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Part-mix flexibility and its impact on performance of flexible manufacturing system: A Review

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Abstract This work is performed to reveal the background of the manufacturing flexibility, flexible manufacturing system and the performance measures of a manufacturing system. In this study we explored about the manufacturing flexibility, shop floor control in FMS, design decision taken into consideration in FMS control, different performance measures like make-span, work-in-process and resource utilization, buffer capacity and use of simulation in the analysis of a simple to moderately complex system. This study is useful to great extent to adopt the desirable decision in a restricted sense under the various assumptions made. Simulation study in real life FMS configuration with wider data sets can be adopted. It is assumed that machines are constantly available for processing of parts; however, system disturbances due to breakdown etc. have not been considered. Inclusion of more components of flexible manufacturing system (FMS) like automated guided vehicles (AGVs), automated storage and retrieval systems (ASRS) etc. can also be studied.

Key Words: manufacturing flexibility, make-span time, resource utilization.

1. Introduction

The introduction of automation in production systems was begins in 20thcentury and facilitates to increase productivity and quality at the same time as reducing the costs. Manufacturing companies have two basic alternatives for addressing the challenges posed by variable demand that are either to build manufacturing plants with excess capacity or to increase the flexibility of their manufacturing plant so that production volume and variety can be varied easily to go with change in market demand. In the present scenario flexibility is one of the key factors which works well in the competitive position of manufacturing industries and is one of the four competitive priorities that comprise industries manufacturing strategies.

Flexible manufacturing system provides a technology that is capable for mid volume and mid variety production. Performance of FMS is greatly dependent on the proper scheduling for its control. The proposed work explores the new horizons for impact of part-mix flexibility on the performance of flexible manufacturing systems. The performance of the system has been studied in view of design, planning and control decisions. Simulation model have been developed using Arena simulation software. The performance parameters like make-span time and resource utilization have been studied and discussed.

The proposed simulation model for the present research work has been developed with four different levels of part mix flexibilities have been developed using Arena Simulation software, in order to investigate the effect of various planning, design and control decisions. Primarily four studies for each of these two performance parameters make-span time (MST) and resource utilization (RU) for each of the system configuration. i.e. Number of Parts (NP) Buffer capacity at the various levels of part-mix flexibility have been conducted and analyzed.

2. Review of Literature

Many of the researchers explored flexible manufacturing system and its components and associated systems like shop floor control, decision control, flexibilities and performance measures etc. in this section of the paper I tried to present brief review about the FMS and its components.

2.1. Flexible Manufacturing System

Flexible Manufacturing System (FMS) is defined as a fully automated manufacturing system Stecke et al. 1984. Stecke and Solberg (1981) studied the approach for solve production-planning problem of FMS. A general framework dividing the problem into several hierarchical structured sub-problems like selection of part-type, grouping of machines, etc. have been suggested. The flexibility provides alternative decision for discrete events on the basis of manufacturing flexibility present in the system; a decision point provides opportunity for controlling the way in which the system should evolve (Wadhwa and Browne,1990). A new perspective for viewing a flexible manufacturing system as a whole control system is proposed by Jia and Li (1999). Sarma et al. (2002) reviewed and developed a modeling framework that addresses the machine-loading problem of FMS. Chan et al. (2006) identify productive and counterproductive performance of an FMS at different flexibility levels in view of physical and operating characteristics of the FMS. Venkata and Manukid (2008) proposed a methodology based on a combinatorial mathematics-based decision-making method for the evaluation of alternative flexible manufacturing systems.

A mathematical model to estimate the possible performance parameters like maximum production rate, make span time and overall utilization was suggested for improvement of FMS performance in respect to make-span time, machine utilization, cost and queue (Ali and Wadhwa, 2010,Singholi et al. 2010, Shafiq 2010). Safitra et al. (2014) studied flexible manufacturing systems in stochastic environment and stated that the successful implementation of the flexible system will increase the capital utilization and competitiveness.

2.2. Shop Floor Control in FMS

The control strategies/job shop scheduling are the activities on the shop floor where inputs are transformed into products and needs to be refocused at different stages so as to optimize the manufacturing operations. According to Smith and Joshi (1994) the shop floor control is responsible for planning, scheduling and controlling the events on the shop floor. A multi agent platform to take care of dynamic shop floor control problems in real-time is proposed by Roy et al. (2001). Choi et al. (2004) developed a three-level controller - shop floor, cell and equipment for hybrid control of system based on object-oriented concept. Researchers have proposed and considered the concurrent control capabilities, particularly at the shop floor level in an FMS (Ali and Wadhwa 2010). In this section literature review is based on the hierarchy as shown in Figure-2.2.

