International Journal of Industrial Engineering, 17(4), 269-278, 2010.

# ANALYSIS OF THE IMPACT OF ROUTING FLEXIBILITY ON THE PERFORMANCE OF FLEXIBLE SYSTEM

**Mohammed Ali* Salahuddin, Mohammad Arshad Islam**

Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India
*Corresponding Author: mohdali234@rediffmail.com

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 paper deals with implementation of manufacturing flexibility at the shop floor level of the industry under consideration. The main objective of this paper is to compare the performance of existing manufacturing system with that of flexibility based manufacturing system. To achieve the objectives simple demo simulation model of the existing and proposed manufacturing system is built and performance compared. Both these system are compared on the following performance measures i.e., total production and total production time. The introduction of flexibility causes a decrease in makespan time, with maximum reduction in the makespan time occurring when routing flexibility is increased from 0 to 1. Also total production of parts increases with the increase in the level of flexibility.

**Significance:** This paper deals with impact of routing flexibility on the performance of flexible system.

**Keywords:** *flexibility; manufacturing flexibility; makespan; routing flexibility; simulation*

*(Received 2 Aug 2009; Accepted in revised form 9 Sept 2010)*

## 1. INTRODUCTION

The pressures due to variety of products, declining volumes and faster response to customers have been felt by many industries. Therefore to achieve these goals it became important for industries to become flexible to cope up with changing customers demand. Industries producing products in small batches relied on stand alone processing machines, which were coordinated by human operators and schedulers. Although a small batch shop usually had lower unit output than a shop dedicated to one or two lines it had the ability to produce a variety of products in small volumes. With the advent of Computer Numerically Controlled (CNC) machine tools had made the process of machining both automatic and flexible. Our initial motivation is based on the impact of routing flexibility on the performance of the manufacturing system. The industry on which this paper is based is involved in manufacturing different types of buckles. These buckles are used for fastening of saddles at the back of horses. This industry produces three types of buckles simultaneously of different batch sizes. The main objective of this paper is to compare the performance of existing manufacturing system with that of routing flexibility based manufacturing system. To achieve the objectives simple demo simulation model of the existing and proposed manufacturing system is built and performance compared.

The layout of this paper is as follows: Section 2 comprises a brief account of the literature review to prepare and develop the concepts for this paper. This is followed by Section 3 which gives the explanation of existing as well as the proposed production system to be formulated. Then the simulation model is explained in Section 4. Section 5 deals with results as obtained by simulation. The industrial applications of the proposed methodology are discussed in Section 6. Finally conclusions are stated in Section 7.

## 2. LITERATURE REVIEW

Some researcher considers flexibility as a competitive necessity rather than an option (Hill, 1995). Flexible Manufacturing System (FMS) is a crucial for the whole production system as it can process parts as much as three times faster than ordinary job shop due to its ability to comply with changes in production mix and in lot size. The role of flexibility can be viewed as one that provides alternative decision solutions to certain discrete events, which the system should evolve (Sethi and Sethi, 1990). Wadhwa et al. (1998) indicates that manufacturing flexibility in the form of routing and machine flexibility could be judiciously exploited towards lead-time reduction in multi-product manufacturing system. Bengstonn (2000) linked the design of the shop floor with manufacturing flexibility to find out whether flexibility in the system is been tapped or not. Anglani et al. (2002) used simulation package such as Arena and AutoMod for evaluating the performance of flexible manufacturing systems. Similarly cases for alternate routing in scheduling in case of machine breakdown and scheduling of part in a job type FMS with alternate machine tool has been studied with help of simulation by Abdin (2003). Mohammed and Wadhwa (2005) evaluated the performance of partial flexible system with makespan as performance measure. Chang (2005) has developed mathematical models for a system with routing flexibility. Park (2005) proposed a methodology for creating a virtual model for a flexible manufacturing system. Nsakanda et al. (2006) alternative routings for each part type, the processing sequence of parts, the trade-off between intercellular and intracellular costs and the option of outsourcing. The availability of multiple machines of the same type and production planning aspects are present. Wadhwa et al. (2008) studied the impact of planning and control strategies on the performance of flexible manufacturing system. Ahkioon et al. (2009) showed that the routing and process flexibilities can be incorporated within the cellular manufacturing system design without significant increase in the system cost. Hence it is observed lot of work is done in the direction of impact of routing flexibility on the performance of flexible system. However very little work is done while considering the real life problem. This work highlights the application of routing flexibility in real life problem.

