# Implementation Issues in FMS: A Literature Review

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**Abstract-In today's very competitive, dynamic and unpredictable manufacturing environments it is critical to improve manufacturing performance in order to be able to compete. Flexibility becomes an important characteristic of manufacturing systems and organizations; thus the flexible manufacturing systems (FMS's) are becoming popular in today's scenario. A flexible manufacturing system (FMS) incorporates numerically-controlled machine tools, robots, automated material handling systems, and automated inspection and self diagnostic facilities into a single production system whose integration is under the control of a hierarchical information system network. On one hand, the benefits of implementing FMS result in production maximization and prevent stations from being idle. FMS offers lower carryover effects when stations interrupt, and also lowers the cost of maintaining spare part inventories due to the fact that similar equipment can share components. The goal of this paper is to present the comprehensive review of various issues involved in FMS environment. The study helps the practioners in providing the guidelines of whether it is futile investment in adopting the FMS environment and helps in bridging the gaps between the various crucial aspects required for its implementation.**

**Key words: Flexibility, Flexible Manufacturing System (FMS), Performance Measures, Decision variables**

## I. Introduction

Flexible manufacturing systems (FMS's) have been an important breakthrough towards fully automated and computer-integrated production. A flexible manufacturing system (FMS) is essentially a computer-controlled production system, which brings together different standalone machines and control equipment capable of processing a variety of part types or jobs.

FMS differs from the conventional systems in terms of flexibility in the flow of materials from one tool to another and performing the operations as per the required sequence. Each part can follow a variable route through the system. In a nut shell, flexibility in material handling, in combination with multipurpose tools, makes it possible for a flexible manufacturing system to process a great diversity of parts. (Cardinali, 1995)

The importance of FMS can be analysed from the fact that in the 19th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2009), held at England, experts and delegates from more than 37 countries assembled to identify the best-practices and future trends within the area of advancing technologies in flexible automation and intelligent manufacturing.

Some of the advantages of FMS include: improved capital/equipment utilization, reduced work in progress and set up, substantially reduced throughput times/lead times, reduced inventory and smaller batches, and reduced manpower.

This paper is an attempt to make a comprehensive review of Flexible Manufacturing Systems covering their essential and crucial aspects. The facts related to the flexibility issues of FMS are discussed in section 2. Further on, light in thrown on the key issues, the decision variables and performance measures in FMS. Case studies discussing the implementation of FMS are also presented in the paper. The paper is concluded in the last section.

## II. Flexibility in FMS

Flexibility is defined as ability of the system to easily adapt change between the existing part types and operations/routes required tom process a component. It, also, quickly and economically make the system to add new parts and processes to the system. The flexibility has seen to have positive effect on the performance of FMS with efficiently utilized manufacturing system and is beneficial to deal with changes occurring in FMS as result of conditions like machine breakdowns, change in customer needs, introduction of new products and updating of existing products. By increasing the flexibility of FMS it may be possible to produce wider variety of products, possibly with addition types of machines or more complex version of planned machines. The flexibility hence becomes an essential characteristics to be considered while designing and operating manufacturing systems. Oke (2005) considered flexibility as one of the important weapon to meet the uncertainties of the manufacturing environment. Investments in manufacturing flexibility enable organizations to better adapt to uncertainty, redefine or reduce uncertainty and competitive position, or bank the capability to address a perceived future uncertainty ( Ketokivi, 2006).

The different types of flexibilty that exist in any manufacturing systems are reported in literature. Based on the study conducted by Browne et al (1984), Slack (1987), Sethi and Sethi (1990) and Groover (2006) the different types of flexibilities are complied in table 1. Their study helps the organizations to quickly adapt the uncertainties occurring from wide variety of sources.

With the wide variety of options, ranging from hard technology solutions, such as robotics and flexible manufacturing systems, to people focused options, such as cross-training, to external practices, such as outsourcing; managers are faced with the challenge of choosing flexibility tools and techniques that adequately address uncertainty, yet are aligned with broader manufacturing goals, organizational strategies, and management philosophies, such a lean production.