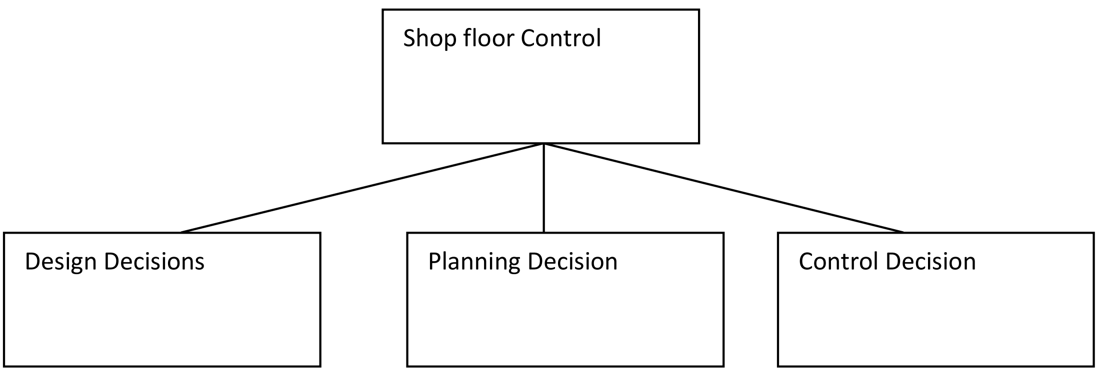

Figure-2.2: Components of shop floor control.

Manufacturing flexibility, buffer capacities are considered as design decisions and number of part types system load condition are taken as planning decision and dispatching rules, sequencing rules are considered as control decisions.

2.2.1. Design Decisions

The decisions related to selection of manufacturing flexibility buffer capacity have been considered as design decisions. Literature review under this category is based on Figure-2.3.

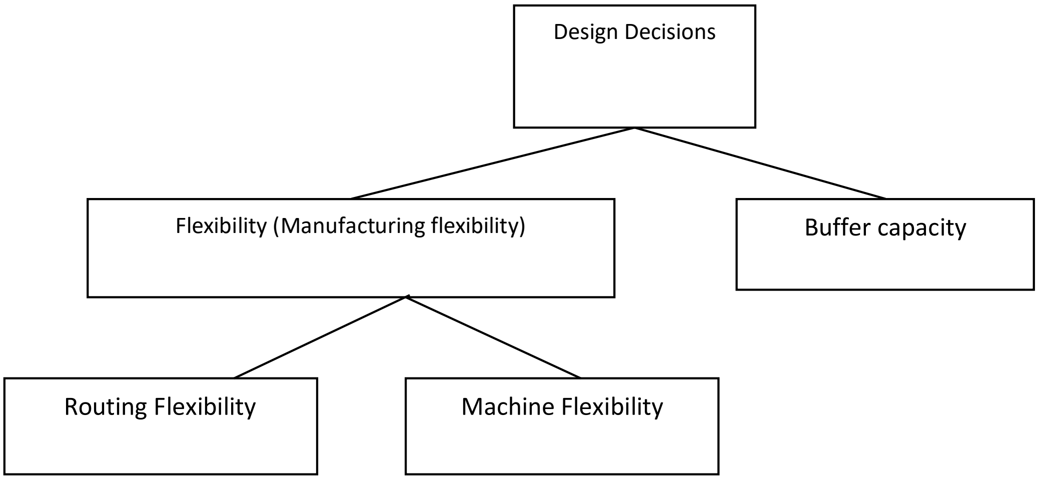

Figure-2.3. Components of design decisions.

2.2.1.1. Flexibility

Flexibility is the ability to adapt to changing circumstances. A similar definition says that flexibility is the ability to rapidly adapt the processes to produce what customers want when they want it without wasting production recourses. These definitions suggest that flexibility has to do with changes due to changing circumstances. The reactive nature of flexibility deals with environmental uncertainty, both internal and external, faced by an organization Slack (1983), whereas proactive nature of flexibility allows an organization to 'redefine market uncertainties' or influence what customers have come to expect from a particular industry Gerwin (1993). Cheng et al. (1997) defines three types of flexibility that is diversity flexibility to handle the variety of change, response flexibility to cope with the rate of change and volume flexibility related to the magnitude of change. Koste and Malhotra (1999) presents definition of ten types of flexibility namely; machine flexibility, labour flexibility, material handling flexibility, routing flexibility, operation flexibility, expansion flexibility, volume flexibility, mix flexibility, new product flexibility, and modification flexibility. Tyagi et al. (2015) used Fuzzy DEMATEL approach for studying the flexibility in the supply chains.