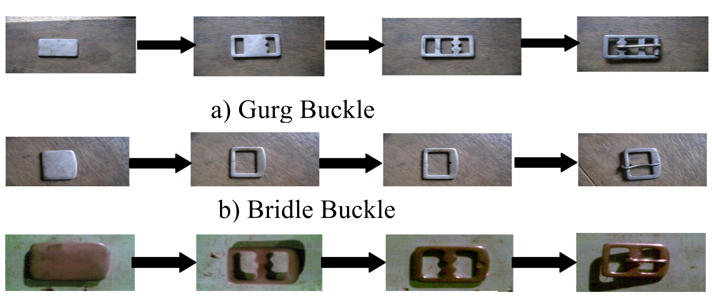
## 3. PRODUCTION SYSTEMS

It is imperative for any business of today to be profitable and efficient that it must adopt and make best use of the opportunities coming their way. The basic aim of this study is to give the manufacturer a simple way of saving time and making more products. After analyzing the existing manufacturing shop floor, ways of improving the performance of the manufacturing system is identified. The shop-floor under consideration deals with manufacturing discrete parts namely buckles. Table 1 below shows the details of operation and the machines required for producing buckles.

**Table 1. Different operations and machines required for producing the buckles type**

| S.No. | Part type | Operations | Machines |
|---|---|---|---|
| 1 | Gurg buckle | Cutting | Power press(30 tons) |
| | | Punching | Power press(20 tons) |
| | | Forging | Power press(50 tons) |
| | | Pin and roller installation | Manual |
| | | | |
| 2 | Bridle buckle | Cutting | Power press(30 tons) |
| | | Punching | Power press(20 tons) |
| | | Forging | Power press(50 tons) |
| | | Pin installation | Manual |
| | | | |
| 3 | Step leather Buckle | Cutting | Power press(30 tons) |
| | | Punching | Power press(20 tons) |
| | | Forging | Power press(50 tons) |
| | | Pin installation | Manual |

Figure 1 gives step by step details of each process (cutting, punching, forging & pin installation). Table 2 shows the operation time, lot transfer time and the machine on which the respective operation are performed. The model of the existing production system and proposed flexible system is Java language. The systems are compared on the basis of average time per product, total production time (makespan) and total production.



a) Gurg Buckle

b) Bridle Buckle

c) Step Leather Buckle

**Figure 1. Layout of the conventional model**

The schematic diagram of existing production system is shown in Figure 2. It employs a linear rigid structure of production, with each machine capable of performing only one operation. Fallacies of this system will become more pronounced in case of breakdown of any one machine, this would stop the total production of the plant. The performance of the system is improved by introducing flexibility in the manufacturing process. The experimental results shows how these types of flexibilities affect the time per product, total production and other important parameters of the shop floor. The results will help the management obtain better insight and guidelines for determining priorities or the scale, or scope, of various decision items relating to design, process and operations improvement, investment in new equipment and tools, and the like.

**Table 2. Operation, lot transfer time and machine on which operation is performed**

| Parts | M1 (OT) (sec) | LTT (sec) | M2 (OT) (sec) | LTT (sec) | M3 (OT) (sec) | LTT (sec) | M4 (OT) (sec) |
|---|---|---|---|---|---|---|---|
| **P1** | 4.1 | 10 | 4.8 | 11 | 4.8 | 11 | 9.6 |
| **P2** | 3.6 | 11 | 3.8 | 11 | 3.7 | 12 | 9.4 |
| **P3** | 3.4 | 12 | 3.6 | 10 | 3.6 | 12 | 9.2 |

*OT: Operation time; LTT: Lot transfer time;P1: Gurg buckle; P2: Bridle buckle;P3:Step Leather Buckle*

It is apparent from the schematic shown, that there are four machines available for performing four different operations on three different parts P1, P2 and P3. The raw materials for different parts enter at M1 for O1 in IB-1. The time required for operation of each type of buckle for O1 is different. As soon as the lot specified is completed in OB-2, the lot is transferred to the next machine M2 for O2 in IB-2. The lot transfer time (LTT M1-M2) as specified is taken to transfer this lot from OB-1 to IB-2. This process is repeated till the final lot of parts comprising P1, P2 and P3 is moved out of OB-4. The lot size is specified before execution of the program in the simulation. This variable is important as it has profound effect on the inventory and work in process of the system. Number of shift also has to be given as this is important for the total production. It also affects the parts left in the input and output buffers as when the work would stop these parts would become part of the inventory. The lot transfer time for each machine to another may be same or different depending on the working condition. Through the results obtained from the simulation based on this model we would compare the existing production system to the flexible production system. Coupled with the variables we have taken which are lot sizes and number of shift would give us valuable tool for comparison. The existing production system is made flexible by introducing routing flexibility. Routing flexibility provides an answer to the strategic needs of meeting customer requirements. It is defined as the ability to process a given set of part types using more than one route through the system (Browne et al. 1984; Sethi and Sethi, 1990). Figure 3 and 4 shows the system at routing flexibility level 1 and level 2 respectively.

