Simulation Modeling of Control Strategies in Flexible Manufacturing System

SUBHASH WADHWA

Professor, IIT, Delhi

Indian Institute of Technology-Delhi, India

swadhwa@mech.iitd.ernet.in

AJAY SINGHOLI

Senior Lecturer, Department of Mechanical & Automation Engineering,

Indira Gandhi Institute of Technology, Delhi-6, India

ajay.igit@gmail.com

ANUJ PRAKASH

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

anujpra@gmail.com

Phase-III: Theme Based Paper

ABSTRACT

- *A flexible manufacturing system (FMS) is designed to combine high productivity and production flexibility. But the controlling of an FMS requires high skills. Furthermore, the decisions at this stage have to be made very carefully in order to ensure that the manufacturing system will successfully satisfy the demands of an ever-changing market. Discrete-event simulation has been widely used to control such complex system. On the other hand, simulation is more and more used for decision making and evaluate control strategies. In this paper, we propose a logic simulation model which corresponds to the modeling of the computer control system. This paper also describes the various control strategies in an FMS. In the last some of the useful simulation techniques along with some simulation packages have been addressed at the end of the paper and these techniques/software will be useful for the modeling and decision making of FMS.*

KEYWORDS

- Flexible manufacturing system
- Control Strategy,
- Simulation
- Simulation Packages

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. 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 technology (IT) based integration and automation (Wadhwa et al. 1997). Due to the inherent complexity of the system and evolution of new techniques and tools, the controlling of an FMS is a very difficult task for the managers (Wadhwa et. al., 2008). Simulation is a very effective technique for understanding the behavior of systems that are too complex to be studied analytically and it also help in making decisions for controlling the system according to the market activities. Some of the applications have concentrated on production technology, machinery and equipments, marketing, selling, production or on general management enhanced with different additional real life tasks (Haapasalo and Hyvonen, 2001).

Keeping in mind all the above issues, the present paper discusses the simulation modeling and various simulation packages to select various controlling strategies of an FMS. In an FMS, the selection of part as well as machine is a decision making strategy and it is also called as controlling strategy which affect the performance of the system. In the real world FMS, to make the decision for such selection in the dynamic manner is feasible only by using any simulation packages. Thus, in the present research, various simulation packages along with sequencing and dispatching strategy have been discussed.

The remainder of the present paper has been organized in the following manner: the prominent literature has been reviewed in section 2. Section 3 delineates the description of an FMS. The controlling strategies of an FMS have been illustrated in the section 4. Section 5 described the need of simulation and various paradigms of simulation for modeling of an FMS. Finally, the conclusions are reported in the section 6.

2. Literature Survey

A literature review was carried out to identify the previous research efforts and directions related to our focal area i.e. FMS and its controlling action by using the simulation. Several literatures have been found on the various flexibilities in the flexible manufacturing system. 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. Sinha and Wei (1992) have developed the measure for routing flexibility based on the average number of alternative routes available for processing each part in the manufacturing system. 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. 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.

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). Elmaraghy (1982) has tested different sequencing rule for a system and they have concluded that the SPT (Shortest Processing Time) yields the highest production rate and also reduces average flow time as compared to the others. Blackstone et al. (1984) have also given the similar results about the performance of SPT. 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. The sequencing and routing problem for an FMS with periodic demand has been discussed by Hutchison et al. (1991). The authors have utilized the SPT and MWTQ (minimum waiting time in queue) combination and the results shows the great reduce in make span. For the machine selection, the most of the previous researchers have employed the MINQ and MWTQ. Karsiti et al. 1992 and Waikar et al. 1995 have shown that in most of the FMS systems, the combination of SPT/MINQ performs better. In another study, Shmilovici and Maimon 1992, have also appreciate the MINQ as dispatching rule. Akturk and Ozkan (2001) have proposed a multistage algorithm to solve the scheduling problem in FMS by considering the interrelated sub problems of processing time control, tool allocation and machining conditions optimization. The main objective was to minimize total production cost consisting of tooling, operational and tardiness costs. Buitenhek et al. (2002) have stated that the control mechanism in FMS specifies which part to process next at a machine upon the competition of the current operation. 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, they have worked on very few dispatching and sequencing rules and simultaneously there is no consideration of any type of flexibility. Park (2005) believes that simulation is very useful for decision making, pointing out scheduling errors, controlling and even for creating manufacturing strategies. Simulation modeling can result in experiential learning in very short duration of time. The simulation models are inherently interesting to both practitioners and learners; and therefore they prove to be more effective in business environments. Even with its few limitations, simulation is an excellent tool for the analysis of complex systems and validation of the new systems (Chan et al. 2007). Bhaskaran (1998) has also studied the impacts of various factors that amplify the dynamics and stability of a manufacturing system using simulation. With the aim of understanding the effect of flexibility on the performance of system, Garavelli (2003) used simulation to evaluate the performance of a system under three degrees of flexibility: total flexibility, no flexibility and limited flexibility.

