



FMS: State of the Art and Current Issues

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Abstract

The paper is based on the planning phase for manufacturing environment. Since the parts are operated at various operational conditions, the flexible manufacturing system due to its inherent flexibility will take care of the variation in operational conditions to give the desired output. The struggle for higher quality, lower cost and shorter response time always pre-dominates any competitive industry. Consequently, manufacturing system become more complex with a larger set of uncertainties. Thus, FMS is the emerging requirement along with its components such as, automated guided vehicles and automated storage and retrieval system which play a more proactive role. In this paper we developed a conceptual model for the integration of AGVs and ASRS with FMS.

1. Introduction

During recent years, the manufacturing organizations are facing many unpredictable market changes such as shortened product life cycles, technological advancement, intense pressure from competitors, and ever growing customers' expectation for high quality products at a lower cost. The market conditions are becoming more dynamic and more customers driven. The manufacturing performance is no longer driven by the product price; instead other competitive factors such as flexibility, quality, and delivery have become equally important. In today's competitive global market, for their survival, the manufacturing companies need to be flexible, adaptive, responsive to changes and be able to produce a variety of products in a short time at a lower cost. So, manufacturing flexibility is the most sought after property of the modern production systems and such type of flexibility can be attained through the adaptation and implementation of Flexible Manufacturing System (FMS). FMS can respond quickly and smoothly to unexpected changes in the market.

Implementation of FMS or any sub-system of FMS, in a FMS environment is one of the expensive and complex problems of an organization. In this concern the review is being done on flexibility, manufacturing flexibility, flexible manufacturing system, AGVs, AS/RS, buffers, performance measures, simulations, optimization techniques, system configuration etc.

2. Flexibility

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 system, which accommodates the ability to cope with customers' preference changes. Conversely, Sethi and Sethi (1990), Hyun and Ahn (1992) recognize flexibility as a multi-dimensional concept within the manufacturing functions and can be either reactive or proactive in nature. The reactive nature of flexibility deals with environmental uncertainty, both internal and external, faced by an organization, 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).

3. Manufacturing Flexibility

There are number of manufacturing flexibility reported in literature. 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. Sethi and Sethi (1990) proposes eleven types of flexibility adding three more that is material handling, program and market flexibility to this list of Browne et al. (1984). Koste and Malhotra (1999) presents definition often types of flexibility namely; machine flexibility, labor flexibility, material handling flexibility, routing flexibility, operation flexibility, expansion flexibility, volume flexibility, mix flexibility, new product flexibility, and modification flexibility. Braglia and Petroni (2000) presents an empirical study to classify different types of flexibility that is machine flexibility, routing flexibility, process flexibility, product flexibility, volume flexibility, expansion flexibility, and layout flexibility. From the above review we observe that there are numerous types of manufacturing flexibility addressed in the literature. This study concentrates on machine, routing and sequencing flexibility.

3.1 Machine flexibility

Wadhwa and Rao (2000) observe that the flexibility of different systems might be measured relatively. One possible measure of this form of flexibility could be the time taken to set up the machine to perform some operation on a different part type. Sethi and Sethi (1990) point to "numerical control, easily accessible programs, automatic tool changing ability, sophisticated part loading devices, size of the tool magazine, standardized tools, number of axes, etc." as sources of machine flexibility. According to Barad et al. (2003) machine flexibility is the most fundamental flexibility type. It is easily grasped as a concept and easily measured on range and response dimension. On the range dimension machine flexibility is measured as the set of different tasks it is capable of performing. On the response dimension it is measured in terms of the duration of its preparation tasks (setup). These may be related to the time needed to change tools in a tool magazine, the positioning time of a tool, etc. We have chosen to concentrate on the set of different task the machine is capable of performing for machine flexibility.