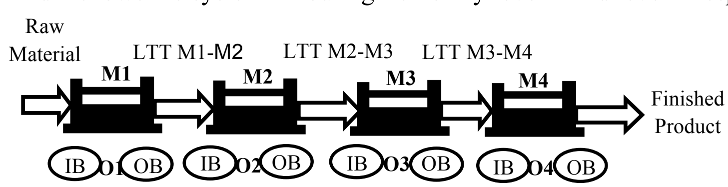



**Figure 2. Layout of the conventional model**

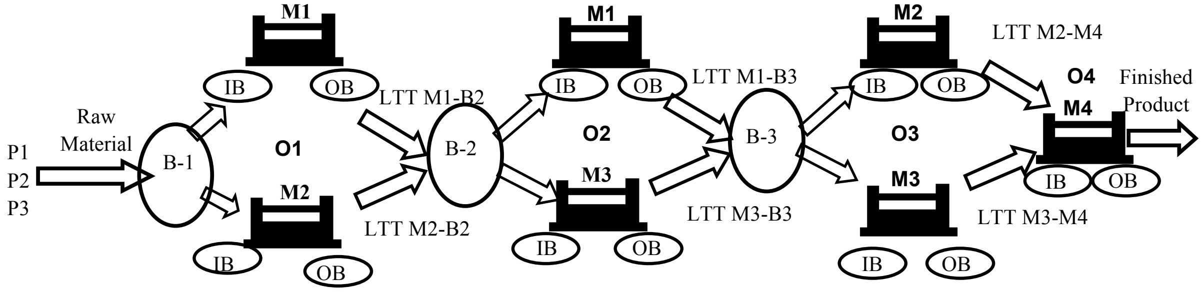



**Figure 3. Model for Routing Flexibility at Level 1**

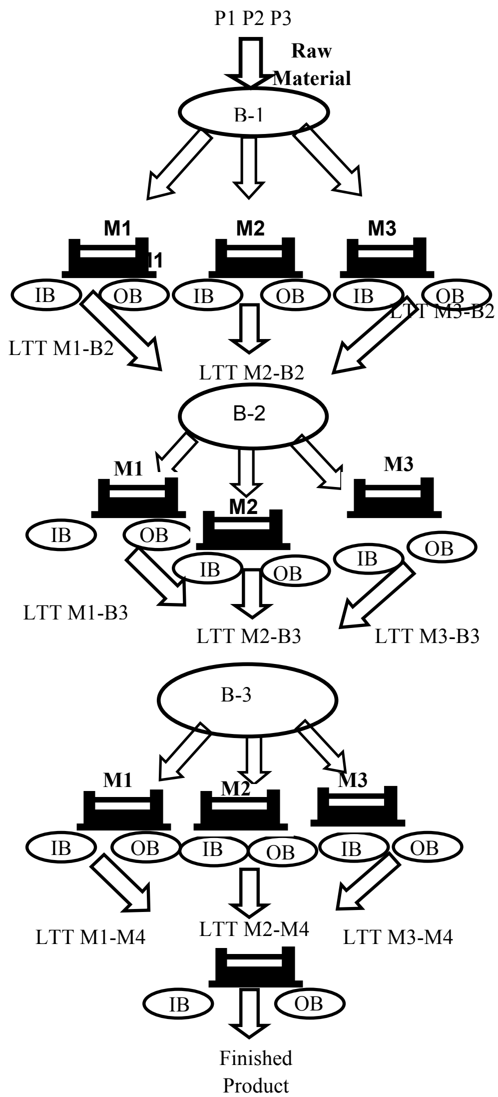



**Figure 4. Model for Routing Flexibility Level 2**

## 4. MODEL DEVELOPMENT

This section comprises of the development of the model by using Java programming language. The model is first developed for conventional manufacturing system and then for flexibility focused manufacturing system. The following assumptions are made for creating a working model of the existing system and proposed flexibility. These are all operation time and transportation time are deterministic, raw materials are always available, machine never breakdowns. Moreover each machine performs single operation at a time and pre-emption is not allowed. In the following sections the descriptions of the developed simulation models are discussed.