2.2.1.2. Manufacturing Flexibility

Flexibility is an inherent attribute and an intangible asset of a manufacturing enterprise. Knowledge about its own inherent flexibility helps the enterprise to manage it in a more effective manner towards organizational performance empowerment. Flexibility is a word that is broadly used, but the concept of flexibility remains fuzzy. George Stigler first introduced the concept of flexibility in 1939 as reported by Carlsson (1989). A flexible system is the system, which accommodates the ability to cope with customers' preference changes. There are several types of flexibility mentioned in literature.

Some of the researchers describes flexibility in two main contexts: action flexibility, where outside intervention is required before the system can respond to change, and state flexibility where a system's capacity to respond to change is contained within the system. Carlsson (1989) discusses about Type-I and Type-II flexibility. Type-I flexibility accommodates known uncertainty and Type-II flexibility take care of unknown flexibility. Flexibility is considered as a multi-dimensional concept within the manufacturing functions and can be either reactive or proactive in nature. Tiwari, et al. (2013) used the flexibility as a tool for supplier selection in the disastrous environments. Shafiq et al. (2017) investigated the use of simulation towards an experience based collective computational intelligence for manufacturing.

2.2.1.5 Buffer capacity

Buffer capacity is defined as the maximum number of parts that can be stored for further processing. Buffers can be used as a safety stocks so as to minimize the risk due to a sudden breakdown. If breakdowns happen, production can be continued by pulling parts from buffers. The output performance of the system is determined by that of the limited resource.

Chan and Chan (2004) investigated the effects of local buffer sizes, changing the ratio of part mix and machine failure in the context of FMS, suggesting that infinity buffer size is not a good choice for an FMS. It is also reported in the literature that some used a hybrid algorithm to study more complex FMS with alternative routing, limited buffer size, and dual resource. Shafiq et al. (2010) proposed a framework for studying the effect of many parameters along with buffer capacity, on the performance ofFMS. Reddy and Rao (2013) evaluated the performance of the flexible manufacturing system using 'Automod' with dedicated input and output buffers. Ahmad et al. (2014) explained the experimental design issues of the FMS under stochastic environment. They investigated the effect of different input factors by considering the part inter-arrival time and processing time is stochastic. Rashmi and Bansal (2014) have made an attempt to find the optimum solution by using Ant Colony Optimization algorithm. These results increase in AGV utilization and hence the overall efficiency of the system will increase. Kulkarni and Bhatwadekar (2015) studied an integrated dynamic scheduling system with buffer sizes, material handling system, etc. and tested these factors for different sizes of dynamic scheduling problems. Dilbagh et al. (2016) studied the stochastic behavior of an industrial system.

2.3. Performance Measures

Performance information of the system provides data to achieve the goals and objectives of the system. A large variety of performance measures normally used in manufacturing simulation is make-span time, work in process, machine/resource utilization, throughput, queue time queue length. In an expensive modern manufacturing system like FMS, resource utilization is of prime importance to the customer.

Usually the performance criteria like make-span and average resource utilization are used by many researchers for evaluating performance of FMS Singholi et al., 2010. A successful implementation of flexibilities in any of the manufacturing system results to the decrease in production cost, lead time, inventory, tooling, direct labor content, floor space, Work-in-Process and assembly (Saygin et al., 2001).

In the present research work the performance measure considered are make-span time, work in process, average resource utilization, waiting numbers in queue and Waiting time in queue for evaluating the impact of Flexibilities on FMS under deterministic environment.