Table `1: Types of flexibility (compiled from Browne et al (1984), Slack (1987), Sethi and Sethi (1990) and Groover (2006))

| **Type of flexibility** | **Definition** |
|---|---|
| **Range flexibility** | The total envelope of capability or range of states which the manufacturing system is capable of achieving, i.e. short-term flexibility |
| **Response flexibility** | Ease, in terms of time and cost, with which changes can be made within the capability envelope, i.e. long-term flexibility. |
| **Routing flexibility** | Ability to process parts with different routes |
| **Part flexibility** | Set of part types that a system can produce without major set-ups |
| **Volume flexibility** | Ability to operate profitably at different output volumes |
| **Expansion flexibility** | Ease and capability to expand volumes as needed |
| **Machine flexibility** | Various types of operations that a machine can perform without requiring excessive operation changeover costs and/or times |

## III. Key Issues in FMS

Various key issues are identified in FMS studying the related literature and are complied in this section. This section discusses the brief review of the key issues related to FMS.

### *3.1 Machine Loading*

Machine loading problem deals with the allocation of jobs to various machines under technological constraints to meet certain performance measures. Machine loading encompasses various types of flexibilities pertaining to part selection and operation assignment along with constraints ranging from simple algebraic to potentially very complex conditional constraints like capacity of machine, capacity of tool magazine, tool requirement of different operations, overutilization and under utilization cost of machines (Abazori et al (2012). Kumar et al (2006) defines machine loading as set of tools that are required to produce parts using different resources such as material handling systems, pallets, jigs and fixtures and considers how the parts be assigned so that optimum productivity can be reached. In order to solve machine loading problems adequately, some objectives are laid down by various researchers and are compiled by Kumar et al (2006). The issues are presented in table 3.

Table 3:Objectives of machine loading (compiled from Kumar et al (2006))

| **S.No** | **Objectives of machine loading** |
|---|---|
| 1. | Maximization of number of alternative routings |

| | |
|---|---|
| 2. | Maximization of the differences of load among the machines |
| 3. | Maximization of the total profit |
| 4. | Minimization of flow time and minimization of WIP |
| 5. | Minimization of inventory costs |
| 6. | Minimization of load of re-fixturing stations |
| 7. | Minimization of load of tool transport system |
| 8. | Minimization of load of workpiece transport system |
| 9. | Minimization of makespan |
| 10. | Minimization of manufacturing costs |
| 11. | Minimization of number of tool magazine configuration changes |
| 12. | Minimization of system unbalance and maximization of throughput |
| 13. | Minimization of the number of tardy jobs |
| 15. | Minimization of the total (weighted) tardiness |
| 16. | Minimization of total overload and underload of the machines |

### *3.2 Automatic Guided Vehicles*

An FMS requires a capable material handling system to move material/parts safely and economically across the system. Automatic guided vehicles (AGV's) are defined as the driverless transport system to move the one or more parts at same time. Vis (2006), in his study, reflected that advances in AGV technologies have enhanced the flexibility and autonomy. Also, Erol et al (2012) pointed AGV's as one of the effective ways for material handling of different parts due to better routing flexibility, space utilization, safety and product quality. Deadlock and collisions are one of the critical issues affecting the performance of FMS and AGV's should have capability to obstacles and the ability to return to its original path without any collision. Hsueh (2010) defines three methods to avoid the condition of deadlock and collisions within the FMS. These are - design the layout of guide paths in such a way that conflicts and deadlocks are avoided; divide the traffic area into several non-overlapping control zones; or develop routing strategies to prevent conflicts and deadlocks. He suggested load exchangeable AGV method to avoid deadlock and collision; therefore, the load of an AGV is always on its shortest path, resulting in higher system performance and avoiding unnecessary waiting times.

### *3.3 Sequencing and Scheduling*

Sequencing, scheduling and loading rules are basically the planning problems which are the decisions that have to be made before the FMS can begin to produce parts. Once the FMS is 'set-up', production can start. At the FMS planning stage, the FMS has been implemented and is in production. The FMS scheduling problems are concerned with running the system by optimally scheduling the flow parts throughout the FMS. From the part numbers which are to be processed on the system, subsets are made pertaining to the production orders, requirements from another department in the factory or from a sister plant or customer orders, or maybe forecasted demand. (Stecke, 1985) Table 4 gives a comprehensive literature review for scheduling the FMS, which is one of the most critical planning issues. The table lists the key findings of each research. The study shows that an optimum schedule for a system can be obtained by adopting methodologies like simulated annealing, tabu search, integer programming model, neural networks, RapidCIM, etc. The application of each methodology and the expected outcomes depend upon the type of FMS and its application area.