### 4.1 Simulation Model

Through the observation of the manufacturing process present in the shop floor and the, models were developed which can be used to better the work flow pattern. A step by step procedure is given here to run the software, for analyzing the different productions systems with different inputs. The results in the simulation of all kinds of production system are given in the form:

1. Total Production

2. Total Production Time or Makespan

The simulation provides an easy way to analyze the different systems on the same parameter. The simulation of flexible models also gives the movement of different parts as it goes through the shop floor.

### 4.2 Conventional Model

As present manufacturing system produces three types of product (buckles), simulation models are developed to operate under three different conditions. These are:

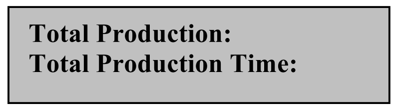
1. Production of only one type of product.
2. Production of two types of products simultaneously.
3. Production of three types of products simultaneously.

The explanation of working of three types of product simultaneously is given below.

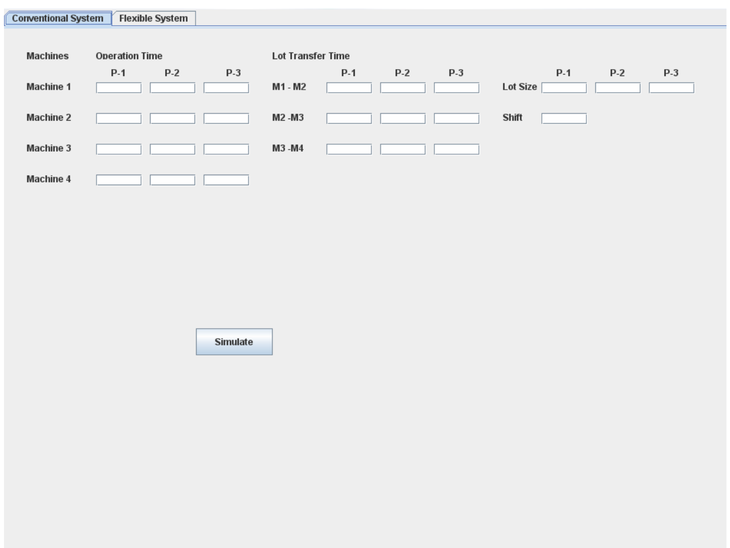
*For Production of three types of products simultaneously*

Figure 5 shows the selection of parts in conventional manufacturing system. Three parts are selected as shown in Figure 5a. If OK button is clicked, next window appears as shown in Figure 5b. This window allows one to enter different values of operation time, lot transfer time, lot size and shift. After entering the values as one clicks the 'Simulate' button, a new window appears as shown in Figure 5c. This figure shows the results in the form of total production, time per product and total production time for three products.


**a) Selection of part option**




**c) Simulation Results**




**b) Input for three parts**

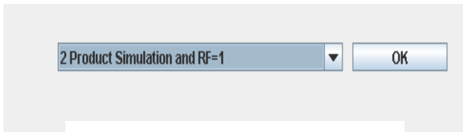
**Figure 5. Selection of parts in conventional system**

### 4.3 Flexibility Based Model

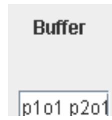
This section comprises of the simulations developed for the different levels of routing flexibility. Apart of giving the results like in the conventional model it also shows the flow of different parts through the production system.

*Routing Flexibility level 1 (RF=1)*

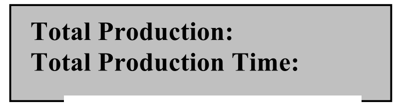
Figure 6 shows the illustration of flexibility based model (RF=1). Figure 6a allows one to select the routing flexibility level. One can enter a desired pattern of parts coming for the operation 1 in text box (Buffer Figure 6b). After selecting an option and clicking OK, next window appears as shown in Figure 6c. This window shows that two machines are available for each operation at a time. As soon as one click the 'Execute' button, different parts appear in the text boxes (Input Buffer) that have selected the two machines on 'Minimum operation time' basis. Also at the same time, summation of operation times of all the parts that have gone passed the machine, appears in the textboxes (Output Buffer) for respective machines. Similarly model can be executed for Operation 2, Operation 3 and Operation 4. Also entering the values of lot transfer time, lot size and shift. After entering the values as one clicks the 'Simulate' button, a new window appears as shown in Figure 6d. This figure shows the results in the form of total production and total production time or makespan.