The total time required for completing all of the jobs is make span time and is desirable to be minimum hence the flexibility and sequencing of jobs are important issues. Li and McMahon (2007) studied the impact of operation sequencing flexibility, scheduling flexibility and processing flexibility on various performance measures of manufacturing system like make-span, the balanced machine utilization, manufacturing cost and job tardiness. Wadhwa et al. (2008) studies the make span performance of FMS under planning and control strategies with different routing flexibility. Ali and Wadhwa (2010) considered make-span as the performance measure to study an FMS with variation in routing flexibility. Sharma et al. (2013) presented a comprehensive review of various issues involved in flexible manufacturing system. They revealed that make-span is one of the key measures to evaluate the performance of an FMS. Al-Kahtani et al. (2014) concluded that the make-span decrease whereas machine utilization and production cost increase with the increase of routing flexibility level. Kazim et al. (2014) developed codes in C++ for getting optimum sequence of operation to minimize the make span time and reduce the machine idle time and minimize the utilization of machines. Reducing make span of parts results decrease in the carrying cost of unfinished parts and decrease in the inventory of parts that are waiting for other parts to be processed. As explored by the researchers that make span is a critical performance measure for a manufacturing system.

Next performance measure considered is work in process. Reduction in work in process and manufacturing lead times is the most positive response that would made with regard to the performance improvement of an FMS. Vieira et al. (2003) noted that the issues like WIP reduction, total cost minimization, job profitability, etc. are more important for managers then time base performance measures. Mehdi et al. (2013) investigated that production rate, machine and material handling utilization rate for an overloaded manufacturing system, the real-time rescheduling outperforms without rescheduling, but it has a counter impact on WIP. Singh et al. (2014) recorded statistical data such as work in process levels and cycle time as an output report in the simulation model developed in ARENA simulation software.

Resource utilization is the actual percentage of machine working time. When the system is lightly loaded, the faster machine tends to process all jobs, as and when system becomes heavily loaded, less efficient machines steadily take on more work, until a saturation point reached.

Al-Titinchi and Al-Aubidy (2004) used colored Petri Net (CPN) an interactive hierarchical model for FMS and evaluated the performance of the system for machine utilization, average flow time and maximum flow time. It was investigated that an insignificant effect of the sequencing priority on these performance measures. Singholi et al. (2010) explored and suggested some methods for the improvement in the performance of a flexible manufacturing system. Make-span time, overall machine utilization and maximum production rate as the performance measures for a case study. Burnwal and Deb (2013) presented a cuckoo search (CS) – based approach for scheduling optimization of an FMS by reducing manufacturing delay penalty and increase in the machine utilization. Using MATLAB results have been verified with genetic algorithm and particle swarm optimization. The results show that the CS-based approach has been found better performance. Kazim et al. (2014) developed codes in C++ for getting optimum sequence of operation to minimize the make-span time and reduce the machine idle time and maximize the machine utilization.

2.4 Simulation

Implementing an FMS involves a significant investment of managerial time and effort in addition to capital investment. Thus, a simulation model is used as test bed to mimic the operation of FMS under different design planning and control alternatives Simulation is one of the most widely used operation research and management technique. (Ross 2002, Law and Kelton 2003 and Banks *et al*.2009). Jahangirian *et al.* (2010) report the results of a review of simulation applications published within peer-reviewed literature between 1997 and 2006 to provide up-to-date picture of simulation technique within manufacturing and business.

Jeong and Kim(1998) suggest that simulation can work as decision support system for real scheduling of FMSs. Cheong et al. (2003) observe that discrete-event simulation is an indispensable tool for detailed scheduling under high dynamic and unpredictable manufacturing system. Wadhwa (2005) evaluated performance of partial FMS using simulation. Wadhwa et al. (2008) studied the performance of FMS consisting of six machines with six parts under planning and control strategies. Zaied (2008) discuss the use of simulation to schedule the processing orders.

Singholiet al. (2010) investigated the performance developing simulation model using Arena Software. Ali and Wadhwa (2010) used Taguchi method for identifying the important parameters and DES for study of various parameters for performance improvement. Agarwal Anil Kumar et al. (2011) investigated the use of Ant colony optimization technique for group technology application. Taktaket al. (2012) relates the use of computer simulation through development of computer assisted application. Mishra M et al. (2012) used simulation modeling for evaluating the impact of supply chain. Caprihan et al. (2013) used simulation for empirical estimation of impact of information delays. Kumbhaj and Patil (2014) developed a simulation model for loading problem of production management.

Shafiq et al. (2015) studied Virtual Engineering Object towards experience-based Design and manufacturing for industry. Kulkarnui and Bhatwadekar (2015) studied a system of 11 machines of five types and three types of jobs in different batch size and four loading and unloading stations to evaluate make span. Rajeev Kumar and Mishra M (2016) investigated use of simulation modeling for performance evaluation for different part-mix ratio and routing flexibility. Michael E et al. (2017) investigated the use of simulation for an optimal integrated QSMS model from cluster analysis.