3.2 Routing Flexibility

As defined in Browne et al. (1984) routing flexibility is exhibited when machines break down. It provides the reduction in lead-time and is given by the fractional decrease in the total job makespan using alternative routes. Nagarur (1992) develops mathematical models and measures of routing, and machine flexibility. Wadhwa et al. (1998), shows that the makespan performance deteriorates with an increase in decision delays and the deterioration is higher at higher levels of routing flexibility. That means, while in general it is advantageous to have more

flexibility, the advantage of having more flexibility decreases with an increase in sequencing decision delays. Zhao et al. (2001) considers genetic algorithm to the scheduling of FMSs with multiple routes. Barad et al. (2003), states that routing flexibility is the capability of processing a part through varying routes. For a given number of machines in the system routing flexibility will increase with the individual versatility of the machines in the set. The rationale of routing flexibility is to cope with short term disturbances, such as breakdowns and changes in requirements by enabling material handling, flexible transporting network and on-line control Routing decisions involve selecting the routes that should be followed by each part in the production mix to maximize use of workstation resources.

3.3 Sequencing Flexibility

Although there is a vast literature on the job scheduling and the material-handling devices dispatching and routing for an AGV, but there are few researchers that consider explicitly the simultaneous scheduling of jobs and vehicles. Jaikumar and Solomon (1990) study a manufacturing system integrated with a central warehouse by means of AGVS. Their primary objective is to maximize the utilization of machines. Their secondary objective is to minimize the total travel time and therefore to minimize the fleet size. They proposed a polynomial time machine sequencing algorithm. Lacomme et al. (2005) addresses the scheduling problem in automated manufacturing environments, they concentrates in particular on the job-input sequencing and vehicle dispatching problems in a manufacturing environment using a single-vehicle automated guided vehicle system. The problem is solved using a branch-and-bound coupled with a discrete event simulation model. The branch-and-bound focuses on the job-input sequencing problem to determine the order in which the jobs enter the manufacturing system. A benchmark test is performed to investigate the system performances and the makespan depending on the job input sequencing, the vehicle and machine dispatching.

4. Flexible Manufacturing System

A Flexible Manufacturing System (FMS) is a highly automated system that manufactures parts Sethi (1990). One of the first approach to the production-planning problem in FMSs has been proposed by Stecke (1981). Paulli (1985) addresses the scheduling problem by proposing a hierarchal algorithm based on the similarities with the job shop-scheduling problem. It minimizes the makespan of a set of jobs in an FMS in which operations can be performed by more than one machine. The role of flexibility can be viewed as one that provides alternative decision solutions to certain discrete events, which the system should evolve. Wadhwa and Browne (1990) refer these events as decision points. Depending on the type of flexibility present in the manufacturing system, decision point provides opportunity for controlling the direction in which the system should evolve. Decision choices are typically exercised using control strategy, which manifest themselves as sequencing, dispatching and/or queue selection rules. Roy et al. (2001) proposes multi agent platform to take care of dynamic shop floor control problems in real-time. Sarma et al. (2002) develops a modeling framework that addresses the machine-loading problem of FMSs. Venkata and Manukid (2008) proposed a methodology based on a combinatorial mathematics-based decision-making method for the evaluation of alternative flexible manufacturing systems. The methodology is developed to judge the relative merits of different flexible manufacturing systems for the industrial

application considered. Several stochastic modeling methods have been applied to FMS reliability and performance.