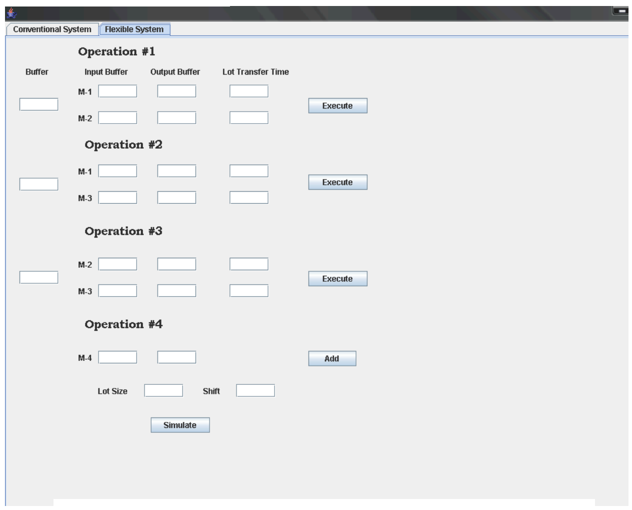

a) Selection of RF level




b) Parts




d) Simulation Results

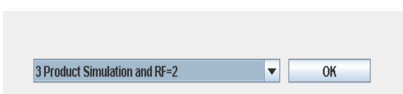



c) Input for flexibility based model

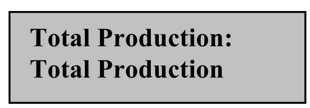
**Figure 6. Illustration of Flexibility Based Model (RF=1)**

*Routing Flexibility level 2 (RF=2)*

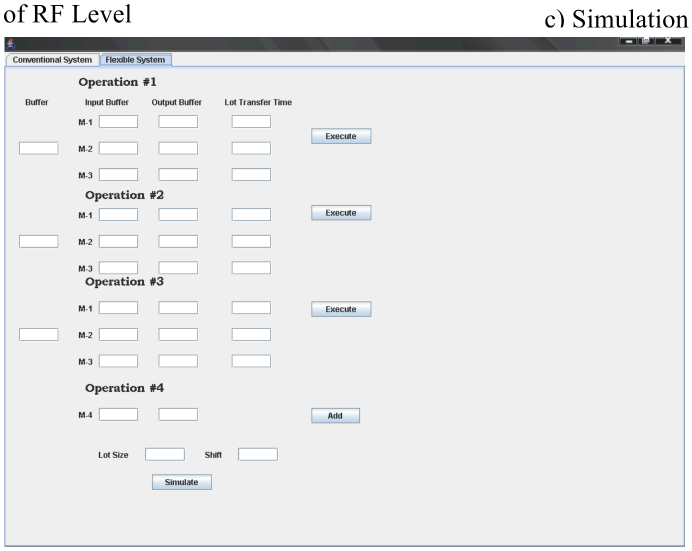
Figure 7 shows the illustration of flexibility based model (RF=1).




a) Selection of RF Level




c) Simulation Results




b) Input for flexibility based model (RF=2)

**Figure 7. Illustration of Flexibility Based Model (RF=2)**

## 5. RESULTS

Through the simulation models, we simulated different production system under various conditions. The simulation model for both conventional and flexible was created with Java. In this chapter we discuss the results as obtained from simulation.

### 5.1 Impact of Routing Flexibility on Makespan Time (MST)

Figure 8 shows the variation of makespan time with increase in lot size at different levels of routing flexibility. Since the makespan time is the time required to process a single lot of parts. As is expected we observe that with the increase in the lot size, there is marked increase in the makespan time. At RF=0, the makespan time is maximum at all the levels of the lot size. The introduction of flexibility causes a decrease in makespan time, with maximum reduction in the make span time occurring when routing flexibility is increased from 0 to 1. This marked reduction in MST happens at all lot sizes. However with further increase in the routing flexibility, there is a marginal decrease in the make span time. This is visible at all the levels of lot size. Figure 9 shows the percentage decrease in makespan time of the flexible system. It is again seen that the percentage decrease in makespan is more at RF=1.

