this control part moves to the SEARCH module where it scans the queue to find out any part waiting for the specified period of time. If it is unable to find any part in the queue that has waited for the specified period of time then it is disposed off. If it is able to find the part then that part is removed from the queue given higher priority and sent ahead of all the parts in the queue. In this the part waiting for long or part having high processing time, which is been displaced by SPT, rule is given higher priority for processing. This logic applies to all the machines in the manufacturing system.

## Key Assumptions

The key assumptions made in this paper are each part is completed before it is dispatched for next operation, pre-emption is not allowed, there are no breakdowns and all machines are available through out the simulation run, each machine can process only one operation at a time, all times are deterministic, set up time is included in the processing time and jobs do not re-cycle due to any change or inspections.

## Results and discussion

With the help of the above model, simulation studies have been carried out to understand the effect of routing flexibility and control strategies on the make-span of flexible manufacturing system. The independent variables are routing flexibility. The dependent variable is the make-span time. Next we discuss the results obtained by simulation with different static and dynamic rules.

## Effect of routing flexibility on flexible system performance with static priority rule

This part of the studies focuses on the effect of routing flexibility on flexible system performance. The results of the simulation study are shown in Figure 5. This experiment is carried with SPT/MINQ combination of sequencing and dispatching rules. It is observed that, under the given conditions, the make-span time reduces with the increase in the level of routing flexibility. We observe that there is about 7.8 % reductions in make-span time when routing flexibility is increased from 0 to 1 (see Table 2). When SPT/MINQ combination is used then the make-span time decreases with increasing levels of routing flexibility. This influence is not uniform at all the flexibility levels.

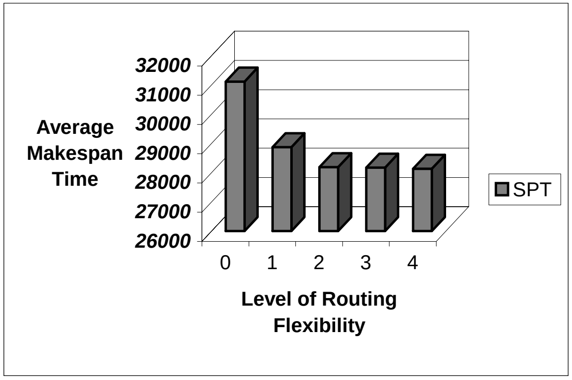


**Figure 5: Effect of routing flexibility on make-span (SPT/MINQ)**

**Table 2: Percentage reduction in Make-span with increase in RF (SPT/MINQ)**

| RF | MST | At each level | From zero level |
|---|---|---|---|
| 0 | 31109 | | |
| 1 | 28866 | 7.8 | 7.8 |
| 2 | 28184 | 2.4 | 10.4 |
| 3 | 28168 | 0.1 | 10.4 |
| 4 | 28128 | 0.1 | 10.6 |

Th [illegible] ns that use routing flexibility are likely to achieve shorter make-span time as compared to those that do not use it. The results also indicate that the first level of routing flexibility (RF=1) provides the greatest benefit, followed by lesser and lesser benefits at subsequent levels. Next we analyze the result by changing the sequencing rule from SPT to FCFS. The dispatching rule is MINQ as used in the previous experiment. Figure 6 it is seen that with FCFS/MINQ combination of sequencing and dispatching rules there is reduction in the make-span time till the level of routing flexibility is 3, there after there is deterioration in the make-span time and then there is marginal gain. Hence from this experiment we conclude that there is effect of sequencing rule on the make-span of the flexible system. In this case also we see that there is about 20.1 % reductions in make-span time when routing flexibility is increased from 0 to 1 (see table 3). There after increase in routing flexibility beyond the level 1 is found to be inconsequential. Next the impact of dynamic rule on the system performance is discussed.