5. Automated Guided Vehicles (AGV)

Since the development of the first Automated Guided Vehicles in the early 1950s, rapid progress has been witnessed in both research and applications of AGVs. AGVs are now found in all types of industries, with the only restrictions on their use mainly resulting from the dimensions of the goods to be transported or spatial considerations. Many applications of AGVs are technically feasible, but the purchase and implementation of such systems is usually based on economic considerations. Where as the AGVs have been found to reduce the damage to inventory, make production scheduling more flexible, and increases the performance. Much research has been done to analyze the performance and increase the efficiency of the AGVs. Performance of the AGVs are measured in many ways by different researchers Qiu and Hsu (2002) analyzed the efficiency in terms of the distance traversed and the time requirement for AGVs to complete all pickup and drop-off (or P/D for short) jobs. Klien and Kim (1996) compared single and multi-attribute dispatching rules are for selected performance measures such as queue length and load waiting time in each department, vehicle travel time, and job completion time. The superiority of the multi-attribute dispatching rules is demonstrated for these measures. There are many factors that affect the efficiency of an AGV system including how vehicles are routed and schedules. Taghaboni and Tanchoco (1995) used a simulation technique to study the effectiveness of a new dynamic approach to AGV routing. But, the control of AGVs in FMS is a challenging problem.

5.1 Controlling of AGVs

An AGV is a driverless vehicle usually controlled by an on board computer, and is able to carry workpieces rapidly among the workstations following guidepath loops. Communication with the central computer is usually established with dedicated wiring in the floor. Automated material handling systems, though more flexible and capable than their counterpart (non-computer controlled systems), do pose more serious and challenging operational control problems.

5.2 Scheduling and Routing of AGVs

Scheduling of AGVs aims to dispatch a set of AGVs to pick up the jobs from a centralized load/unload station and dispatch them to different workstations according to some priority. Certain goals are kept in mind while deciding the scheduling of AGVs. These goals are related to resources such as minimizing the number of vehicles while maintaining the system throughput or minimizing the total travel time of all vehicles Akturk and Yilmaz (1996). Routing of AGVs involves finding a suitable route, e.g., shortest distance path, shortest time path or minimal energy path for every vehicle from its origin to its destination based on current situation.

For solving scheduling and routing problems of AGVs, many algorithms have been suggested in the literature, Qiu et al. (2002) conducted a detailed survey of such algorithms and suggested that the existing work can be classified into four general categories:

- Algorithms for general path topology
- Path layout optimization
- Algorithms for specific path topologies

- Dedicated scheduling algorithms.

Works in the first category usually treat the problem as a graph theory problem and use approaches such as shortest path algorithm to get an optimal route. Optimization techniques such as integer programming have been used for path network design in which the routing control is generally simple. Algorithms for path networks are restricted to specific topologies such as single-loop, multi-loops, meshes, etc., and these are developed to decide the route and control of AGVs. Raj et al. (2007) have been discussed the contributions made by different authors in the development of AGV scheduling algorithms.

6. Automated Storage and Retrieval System (AS/RS)

Automated Storage and Retrieval Systems refers to a fully automated material handling system controlled by computers that enable all the operations which are unloading goods from carrier, to the loading of goods for shipment automatically. Although AS/RS have been the subject of extensive research, their performance under different types of demand remains relatively unexplored. Much of the work is carried out by many researchers. Hur and Nam (2006) derived several performance measures and include the expected number of commands in the system, the expected waiting time, the probability that an arbitrary command cannot enter the system (the ‘blocking probability’) and the utilization of the storage/retrieval machine. Performance of flow-rack automated storage and retrieval system configurations investigated by Sari et al. (2007). They considered a large mix of different product types, which has not been studied in the literature. Specifically, they derives expected retrieval time models by analyzing the impact of pickup/delivery stations and restoring conveyor locations based on randomized storage and retrieval. Shunji and Mituhiko (2008) discussed the routing problem for unit-load AS/RS with separate input and output points is considered under the shared storage policy. The problem is to find an optimal travel route of a storage and retrieval machine to process given storage and retrieval requests so that the total travel time is minimized. Gonzalo and Carlos (2008) introduced a Petri net-based approach for scheduling manufacturing systems with blocking. The modeling of the job routings and the resource and blocking constraints is carried out with the Petri net formalism due to their capability of representing dynamic, concurrent discrete-event dynamic systems. In addition Petri nets can detect deadlocks typically found in systems with blocking constraints. They concenter makespan time is the optimization criterion.