### *3.4 Tool Management*

In Flexible Manufacturing Systems (FMS), tool management decisions play a crucial role in achieving high productivity and this had been recognised as important criteria in automated manufacturing literature for several years. . The need for tool management stems from the high variety and number of cutting tools that are typically found in automated manufacturing systems. The adoption of appropriate tool management policies allows the desired part mix and quantities to be manufactured efficiently while achieving improved system performance. Gray et al (1993) defines tool management as getting the right tool, to the right place and at the right time. Many studies have been conducted for different aspects of tool management which includes tool switching, tool allocation and tool sharing. Konak et al (2008) studies the tool switching problem and proposed the algorithm to minimise number of tool setting instants. They pointed in their study that minimizing the number of tool switches is the relevant when the tool switching time significant is compared to the processing times.

Table 4: FMS Scheduling – A literature review

| S.no | Objective | FMS type and Application Area | Methodology Used | Key Findings |
|---|---|---|---|---|
| 1 | Multi Criteria Dynamic Scheduling and control for FMSs. (Shnits, et al, 2004) | FMS with 2 CNC m/cs and 2 part types, ASRS, Pallet system, and Quality Control center is considered for the development of a dynamic scheduling system for FMS. | A two-level hierarchy is used. The first level determines a dominant decision criterion & relevant scheduling rules based on actual shop status. The second level uses simulation (Arena 7) to select the best scheduling policy. | The proposed methodology is used to find FMS performance (compare Mean flow times and Mean tardiness) for different scheduling policies. The control mechanism as also tested for single decision criterion, for which the results were inferior to those in the case of two decision criteria. |
| 2 | Modelling and Heuristics of FMS scheduling with multiple objectives (Low et al., 2006) | FMS with 3 m/cs, 4 part types, and different operations on each with defined Due Date is taken for developing optimal sequences w.r.t 3 objectives - Mean flow time, mean Tardiness, and Mean M/c idle time. | Heuristic approach using: Simulated Annealing & Tabu Search | Using a multi-objective mathematical model, though the optimal schedule was obtained, but the no. of variables and constraints increase drastically. So, SA and Tabu search was used which gave the results efficiently and effectively. |
| 3 | Mathematical Modelling and heuristic approaches to operation scheduling problems in an FMS environment (Low and Wu, 2001) | 2 X 2 FMS to apply Mathematical Model based on single objective (min tardiness) | 0-1 Integer Programming Model and a heuristic with 2 procedures - SIP (Seq improving procedure) and REP (Route Exchanging Procedure) | Optimum schedule is obtained using 0-1 Integer Programming Model. But, the approach becomes excessively lengthy as size of FMS increases. So, heuristic approach is used (SA). But, for no. of jobs > 50 and m/cs > 6, instead of SA, Tabu search gives better results. |
| 4 | A review of Machine Learning in Dynamic Scheduling of FMS (Priore et al, 2001) | Considers a general FMS and compares the performance on the basis of literature review. | Dynamic scheduling of FMS by means of Dispatching Rules based on Machine Learning. 2 approaches are used - first a rule is selected by simulating a set of dispatching rules; second, based on Knowledge Base, best rule is identified. | A classification of general scheduling approaches is done. Two ways of dynamically modifying the dispatching rules are used to show their improvement upon static case. Paper lists the generalised shortcomings of KBS |
| 5 | A new method of FMS Scheduling using Optimisation and simulation (Priore et al, 2001) | 2X2 FMS | Break and Build Model- A multi-objective optimisation and simulation technique | The problem is solved in 3 stages of BBM - In building stage, an optimum schedule was built using heuristics. In Breaking Stage, was used to determine break-even point using break even analysis. In the rebuilding stage, the most proper schedule is selected using simulation. |