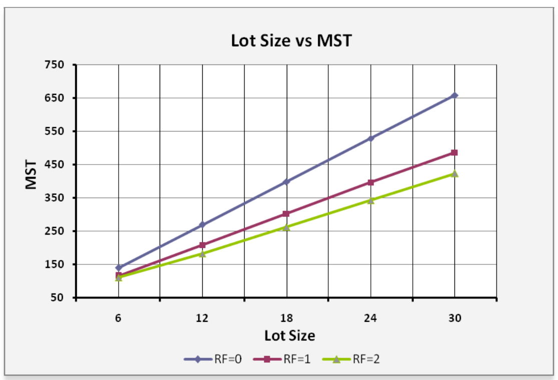



**Figure 8. Impact of lot size on MST at different levels of routing flexibility**

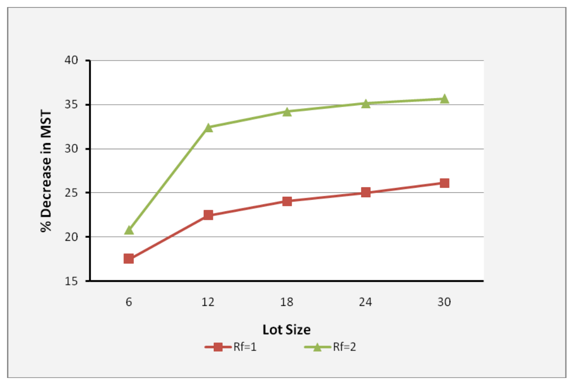



**Figure 9. Percentage decrease in makespan time**

Table 3 shows the percentage increase of makespan time at different level of lot size for different flexibilities. It is observed from the table that maximum increase of make span time takes place when lot size is increased from six to twelve for all levels of flexibilities. But the percentage increase of MST goes on decreasing as flexibility increases.

**Table 3. Comparison of Routing Flexibility with respect to MST**

| | Makespan Time (sec) | | | | | |
|---|---|---|---|---|---|---|
| **Lot size** | RF=0 | | RF=1 | | RF=2 | |
| **6** | 138.8 | | 114.5 | | 109.9 | |
| **12** | 268.6 | 0.94 | 208.3 | 0.82 | 181.49 | 0.65 |
| **18** | 397.8 | 0.48 | 302.1 | 0.45 | 261.7 | 0.44 |
| **24** | 528.0 | 0.33 | 395.9 | 0.31 | 342.5 | 0.31 |
| **30** | 658.0 | 0.25 | 486.1 | 0.23 | 423.3 | 0.24 |

The Figure 9 shows the percentage decrease in MST for routing flexibility based production system as compared to that of no flexibility model. The percentage decrease in MST is positive for all lot sizes and maximum rate of increase is when lot size changes from 6 to 12. The graph also shows that for RF=2 the rate of decrease of MST is maximum and then on the there is not much change in MST. As for RF=1 the rate of decrease in MST remains almost constant throughout.

### 5.2 Impact of Flexibility on Total Production

Figure 10 shows the variation of total production in one shift with lot size. As is apparent from the graph total production of parts drastically increases with the increase in the level of flexibility. At RF=0 the total production is least, and there is insignificant increase in the total production with the increase in lot size. As for RF=1 and RF=2, the total production with lot size equal to six is almost same. But total production increases with the increase in lot size more with RF=2 than RF=1, with maximum when lot size changes from six to twelve. This is reflected in Figure 11.