7. Performance Measures

Performance measures are used to assess accountability and make decisions. It may be difficult to determine whether the reported performance measures are the most relevant measures of the achievement of a goal or objective. Performance information provides data about the achievement of goals and objectives, but does not provide the information needed to assess whether the goals and objectives of the organization are the most appropriate ones and the ones that most clearly reflect the values of the goal. In order to measure anything we need to understand its dimension and the metrics or measures along these dimensions. From the literature we will consider makespan, production rate, average machine utilization etc. as performance measures to study the performance of the system. The motivation for selecting makespan is that we believe it is not necessary that if the makespan improves then the machine utilization will also improve.

7.1 Makespan

To minimize the total time to require completing all of the jobs requires proper sequence of jobs. The benefit of minimizing the makespan is that parts spend less time in the shop. This decreases the cost of the carrying an inventory of unfinished parts on the shop floor. Also there is a decrease in the inventory of finished parts that are waiting for other parts to be processed. Wadhwa et al. (2008) studies the makespan performance of FMS under planning and control strategies with different routing flexibility.

7.2 Average Machine Utilization

Machine utilization increases as jobs arrive to be possessed more frequently. When the system is very lightly loaded, the faster machine tends to process all of the jobs arriving. As the system becomes more heavily loaded, less effective machines gradually take on more work, until a saturation point reached. The FMS is a crucial resource for the whole production system, as it can process parts as much as three times faster than ordinary job shops, due to its ability to comply with changes both in production mix and in lot size. However, the cost per hour of its machines is sensibly higher than the cost of machine of an ordinary job shop. As a consequence, the cell needs to be utilized as much as possible.

7.3 Productivity

Despite the widely proclaimed benefits of the FMS technology, industrial practitioners are still questioning if such a technology is economically justifiable since it usually consumes enormous investment dollars. Chen and Adam (1991) performed an extensive empirical study on 84 FMS project cases which reaffirmed FMS's positive impact on productivity, but found little evidence about quality improvement. To realize the expected benefits of an FMS, one must understand operational issues related to an FMS.

8. Simulation

Discrete event simulation is considered as powerful tool to help understand and manage complex manufacturing system. A system is defined as a collection of entities usually machines, materials, people that act and interact towards the accomplishment of some logical end. Low and Kelton (1991). Mahmoodi et al. (1990) used computer simulation to test scheduling rule under various levels of shop load. Similarly Mohammad and Wadhwa (2005) evaluated the performance evaluation of partial FMS with the help of simulation. Wadhwa et al. (2008) studied the performance of FMS under planning and control strategies with the help of simulation. They developed a simulation model of a manufacturing system consisting of six machine and six parts.

The problem of simultaneous scheduling of machines and vehicles in flexible manufacturing systems is addressed by Deroussi et al. (2008). They consider the transportation aspect as an integral part of the optimization process. To deal with this problem, they described three different metaheuristics: iterated local search, simulated annealing and their hybridisation. Computational results are presented for a benchmark of 40 literature instances.

9. Optimization techniques

An analytical modeling strategy as the screening device for use prior to the simulation phase in the design of zone control automated guided vehicle systems (AGVS) is proposed by Charles (1990). This is done through a process which specifically evaluates the system operating dynamics associated with vehicle fleet size, guidepath layout, workstation storage capacity, routing, and, to a less precise extent, vehicle dispatching. The objective of the analytical model is to reduce the extent of simulation modeling necessary to design a zone-control AGVS for a given materials-handling workload.

Chang and Tanchoco (1991) presents an efficient algorithm for finding conflict-free shortest-time routes for automated guided vehicles moving in a bidirectional flow path network. The proposed algorithm is based on Dijkstra's shortest-path method.

Qiu et. al. (2002) first considers the emerging problems of AGV scheduling and routing. And then differentiates it from several related problems and classifies major existing algorithms for the problem.

