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Enactment Concerns in FMS: A Literature Review

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Abstract: *In the present era of very competitive, dynamic and unpredictable manufacturing environments it is uncertain to improve manufacturing performance in order to be able to compete. Flexibility becomes a paramount characteristic of manufacturing systems and organizations; thus the flexible manufacturing systems (FMS's) are becoming favored in today's scenario. A flexible manufacturing system (FMS) integrates 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 propose lower carryover effects when stations interrupt, and also reduce the cost of maintaining spare part inventories due to the fact that similar equipment can share components. The aim of this paper is to extant the comprehensive review of various concerns involved in FMS environment. The study helps the practitioners 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 enactment.

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

I. Introduction

Flexible Automation as a topic of research has been around for at least a half century. In the late 70's, flexible manufacturing cell/systems (MFC/MFS) started playing pivotal roles in modern industry, in particular automobile industry. However, the journey of going from a theory or vision to an art or reality did not end there and then. In the last two decades, flexible automation has taken on many new concepts, technologies and practices. This evolution process has resulted in numerous new terminology in replacement (or sometimes in favor) of flexible automation. Nonetheless, the ultimate goal remains - empowering the modern industry with different "versions" of automation technologies in order to meet the ever-diverse and ever-changing market. It is the time that we go back to the "basics", i.e. flexible automation by embracing a raft of new technologies that are evolved from the basic concept of flexible automation. 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 analyzed 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.
This paper is a venture to make a comprehensive review of Flexible Manufacturing Systems covering their essential and crucial aspects. The facts related to the flexibility concerns of FMS are discussed in section 2. Further on, light in thrown on the key concerns, the decision variables and performance measures in FMS. Case studies discussing the enactment of FMS are also presented in the paper. The paper is ceased in the last section.

II. Flexibility in FMS

Flexibility is an attribute that allows a mixed model manufacturing system to cope up with a certain level of variations in part or product style, without having any interruption in production due to changeovers between models. Flexibility measures the ability to adapt "to a wide range of possible environment". To be flexible, a manufacturing system must possess the following capabilities these capabilities are often difficult to engineer through manually operated manufacturing systems. So, an automated system assisted with sensor system is required to accomplish the needs and requirements of contemporary business milieu. Flexible manufacturing system has come up as a viable mean to achieve these prerequisites. The term flexible manufacturing system, or

FMS, refers to a highly automated GT machine cell, consisting of a group of computer numerical control (CNC) machine tools and supporting workstations, interconnected by an automated material handling and storage system, and all controlled by a distributed computer system. The reason, the FMS is called flexible, is that it is capable of processing a variety of different part styles simultaneously with the quick tooling and instruction changeovers. Also, quantities of productions can be adjusted easily to changing demand patterns. The different types of flexibility that are exhibited by manufacturing systems are given below:

1. Machine Flexibility-It is the capability to adapt a given machine in the system to a wide range of production operations and part styles. The greater the range of operations and part styles the greater will be the machine flexibility. The various factors on which machine flexibility depends are: Setup or changeover time, Ease with which part-programs can be downloaded to machines, Tool storage capacity of machines, Skill and versatility of workers in the systems.

2. Production Flexibility- It is the range of part styles that can be produced on the systems. The range of part styles that can be produced by a manufacturing system at moderate cost and time is determined by the process envelope. It depends on following factors: Machine flexibility of individual stations, Range of machine flexibilities of all stations in the system.

3. Mix Flexibility- It is defined as the ability to change the product mix while maintaining the same total production quantity that is, producing the same parts only in different proportions. It is also known as process flexibility. Mix flexibility provides protection against market variability by accommodating changes in product mix due to the use of shared resources. However, high mix variations may result in requirements for a greater number of tools, fixtures, and other resources. Mixed flexibility depends on factors such as: Similarity of parts in the mix, Machine flexibility, and Relative work content times of parts produced.

4. Product Flexibility- It refers to ability to changeover to a new set of products economically and quickly in response to the changing market requirements. The change over time includes the time for designing, planning, tooling, and featuring of new products introduced in the manufacturing line-up. It depends upon following factors: Relatedness of new part design with the existing part family, Off-line part program preparation, Machine flexibility.

5. Routing Flexibility- It can define as capacity to produce parts on alternative workstation in case of equipment breakdowns, tool failure, and other interruptions at any particular station. It helps in increasing throughput, in the presence of external changes such as product mix, engineering changes, or new product introductions. Following are the factors which decide routing flexibility: Similarity of parts in the mix, Similarity of workstations, Common tooling.

6. Volume Flexibility- It is the ability of the system to vary the production volumes of different products to accommodate changes in demand while remaining profitable. It can also be termed as capacity flexibility. Factors affecting the volume flexibility are: Level of manual labor performing production, Amount invested in capital equipment.

7. Expansion Flexibility- It is defined as the ease with which the system can be expanded to foster total production volume. Expansion flexibility depends on following factors: Cost incurred in adding new workstations and trained workers, Easiness in expansion of layout, Type of part handling system used, Since flexibility is inversely proportional to the sensitivity to change, a measure of flexibility must quantify the term “penalty of change (POC)”, which is defined as follows: ***POC = penalty x probability*** Here, penalty is equal to the amount up to which the system is penalized for changes made against the system constraints, with the given probability. Lower the value of POC obtained, higher will be the flexibility of the system.

III. Key issues in FMS

Various key issues are identified in FMS studying the related literature and are compiled 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 underutilization 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 work piece transport system
9	Minimization of make span
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
14	Minimization of the total (weighted) tardiness
15	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, Rapid CIM, 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 recognized 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 minimize 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 types and application area	Methodology used	Key findings
1	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.
2	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	Presents an integer Programming formulation of scheduling in FMS. Based on

			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.	algorithms for each decision stage an optimum schedule is Constructed. Can work for both online and offline scheduling.
3	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 up to 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.
4	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.
5	Mathematical Modeling 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.
6	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.
7	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 generalized shortcomings of KBS

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 technique	Results	Reference
1	Petri nets (PNs)	Works as a powerful tool to formalize rules for allocating and dislocating the zones in AGVS.	Tamini et al (2012)
2	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)
3	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)
4	Genetic Algorithm	This algorithm determines the job sequence while keeping in view its interaction with Operation machine allocation.	Tiwari et al., (2007)
5	Particle Swarm Optimization	An efficient mathematical tool for solving Machine loading problem in FMS.	Ponnambalam and Kiat (2008)
6	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)
7	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)
8	Artificial Intelligence (AI) and Fuzzy Logic	Helps in analyzing 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)
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.

Table 6: Performance measures of FMS

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

CASE 2: 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 labor from 34 to 16 (for the same level of daily output).
5. The overall increase in productivity is 113 per cent.
6. The total labor cost per pair of shoes has reduced by 50 per cent.
7. There is less work-in-process.
8. The staff has been re- and multi-skilled and is 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.

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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