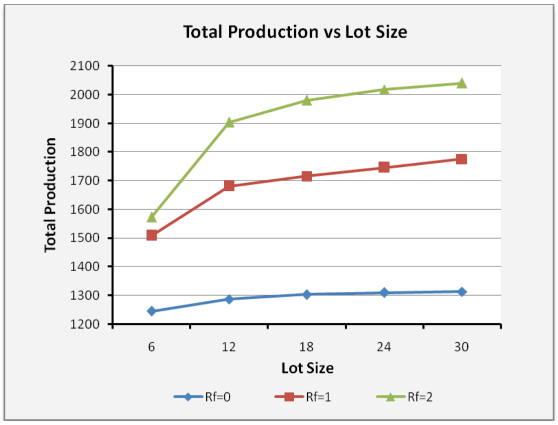



**Figure 10. Impact of lot size on MST at different levels of routing flexibility**

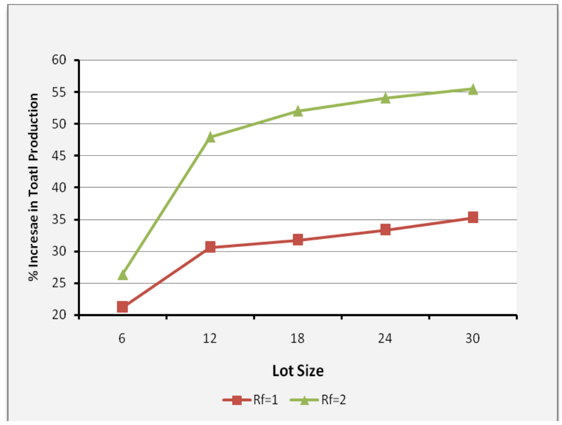



**Figure 11. Percentage increase in total production**

**Table 4. Comparison of Routing Flexibility with respect to Total Production**

| | Total Production (no of parts) | | |
|---|---|---|---|
| **Lot size** | RF=0 | RF=1 | RF=2 |
| **6** | 1245 | 1509 | 1573 |
| **12** | 1287 | 1681 | 1904 |
| **18** | 1303 | 1716 | 1981 |
| **24** | 1310 | 1746 | 2018 |
| **30** | 1313 | 1776 | 2041 |

Table 4 gives the values obtained for total production of parts for a single shift with different level of routing flexibility and lot sizes. It is seen that there is increase in total production with the increase in the lot size. This is visible at all the level of routing flexibility. Moreover with the increase in routing flexibility there is also increase in eth total production. However the increase in total production is maximum when routing flexibility is increased from 0 to 1. Figure 11 shows the percentage increase in total production of parts compared to the model with no flexibility. It could be seen as earlier mentioned that increase in total production is same when lot size is almost equal to six. But the values increase abruptly when lot size is increased for RF=2 compared with that of RF=1. On an average the production for RF=1 increases between 30 to 35% for different lot sizes, and for RF=2 the increase is more than 50%. Hence to obtain the benefits of flexibility in the manufacturing system, lot size of more than six has to be used. Table 5, below gives the values obtained for total production of parts for different number of shifts, with the lot size fixed at 24. It is seen from this table that with the increase in shift, total production increases. Also there is increase in total production with the increase in the level of routing flexibility. Again the maximum increase is obtained when routing flexibility is increased from 0 to 1.

**Table 5. Comparison of Total Production with respect to Shift**

| **Lot size=24** | **Total Production** | | |
|---|---|---|---|
| **Shift** | RF=0 | RF=1 | RF=2 |
| **1** | 1310 | 1746 | 2018 |
| **2** | 2621 | 3492 | 4036 |
| **3** | 3932 | 5237 | 6054 |

The Figure 12 shows the variation total production with number of shifts at lot size of 24. It is seen that there is increase in total production with the increase in flexibility with the change in shift is linear with RF=1 and RF=2 displaying the same amount of increase. Again there is maximum increase in the total production when the routing flexibility is increased from level 1 to level 2.

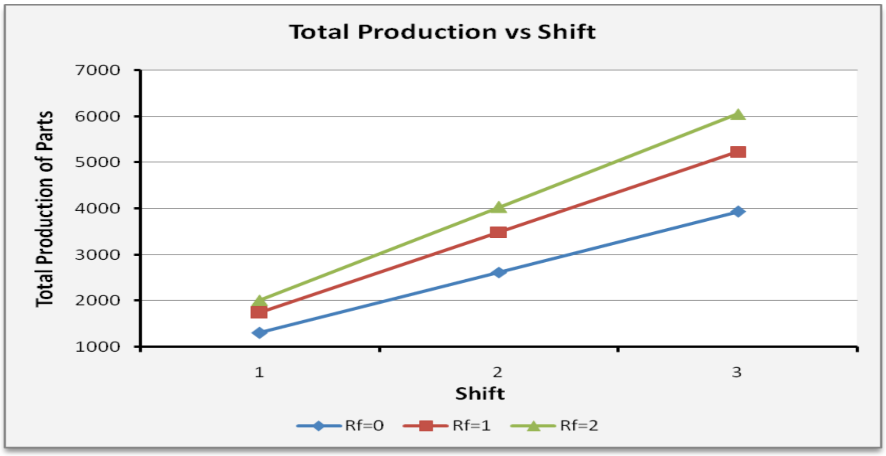



**Figure 12. Variation of total production with number of shift**

## 6. INDUSTRIAL APPLICATION

The flexible manufacturing capabilities can help practitioners in identifying different dimensions of manufacturing flexibility that are significant to their customers. With a limited view of flexibility, practitioners will not be able to implement the right flexibility. This will limit their ability to enhance customer satisfaction. Management plays a very important role in implementing flexibility in the organization. Routing flexibility can be achieved if the management plans, organizes, and coordinates production activities of the organization with the customer expectations. Routing flexibility impacts volume flexibility through the development of new routes to take advantage of idle capacity in the system. It also can be used to increase the variety of products being produced. From a strategic perspective, flexible-manufacturing capabilities may help firms to achieve mass customization.