10. System configurations

There are number of system configurations considered by various researchers. Sabuncuoglu and Lahmar, (2003) have considered a system composed of six multi-purpose machines and a central buffer area. The system comprises a loading/unloading station that contains a central buffer storage area of finite capacity. Each machine has an input and output buffers of finite capacity. Chan, (2004) has studied the impact of operational flexibility and dispatching rules on the performance of FMS. He considered FMS consisting of twelve machines having input buffers of finite capacity. There was common buffer of infinite capacity to take care of blocking of the system. Mohammed (2007) considered six machines to study the performance of flexible manufacturing system in computer integrated manufacturing system context.

11. Conceptual Model of FMS

The efficient application of AGVs in a fully integrated FMS will help industries to face the global and local competition with higher degree of confidence. The need for automated material handling system evolved in response to the problems faced by traditional industrial automation. However, it is essential to integrate AGVs in manufacturing system before the design of a FMS. Moreover the component AS/RS is also to be integrated with FMS for better scheduling of AGVs in the system. The integration between FMS and AS/RS is shown in the Figure 1. The figure shows the flow of parts between different components of an FMS. Parts are selected from the AS/RS through part selection module and an AGV is assigned to carry the selected part. The AGV pick the part from AS/RS and loads on the machine palate. Then the AGV c.carries the processed parts from the machining center to AS/RS either for temporary storage or for shipment.

Figure 2 shows information flow, decision flow and material flow through the entire system. FMS can be viewed as a computer based control on the flow of decision, information, products and resources in any manufacturing system. Wadhwa and Browne (1990) emphasized a proper control on material flow processes involving the flow of entities such as jobs, resources and information through a system. Some of

these flows may be physical flows while the other may be logical flows from one state to another. For instance in FMS the jobs are processed which are physically flowing entities, the resources may be AGVs, the information may be the status of jobs and resources. Each entity flow requires a certain time. The design and control of a system determines the nature of this flow and hence the performance of the system.

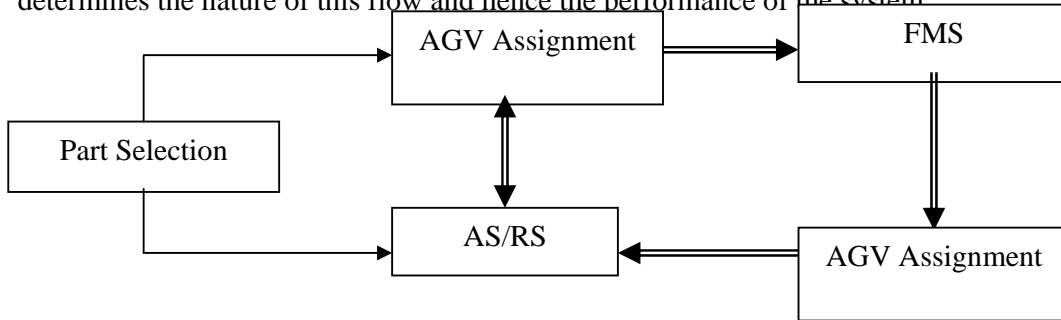


Figure 1. Integration between FMS and AS/RS with AGV

This formulation can be used for planning, routing and sequencing of parts collectively in FMS domain as opposed to the traditional part processing. The semi-finished parts will be sent to the AS/RS, while the machine buffers are blocked and then retrieved for further operations. Finished parts are also sent to the warehouse for storing and dispatching.

In literature often a distinction is made between planning, routing and sequencing. Typically the output of planning consists of material requirements in time. These requirements are passed to the lower control level. Production scheduling focuses on the allocation of finite resources to fulfill material requirement within individual production units. Scheduling should optimize certain goals that are deduced from organizational objectives, e.g. machine utilization, makespan time, set up cost etc.