Thus, with the support of the above reviewed literature, it can be concluded that the simulation is an important technique for analyzing the complex system as FMS. By using this, we can also make the appropriate decision for performance improvement.

3. Flexible Manufacturing System

The term flexible manufacturing system, or FMS, refers to a set of computer numerically controlled (CNC) machine tools and supporting workstations that are connected by an automated material handling system and are controlled by a central computer. FMS technologies represents an evolutionary step beyond transfer lines and offer one means by which manufacturing can address the growing customer demands for quick delivery of customized products. The preceding definition includes the key elements of FMS: (1) automatically reprogram able machines, (2) automated tool delivery and changing (3) automated material handling both for transferring parts between machines and for loading/unloading parts at machines, and (4) coordinated control. Many part types can be simultaneously loaded on to the system because machines have the tooling and processing information to work on any part. Thus, parts can arrive at individual machines in any sequence. By reading a code on the part or following supervisory instructions, the part type can be identified (or verified) and the proper processing sequence can be retrieved from the machines' computer memory. The system may include as many as 20 machines. Small systems of one or two machines are normally referred to as a flexible cell. The generic framework of FMS has been depicted in figure 1.

FMSs are expensive to implement but yield significant savings. Equipment utilization normally runs at most at 30 percent in conventional systems but may be at 85 percent or higher in an FMS. The main inconvenience with such complex system is to control according to demand and availability. The vast number of routine decisions, part and machine selection, and possible system states make the system very complex. The difficulty of achieving dynamic control of complex system has led to the use of simulation control modeling.

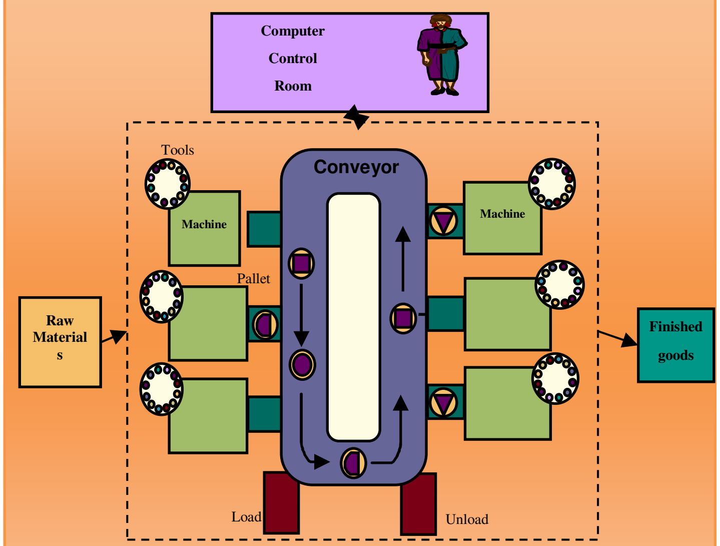

Figure 1. Generic Framework of Flexible Manufacturing System

4. Control Modeling in FMS

Tang et al. [2] consider two kinds of decision strategies for FMS control: pre release (sequencing rule) and post release (dispatching rule) decision. These strategies deal with the allocation of parts to the resources and routing the parts while the system is in operation in a flexible way in order to yield better system performance. The sequencing and dispatching rules are illustrated as below:

4.1 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.

$$SPT = \min_{i \in SJ_q} \left(P_{ij}\right) \quad (1)$$

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

SJ_q = Set of jobs in a queue

(b) Shortest Remaining Processing Time (SRPT): For the selection of job for the next operation, the consideration is given to the job which is having minimum remaining processing time. It can be expressed mathematically as follows:

$$SRPT = \min_{i \in SJ} \left(\sum_{j \in SR_i} P_{ij} \right) \quad (2)$$

Here, P_{ij} = Process time of the operation of i^{th} job, i = Job index,
SJ_i = Set of jobs in a queue, SR_i = set of remaining operation of job *i*