## 7. CONCLUSION

This paper is aimed at comparing the performance of flexibility based production system with conventional system (no flexibility). A salient contribution of this paper is in adopting particular system configurations based on routing flexibility. A demo simulation models of both flexibility based and conventional manufacturing system have been developed that can assist performance evaluation of these system. From the series of experiments conducted on both the system we observe that at small lot sizes, application of flexibility does not have a marked effect on the makespan. The makespan increases linearly with the increase in lot size but for RF=0 the graph is more steep. For total production as a performance measure there is a marked difference between flexibility applied model and the conventional model. Total production increases linearly with the number of shifts but the increase is more marked as we increase the flexibility level. The variation in performance measures is more marked when we introduce routing flexibility level 1 in the conventional model as compared to when we increase the flexibility level from one to two. As the lot sizes increases there is an abrupt change in the performance of the production system with the increase in the level of flexibility, RF=2 makes the system more efficient. However the present paper modeled only on few cases. A wider data set, with an added variety both in the types of parts and machines, as well as operating conditions needs to be modeled for generating better answers for the managers in a manufacturing environment.

## 8. REFERENCES


1. Abdin, M. F. (1986). Solution of Scheduling Problems of Job-Shop type FMS with Alternate Machine Tools. Computers & Industrial Engineering, 11; 1-4, 241-245.
2. Ahkioon, S. Bulgak, A. A. and Bektas, T. (2009). Cellular Manufacturing Systems Design with Routing Flexibility, Machine Procurement, Production Planning and Dynamic System Reconfiguration. International Journal of Production Research, 47; 6, 15, 1573–1600.
3. Anglani, A. A. Grieco, M. Pacella and T. Tolio. (2002). Object Oriented Modeling and Simulation of Flexible Manufacturing Systems: A Rule-Based Procedure. Simulation modeling Practice and Theory, 10; 3-4, 209–234.
4. Browne, J. Dubois, D. Rathmill, K. Sethi, S.P. and Stecke, K. E. (1984). Classification of Flexible Manufacturing System. The FMS Magazine, 114.
5. Chang, A. Y. (2005). On the Measurement of Routing Flexibility: A Multiple Attribute Approach. International Journal of Production Economics, 109; 1-2, 122-136.
6. Hill, T. (Editor) (1995). Manufacturing Strategy: Text and Cases. MacMillan, London.
7. Mohammed, A. Wadhwa, S. (2005). Performance Analysis of Partial Flexible Manufacturing System. Global Journal of Flexible Systems Management, 6; 1, 9-19.
8. Nsakanda, A.L., Diaby, M. and Price, W.L. (2006). Hybrid Genetic Approach for Solving Large-Scale Capacitated Cell Formation Problems with Multiple Routings. European Journal of Operational Research, 171; 1051-1070.P
9. Park, S.C. (2005). A methodology for creating a virtual model for a flexible manufacturing system. Computers in Industry, 56; 7,734-746.
10. Sethi, A.K. and Sethi, S.P. (1990). Flexibility in Manufacturing: A Survey. The International Journal of Flexible Manufacturing Systems, 2; 289-328.
11. Wadhwa, S. Ducq, Y. Mohammed, A. and Prakash, A. (2008). Performance Analysis of a Flexible Manufacturing System under Planning and Control Strategies. Studies in Informatics and Control Journal, 17; 3.
12. Wadhwa, S. Bhagwat, R. (1998). Judicious Increase in Flexibility and Decision Automation in Semi-Computerized Flexible Manufacturing (SCFM) Systems. International Journal of Studies in Informatics and Control.


## BIOGRAPHICAL SKETCH

**Mohammed Ali** took his Bachelor degree in Mechanical Engineering and Master in Industrial Engineering degree from Aligarh Muslim University, Aligarh, U.P., India. Subsequently he did PhD from IIT-Delhi, in the domain of CIM systems in general and Flexible manufacturing system in particular. At present he is Associate Professor in Department of Mechanical Engineering, A.M.U. Aligarh, India. He has taught many subjects ranging from Industrial Engineering, Industrial Management, Economy and Management, Manufacturing Engineering etc. He has publications in international journals and in proceedings of conferences. His interest includes Flexible Systems, Simulation, CIMS etc.