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|---|---|---|---|---|
| 6 | Modelling and Scheduling of a FMS (Sawik, 1990) | 6 m/cs and 4 part types to find detailed operation scheduling in FMS. | A hierarchical decision approach is used. Scheduling is determined by decomposing problem into 4 sub-problems. In first, part types are divided into subsets/batches for simultaneous processing. Then, m/c loading is done. Then, part i/p seq is determined followed by scheduling of operations and sequencing the operations assigned to each m/c. | Presents an integer programming formulation of scheduling in FMS. Based on algorithms for each decision stage an optimum schedule is constructed. Can work for both online and offline scheduling. |
| 7 | Real time scheduling mechanism for a FMS: using simulation and dispatching rules (Jeong and Kim, 1998) | 6 HMC, 2 L/UL stations, a w/p stocker that can store upto 150 pallets with the assumption that processing times and due dates are known. It is used to develop a scheduling strategy to measure the difference between actual and estimated performances | A simulation-based real-time scheduling mechanism in which job dispatching rules vary dynamically based on information from discrete event simulation that is used for evaluating a set of candidate dispatching rules. Rules are selected by simulating the system from the time of rule selection until the end of the planning horizon, but the selected rule is used until another rule is selected. | Performance of the dispatching rules is compared in terms of mean flow times and mean tardiness. Stress was laid on the computation time which was found to be less than 45sec for a dynamic model. |

## IV. Research Technique, Decision Variables and Performance Measures in FMS

An extensive research is reported in literature giving the brief review for the research technique used in the analysis of FMS. Various techniques like simulation (Mehrjerdi, Y. (2009), Tamini et al (2012), AHP (Bayazit (2004), Petri Net (Tamini et al (2012)) etc. Table 5 summarizes various research techniques indicated in literature related to FMS.

Table 5: Research techniques used in FMS

| S.No | Research techniques | Results | Reference |
|---|---|---|---|
| 1. | Analytic Hierarchy Process (AHP) | It is a multiple criteria decision-making methodology in evaluating an FMS. It determines the relative importance of a set of attributes and criteria; like, customer satisfaction, set-up time, cutting speed, profitability, etc. It helps to affirm that individual decision makers capture logical and reasonable preferences when making decisions. | Bayazit (2004), Cheng and Li (2003), |
| 2. | Petri nets (PNs) | Works as a powerful tool to formalize rules for allocating and dislocating the zones in AGVS. | Tamini et al (2012) |
| 3. | Expert Systems | An efficient tool to formulate strategies for placing different FMS components. However, these suffer from deficiencies like, it relegates some of the important aspects involved in FMS design such as cost and quality. | Borenstein et al., (1999) |

| | | | |
|---|---|---|---|
| 4. | Particle Swarm Optimization | An efficient mathematical tool for solving machine loading problem in FMS. | Ponnambalam and Kiat (2008). |
| 5. | Genetic Algorithm | This algorithm determines the job sequence while keeping in view its interaction with operation machine allocation. | Tiwari et al., (2007) |
| 6. | Artificial Intelligence (AI) and Fuzzy Logic | Helps in analysing the problem close to real-life situations, gives better quality solution for large-sized real-life problems. The procedure makes the scheduling decisions in real time trying to meet several measures of performance simultaneously, as can be verified in the simulations accomplished with the developed prototype. | Domingos and Politano (2003), Chan et al. (2005) |
| 7. | Neural Networks based Adaptive Scheduling | This attribute selection algorithm measures the important system attributes that can be used for constructing scheduling knowledge base. | Shiue and Su (2002) |
| 8. | Multi Agent Systems (MAS) | Enables one to consider the autonomy and hierarchy of the manufacturing systems concurrently. Advantageous in dynamic environments where machines are susceptible to failure and part arrivals are unpredictable. | Tripathi et al., (2004) |
| 9. | Simulation | Simulation can reduce the risk of installing an FMS which may not provide sufficient flexibility; A simulation model can represent important characteristics of an FMS more realistically. It may incorporate the complex interactions which may exist between various variables, for example, loading strategy at buffer and at workstations; Alternative FMS designs can be evaluated easily in a controlled environment; A computer simulation model's ability to address directly the measures of performance typically used in FMS evaluation helps to calculate the same measures of system performance for hypothetical FMS configurations as used in judging the real systems. | Mehrjerdi, Y. (2009), Tamini et al (2012) |