(c) 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:

$$MBPT = \max_{i \in SJ_q} \left(\sum_{j \in SR_i} P_{ij} \right) \quad (3)$$

Where :P_{ij} = Processing time of the operation of i^{th} job, i = Job index
SJ_q = Set of jobs in a queue,
SR_i = Set of remaining operations of i^{th} jobs in a queue at an input buffer

4.2 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:

$$MINQ = \min_{k \in SM_a} (N_k) \quad (4)$$

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:

$$MQMWT = \min_{k \in SM_a} (WT_k) \qquad \text{if } N_i = N_j \quad (5)$$

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

To model the control strategies of FMS, we have considered a logical flow model of the control data (i.e., transmission of missions and transmission of reports). This logical flow goes through the model associated with the physical flow of the jobs processing in the workshop. Each job is modeled by an entity called a physical entity, and for each physical entity there is a corresponding logical entity. The logical flow has been shown in figure 2.

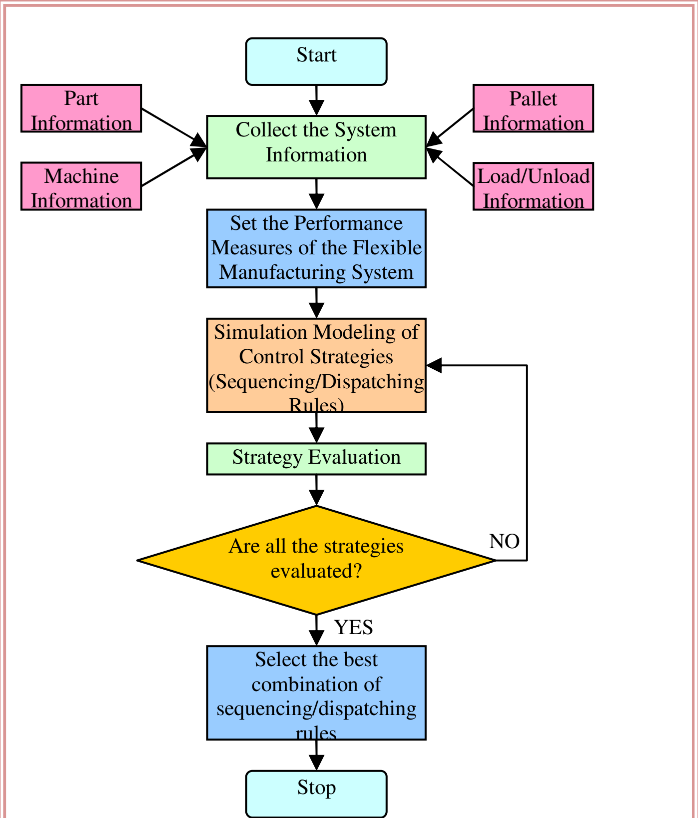

Figure 2. Logical Framework of Simulation Modeling of Control

5. Simulation of Flexible Manufacturing System

Simulation is an operating model of real system which is a numerical technique for conducting experiments with various models and describes the behavior of the complex system over extended period of time. A simulation model consists of elements of the system to be modeled and its detail can be used for any improvement. The propose models of manufacturing and service domain analyze by the simulate of the future performance of the system to understand complex relationship, effect of change in any constraint and identify opportunities to improvement The real utility of simulation lies in comparing such alternatives before implementation. Hence, this will analyze the system in its "as-is" configuration and under a myriad of possible "to-be" alternatives. The output analysis helps us to validate and verify the model leading to constructive conclusions. The results compiled by carrying out simulation for various combinations of logic and by changing some input parameters, can accelerate to achieve desired configuration and result.

5.1 Simulation Packages

The considerable increase in the use of simulation to design and optimize flexible manufacturing systems has been seen since last decades (Hollocks 1992). Initial review of simulation work indicates that many real life cases were modeled using high level programming languages such as FORTRAN and Pascal, Turbo C etc. Some researchers also used general purpose simulation languages such as SIMAN, GPSS, GASP, SIMSCRIPT, SLAM, and SIMULA (Kochhar 1989). Survey reveals that during the last three decades, commercial software packages are available for high end simulation of manufacturing systems; these packages are easy to learn and require less experience and almost negligible programming effort. Examples of these packages include Rockwell Software's ARENA (Based on SIMAN), WITNESS, Pro-MODEL,SIMUL8, SIMFACTORY II, FlexSIM, and AutoMOD.

Simulation packages can efficiently predict the behavior of a complex system. Flexible Manufacturing System is considered one of the most complex manufacturing systems, therefore the simulation software must include following features (Law and Kelton (1991)).