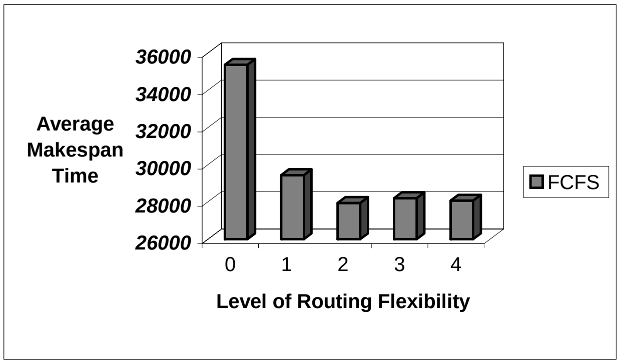


**Table 3: Percentage reduction in make-span with increase in RF (FCFS/MINQ)**

| RF | MST | At each level | From zero level |
|---|---|---|---|
| 0 | 35374 | | |
| 1 | 29445 | 20.1 | 20.1 |
| 2 | 27944 | 5.4 | 26.6 |
| 3 | 28203 | -0.9 | 25.4 |
| 4 | 28072 | 0.5 | 26.0 |

## Effect of routing flexibility on flexible system performance with dynamic priority rule

**Figure 6: Effect of routing flexibility on make-span (FCFS/MINQ)**

For this experiment we have used dynamic priority rule i.e., Modified Shortest Processing Rule (MSPT) in combination with MINQ as dispatching rule. This rule is being used to see if there is any impact of dynamic priority rule on the make-span performance of the system. We are aware of the fact that the major disadvantage of the SPT rule is that it tends to make long jobs wait. Various modifications may

**Table 4: Percentage reduction in make-span with increase in RF (MSPT/MINQ)**

| RF | MST | At each level | From zero level |
|---|---|---|---|
| 0 | 31109 | | |
| 1 | 28253 | 10.1 | 10.1 |
| 2 | 28068 | 0.7 | 10.8 |
| 3 | 27992 | 0.3 | 11.1 |
| 4 | 27949 | 0.2 | 11.3 |

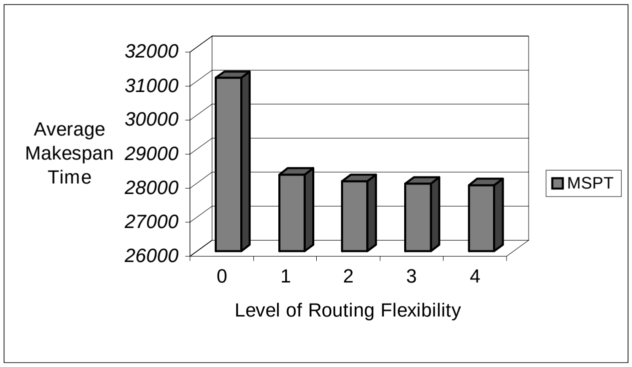


**Figure 7: Effect of routing flexibility on make-span (MSPT/MINQ)**

In [illegible] ans the queue for jobs that have wa[illegible]e jobs at the head of the queue. This job may be the one having longest processing time that has been pushed back by SPT rule. From Figure 7 we observe that make-span time decreases as the level of routing flexibility is increased from 0 to 4. Here also the first level of routing flexibility (RF=1) provides the greatest benefit, followed by lesser and lesser benefits at subsequent levels. Both these rules were used in combination with MINQ dispatching rule. We observe from the Figure 7 that MSPT helps in reducing the average make-span time at all level of routing flexibility. We observe that the maximum reduction in make-span is obtained when the level of routing flexibility is 1. At RF=2 the reduction is not much but again the reduction in make-span is obtained from RF=3 to RF= 4. With dynamic priority rule also it is seen that there is about 10.1 % reduction in make-span time when routing flexibility is increased from 0 to 1 (see table 4). There after increase in routing flexibility beyond the level 1 is found to be insignificant.

## Conclusions

This paper discussed the development and study of control strategy on the make-span performance of flexible system. The control strategy manifests it self in sequencing or priority and dispatching rules. It is seen that different sequencing rule gives different results. The study focused on routing flexibility at five levels: RF=0 to RF=4. From the series of simulation experiment it is seen that there is maximum reduction in the make-span time when routing flexibility is increased from level 0 to 1. There after increase in routing flexibility is found to insignificant. This is true for both static and dynamic rule. The studies also showed that dynamic priority rule, MSPT performs better than SPT but its performance is less than FCFS rule. These observations are important for the designers and managers of flexible systems to arrive at judicious types and levels of flexibility along with good control strategies to attain a given make-span time performance.

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