The performance measures of FMS are reported in table 6. Some of the measures listed in literature includes average WIP, average workstation utilization, make span etc.

| S.No | Performance Measure | References |
|---|---|---|
| 1. | Mean flow time | Kumar and Sridharan (2007) |
| 2. | Average workstation utilization | Tamini et al (2012), Shamsuzzaman et al (2003), Huesh (2010) |
| 3. | Queue length | Goyal et al (1995) |
| 4. | Make span | Tabucanon et al (1995), Shansuzzaman et al (2003), Hsueh (2010) |
| 5. | Throughput time | Shansuzzaman et al (2003), Goyal et al (1995), Buyurgan et al (2007) |
| 6. | Average waiting time | Buyurgan et al (2007), Hsueh (2010), Tamini et al (2012) |

| | | |
|---|---|---|
| 7. | Mean Tardiness | Kumar and Sridharan (2007), Goyal et al (1995) |

## V. FMS IN INDIA

Narain et al, 2004 carried out two case studies in large Indian organizations which use flexible manufacturing systems/cells. These organizations deal in the manufacture of shoes and railway coaches respectively. The concept of FMS, which was initially meant for machining processes, has now been extended to other application areas such as sheet-metal, welding, forging, laser machining, injection moulding etc. (Narain et al, 2004)

*CASE 1: FMS in Shoe manufacturing*

The benefits to the company from the installation of the flexible integrated system are:

1. A state-of-the-art flexible assembly line has been introduced.
2. Improvement in quality with output to international standards has been achieved. (Rate of rejections reduced from 2.5 percent to 1 percent.)
3. There is faster response to the needs of retailers of such footwear.
4. There has been a reduction in labour from 34 to 16 (for the same level of daily output).
5. The overall increase in productivity is 113 per cent.
6. The total labour cost per pair of shoes has reduced by 50 per cent.
7. There is less work-in-process.
8. The staff have been re- and multi-skilled and are working as a team.
9. The floor area required has reduced by more than 50 per cent.
10. The requirement for lasts went down from 450 pairs to 100 pairs for the same volume of production.
11. Inspection has considerably reduced. Supervisors now have a new role in the production process.

*Economic Analysis:*

From the cost data of the company it was found that the introduction of the flexible system would give a net saving of Rs. 210.99 lakhs every year.

*CASE 2: FMS in producing Railway Coaches*

Some of the main benefits that the company derived from the system are as follows:

1. Better quality in the production of components requiring a high degree of precision, e.g. fabrication of interlocking parts with notch size less than 4mm.
2. High accuracy (positioning accuracy 1.3mm) and high speed of cutting (up to 6.0m/min).
3. Reduced scrap owing to the use of nesting software for optimization of sheets. Wastage of material reduced to 3 per cent.
4. Flexibility to cut a range of materials such as metallic, wooden, ply, and paper etc. on the laser-cutting machine.
5. Greater output owing to automatic loading and unloading of the pallets containing sheets on the loading table via AS/RS and on the positioning table with the help of an automatic vacuum lift plate feeder.
6. Proper accounting of material owing to computerized handling through AS/RS.
7. Overhead on stores reduced from 1.2 percent of material cost to 0.85 per cent.

*Economic Analysis:*

The company has gained numerous advantages in terms of maintaining quality, productivity, and flexibility in manufacturing. This case study strengthens the belief that a long payback period should not necessarily be used to discourage investment in such capital-intensive technology.

## VI. CONCLUSION

Flexible Manufacturing System (FMS) is a capital-investment intensive and complex system. In the present market scenario, the customer demand and specification of any product changes very rapidly so it is very important for a manufacturing system to accommodate these changes as quickly as possible to be able to compete in the market. This evolution induces often a conflict for a manufacturing system because as the variety is increased the productivity decreases, hence FMS is a good combination between variety and productivity.

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