1. Generating random numbers from the uniform probability distribution.

2. Generating random values from a specified probability distribution.

3. Determining the next event and passing control to the appropriate block of code.

4. Adding records to, or deleting records from, a list.

5. Collecting and analyzing data.

6. Reporting the results and detecting error conditions.

5.2 Classification of Simulation Software

Usually, there are large variety of features and characteristics associated with simulation packages. Some packages require coding effort, while some require little or no programming effort. Following is the general classification of simulation software (Hlupic and Paul 1993);

1. General Purpose Simulation Languages-A simulation package which is used for different systems with different characteristics. Law and Haider (1989) state that some of these languages are having certain special features for flexible manufacturing such as workstation control, material handling modules etc.

2. Data-Driven Simulators- Law and Haider (1989) define a data-driven simulator as a computer package that allows the modeler to model systems with little or no programming.

6. Conclusion:

This paper describes how simulation can be used in the improvement of decision making and controlling of flexible manufacturing systems. The generalized simulation techniques for flexible manufacturing system have been presented. Simulation can lead to considerable improvements in manufacturing system. It can support the decisions making in complex system like FMS. A generic framework of simulation modeling has also been shown to guide the practitioners to simulate the control strategies of FMS. Finally, the modeling of the various control strategies of the flexible manufacturing system parameters is demonstrated. These simulation techniques can extensively be used for the other decision making problems of FMS.

References

- Akturk, M. S., Ozkan, S., (2001) "Integrated Scheduling and Tool Management in FMS", International Journal of Production Research, Vol. 9, No. 12, pp. 2709-2722.
- Barad, M., Sapir, D.E., (2003) "Flexibility in Logistic Systems—Modeling and Performance Evaluation", Int. Journal of Production Economics, Vol. 85, pp. 155–170
- Bhaskaran S., (1998), "Simulation Analysis of a Manufacturing Supply Chain, Decision Sciences, Vol. 29, pp. 633-657.
- Blackstone, J.H., Phillips, D.T., Hogg, G.L., (1984) "A State of Art Survey of Dispatching Rules for Manufacturing Job Shop Operations", Int. J. of Production Research, Vol. 20, No.1, pp. 27-45
- Browne, J.,Dubois, D., Rathmill,K., Sethi,S.P., Stecke, K. E., (1984) "Classification of Flexible Manufacturing Systems", The FMS Magazine, 114.
- Buitenhek, B., Baynat, B., Dallery,Y, .(2002) "Production Capacity of Flexible Manufacturing Systems with Fixed Production Ratios", I. J. of Flexible Manufacturing System, Vol. 14, pp. 203-222.
- Carlsson, B., (1989) "Flexibility and the Theory of the Firm," International Journal of Industrial Organization, Vol. 7, pp. 179–203.
- Chan F.T.S., Wadhwa S., Bibhushan, (2007), "Inventory performance of some supply chain inventory policies under impulse demands", International Journal of Production Research, Manuscript ID: TPRS-2007-IJPR-0111.
- Chan, F. T. S., (2001) "The Effects of Routing Flexibility on a Flexible Manufacturing System", International Journal of Computer Integrated Manufacturing System, Vol. 14, No. 5, pp. 431-445.
- Chan, F. T. S., (2003) "Effects of Dispatching and Routing Decisions on the Performance of a Flexible Manufacturing