3. Conclusion

This work is a comprehensive review of the background of the manufacturing flexibility, flexible manufacturing system and its components and the performance measures of a manufacturing system. It is found that most of the researchers explored about the manufacturing flexibility, shop floor control in FMS, design decision taken into consideration in FMS control. The performance measures like make-span time, work in process, machine/resource utilization, throughput, queue time, queue length are generally taken into consideration. Simulation studies have been conducted for the analysis of a simple to moderately complex system. This study is useful to new researchers to adopt different control and measuring parameters for the design, selection and analysis of a flexible manufacturing system.

4. Future scope

Simulation study in real life FMS configuration with wider data sets can be adopted. It is assumed that machines are constantly available for processing of parts; however, system disturbances due to breakdown etc. have not been considered. Inclusion of more components of flexible manufacturing system (FMS) like automated guided vehicles (AGVs), automated storage and retrieval systems (ASRS) etc. can also be studied.

5. References

Ali M and Wadhwa S. (2010). The Effect of Routing Flexibility on a flexible system of Integrated Manufacturing. *International Journal of Production Research*. 48(19). 5691-5709.

Ali, M., Ahmad, Z. (2014) "A Simulation Study of FMS Under Routing and Part Mix Flexibility". Glob J Flex SystManag 15, 277–294.

Al-Titinchi AA and Al-Aubidy KM. (2004). Modeling and Analysis of an On-line FMS Scheduling Using Colored Petri Nets. *International Journal of Computing and Information Science*. 2(2). 74-83.

Browne J, Dubois D, Rathmill K, Seth SP and Stecke KE. (1984). Classification of Flexible Manufacturing Systems. *The FMS Magazine*. 114-117.

Carlsson B. (1989). Flexibility and the Theory of the Firm. *International Journal of Industrial Organization*. 7. 179-203. Tiwari AK, Tiwari A, Samuel C and Bhardwaj P. (2013). Procurement flexibility as a tool for supplier selection in Disastrous Environments. *Global Journal of Flexible System Management*. 14. 211-223.

Chan Alan T.L., Eric W.T.Ngai and MoonKaren K.L. (2017) The effects of strategic and manufacturing flexibilities and supply chain agility on firm performance in the fashion industry, European Journal of Operational ResearchVolume 259, Issue 2, Pages 486-499

Chan FTS and Chan HK. (2004). A Comprehensive Survey and Future Trend of Simulation Study on FMS Scheduling. *Journal of Intelligent Manufacturing*. 15. 87-102.

Chan FTS, Bhagwat R and Wadhwa S. (2006). Increase in flexibility: productive or counterproductive? A Study on the physical and operating characteristics of a flexible manufacturing system. *International Journal of Production Research*. 44(7). 1431-1445.

Cheng JMJ, Simmons JEL and Rithie JM. (1997). Manufacturing System Flexibility: The Capability and Capacity Approach. *Integrated Manufacturing Systems*. 8(3). 147-158.

Cheng Yang, Zeliang Yang RuixianCai "Analytical method for evaluation of gas turbine inlet air cooling in combined cycle power plant" Applied Thermal Engineering, Volume 86, pp848-856.

Choi SH and Lee JSL. (2004). A sequencing algorithm for makespan minimization in FMS. *Journal of Manufacturing Technology Management*. 15(3). 291-297.

Cristina Sancha ,Frank Wiengarten,AnnachiaraLongoni&MarkPagell (2020), The moderating role of temporary work on the performance of lean manufacturing systems, International Journal of Production Research Volume 58, -14 pp. 4285-4305.

Dilbagh Panchal and Dinesh Kumar. (2016). Integrated framework for behaviour analysis in a process plant. *Journal of Loss Prevention in the Process Industries.* 40. 147-161.

Gerwin D. (1993). Manufacturing Flexibility: A Strategic Perspective. *Management Science*. 39(4). 395-410.

Jia-Jiunn L and Li L. (1999). An object-oriented FMS real-time and feedback control model. *International Journal of Computer Integrated Manufacturing.* 12(6). 483 – 502.

Kazim SM, Singh AK and Jayswal SC. (2014). Scheduling Optimization in FMS using Genetic Algorithm with Makespan Criterion. *International Journal for Technological Research in Engineering*. 1(12). 1532-1536.

Koste LL and Malhotra MK. (1999). A theoretical framework for analyzing the dimensions of manufacturing flexibility. *Journal of Operations Management*. 18. 75–93.