Systems", International Journal Manufacturing Technology, Vol. 21, pp. 328-338

- Choi, R. H., Malstrom, E. M., (1988) "Evaluation of Traditional Work Scheduling Rules in a Flexible Manufacturing System with a Physical Simulator", J. of Mfg Systems, Vol. 7, No. 1, pp. 33-45.
- Elmaraghy, H.A., (1982) "Simulation and Graphical Animation of Advanced Manufacturing Systems", Journal of Manufacturing Systems, Vol. 1, No. 1, pp. 53-63.
- Garavelli A.C., (2003), "Flexibility configurations for the supply chain management", International Journal of Production Economics, Vol. 85, pp. 141-153
- Haapasalo H. and Hyvonen J., (2001), "Simulating Business and Operations Management – A Learning Environment for the Electronics Industry", International Journal of Production Economics, Vol. 73, pp. 261-272.
- Hlupic, V. and Paul, R. J., (1996), "A Methodological Approach to Manufacturing Simulation Software Selection", Comp. Integrated Manuf Systems, vol. 9 (1): pp 49 - 55.
- Hollocks, B., (1992), "A Well-Kept Secret?: Simulation in Manufacturing Industry Review", OR Insight. vol. 5, pp 12 - 17.
- Hutchinson, J., Leong, K., Synder, D., Ward, P.(1991) "Scheduling Approaches for Random Job Shops Flexible Manufacturing Systems", International Journal of Production Research, Vol. 29, No.5,pp. 1053-1067.
- Karsiti, M.N., Cruz,B.J. Jr. Mulligan, J. H. Jr.(1992) "Simulation Studies of Multilevel Dynamic Job Shop Scheduling Using Heuristic Dispatching Rules", J. of Mfg. Systems, Vol. 11,No. 5 pp. 346-358.
- Kochhar, A. K. (1989), "Computer Simulation of Manufacturing Systems - 3 Decades of Progress", In the Proceedings of the 3rd European Simulation Congress, Editors: D. Murray-Smith, J. Stephenson, R. N. Zobel, San Diego, the Society for Computer Simulation. pp 3 - 9.
- Law, A. M. and Haider, S. W., (1989), "Simulation in Manufacturing - Selecting Simulation software for Manufacturing Applications: Practical Guidelines & Software Survey", Industrial Engineering, vol. 31, pp 33 - 56.
- Law, A. M. and Kelton, W. D., (1991), "Simulation Modeling and Analysis", Singapore: McGraw-Hill, Inc. International Editions.
- Mohammed, A., Wadhwa, S., (2005) "Performance Analysis of Partial Flexible Manufacturing System", Global Journal of Flexible Systems Management, Vol., No.1, pp. 9-19.
- Park S. C., (2005), "A methodology for creating a virtual model for a flexible manufacturing system", Computers in Industry, Vol. 56, pp. 734-746
- Sethi, A. K, Sethi, S. P., (1990) "Flexibility in Manufacturing: A Survey." The International Journal of Flexible Manufacturing Systems, Vo. 2, pp. 289-328.
- Shmilovici, A., Maimon, O. Z., (1992) "Heuristics for Dynamic Selection and Routing of Parts in an FMS", Journal of Manufacturing Systems, Vol.11, No.4, pp.285-296
- Sinha, D., Wei, J.C., (1992) "Stochastic Analysis of Flexible Process Choices," European Journal of Operational Research, Vol. 60, pp.183-199
- Tang, Y, L, (1995), "A framework for part type selection and scheduling in FMS environments", *Int. Journal of Computer Integrated Mfg.,* Vol.8, No. 2, pp.101-115
- Upton, D., (1994). "The Management of Manufacturing Flexibility", California Management Review, Vol.36, No.2, pp.72-89
- Wadhwa, S. and J. Browne (1989) Modeling FMS with Petri Nets. International Journal of flexible Manufacturing Systems. 1. 255-280.
- Wadhwa, S., Aggarwal A. (2000) "Synergism of Flexibility, Integration and Automation in Computer Integrated Manufacturing (CIM) Systems", Studies in Informatics and Control, April.
- Wadhwa, S., Bhagwat, R., (1998) "Judicious Increase in Flexibility and Decision Automation in Semi-Computerized Flexible Manufacturing (SCFM) Systems," Studies in Informatics and Control, Vol.2, No.8.
- Wadhwa, S., Caprihan, R., Kumar, S., (1997) "Modelling of Hysteresis based Control Strategy for Flexible System operating Under periodic Status Monitoring policy", Computers and Industrial Engineering, Vol.32, No.3, pp. 557-574.
- Wadhwa, S., Ducq, Y., Ali, M., Prakash, A., (2008), "Performance Analysis of a Flexible Manufacturing System under Planning and Control Strategies", Studies in Informatics and Control, Vol. 17, No. 3, pp. 51-65
- Wadhwa, S., Rao, K. S. (2000) "Flexibility: An Emerging Meta-Competence for Managing High Technology", International Journal of Technology Management, Vol. 19, No. 7/8.
- Wadhwa, S., Rao, K. S., Chan, F. T. S., (2005) "Flexibility-Enabled Lead-Time Reduction in Flexible System", International Journal of Production Research, Vol. 43, No.15, pp. 3131-3163.
- Waiker, A.M., Sarkar B.R., Lal, A.M., (1995) "A Comparative Study of Some Priority Dispatching Rules under Various Shop Load", Production Planning and Control, Vol. 6, No. 4, pp. 301-310

Volume-1 Issue-1

January 2009-June 2009

Phase-III: Theme Based Paper