Kumar Rajeev and Mishra M. (2016). Simulation of Manufacturing System at different Part Mix Ratio and Routing Flexibility. *Global Journal of Enterprise Information System*. 8(1).

Mallikarjuna K, Veeranna V and Reddy KHC. (2013). Optimum Design of Loop Layout in Flexible Manufacturing System - An Approach of Metaheuristics. *International Journal of Advances in Engineering & Technology*. 6(4). 1693-1702.

Manu. G, Vijay Kumar. M,Nagesh, H, Jagadeesh, D, &Gowtham, M. B (2018), "Flexible manufacturing systems (FMS): A Review", International Journal of Mechanical and Production Engineering Research and Development, 8(2), pp. 323-336.

Mishra M and Chan FTS. (2012). Impact Evaluation of Supply Chains Initiatives: A system simulation methodology. *International journal of Production Research*. 50(6). 1554-1567.

Mishra, R. (2020), "Empirical analysis of enablers and performance outcome of manufacturing flexibility in an emerging economy", Journal of Manufacturing Technology Management, Vol. 31 No. 6, pp. 1301-1322

Odigie Michael E, Badar M Affan, Sinn John W, Moayed Farman and Shahhosseini A Mehran. (2017). An optimal integrated QSMS model from cluster analysis. *The TQM Journal*, 29(3). 438-466.

Roy Daniel and Anciaux Didier. (2001). Shop-Floor Control: A Multi-Agents Approach. *International Journal of Computer Integrated Manufacturing*. 14. 535-544.

S.Wadhwa, A.K.S. Singholi and M.Ali (2010) "Evaluating the effect of part-mix and routing flexibility on FMS performance", Global Journal of FMS, 11(4):17-24.

Safitra M, Ahmad A and Al-Ahmari A. (2014). Experimental Design of a Flexible Manufacturing System. *Proceedings: International Conference on Industrial Engineering and Operations Management, Bali, Indonesia*, January 7-9.

Sarma UMBS, Kant Suman, Rai Rahul and Tiwari Manoj. (2002). Modelling the machine loading problem of FMSs and its solution using a TABU-search-based heuristic. *International Journal of Computer Integrated Manufacturing*. 15. 285-295.

Shafiq SI, Faheem M and Ali M. (2010). Effect of Scheduling and Manufacturing Flexibility on the Performance of FMS. *Global Journal of Flexible Systems Management*. 11. 21 - 38.

Shafiq Syed, Sanin Cesar, Toro Carlos and Szczerbicki Edward. (2015). Virtual Engineering Object (VEO): Toward Experience-Based Design and Manufacturing for Industry 4.0. Cybernetics and Systems. 46(1-2). 35-50.

Singholi A, Chhabra D and Ali M. (2010). Towards Improving the Performance of Flexible Manufacturing System: A Case Study. *Journal of Industrial Engineering and Management*. 3(1). 87-115.

Slack Nigel. (1983). Flexibility as a Manufacturing Objective. *International Journal of Operations and Production Management*. 3(3). 4-13.

Smith JS and Joshi SB. (1994). Formal models of execution function in shop floor control. *Computer control of flexible manufacturing systems*. 285-314.

SomenDey, R. R. K. Sharma & Balbir Kumar Pandey (2019) "Relationship of Manufacturing Flexibility with Organizational Strategy" Global Journal of Flexible Systems Management volume 20, pages237–256.

Stecke Kathryn and Solberg James J. (1981). Loading and control policies for a flexible manufacturing system. *The International Journal of Production Research*. 19(5). 481-490.

TyagiMohit, Kumar Pradeep and Kumar Dinesh. (2015). Assessment of Critical Enablers for Flexible Supply Chain Performance Measurement System Using Fuzzy DEMATEL Approach. *Global Journal of Flexible Systems Management*. 16(2). 115–132.

Venkata RR and Manukid P. (2008). Flexible Manufacturing System Selection using a Combinatorial Mathematics-based Decision-making Method. *International Journal of Production Research*. 46(1). 1-24.

Wadhwa S and Browne J. (1990). Modeling FMS with Petri Nets. *International Journal of flexible Manufacturing Systems*. 1. 253-280.

Yadav A and Jayswal S. C. (2019), "Evaluation of batching and layout on the performance of flexible manufacturing system", The International Journal of Advanced Manufacturing Technology, volume 101, pp 1435–1449.