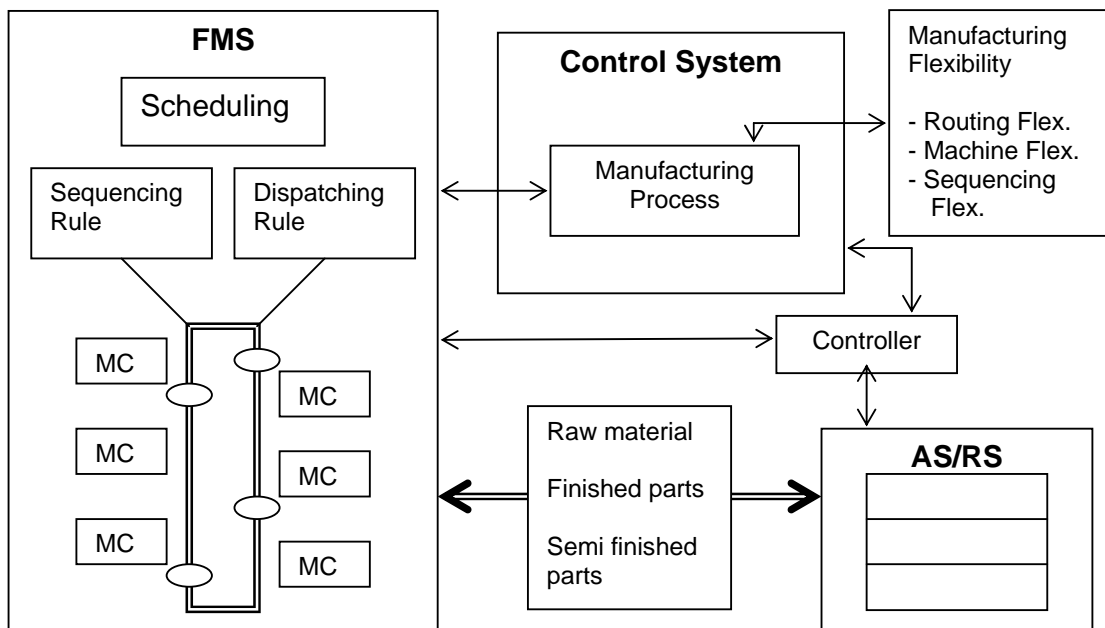


Figure 2 Conceptual Model

In the stochastic manufacturing environment, scheduling decisions incorporate the uncertainties of the system and are usually implemented through dispatching rules that assign priority indices to various jobs waiting at a machine where the job with highest priority is performed next. Depending on the level of scheduling, sequencing decision is made on the shop floor.

In order to fully address the planning, routing and sequencing of AGVs in FMS, the processing of the parts should be considered in unison. This research presents a model, which integrate AGVs and AS/RS in FMS domain. To the best of our knowledge, there is no study to date that integrates AGVs and AS/RS within FMS. We believe that investigating the effect of AGV flexibilities on the system performance is a necessary step towards the development of FMS.

12. Conclusions

Several approaches have been applied to solve the scheduling problems of AGVs in the FMS environment. But the approaches discussed in the literature are quite diverse in nature and it is very difficult to find out the optimal solution in real-life situations. Scheduling of AGVs is still a topic for research, as guide path, sequencing, routing and dispatching rules for the vehicles are being developed and improved. Besides these difficulties in the use of proper techniques in preparation of different algorithms, following shortcomings may be noted in the reported research work:

1. Most of the analytical models, which have been developed for AGV system, deal with small number of AGVs. As the number of AGVs increase, they present non-optimal results.
2. Very few authors consider multiple flexibilities in FMS under stochastic environment.
3. Mutual relationship between AGVs and other material handling devices like AS/RS has not been adequately explored.
4. Study of FMS under finite AS/RS capacity is also not adequately explored.
5. Generally, the layout and control problems of AGV system have been treated separately despite the fact that these issues are highly inter-related.

A large number of techniques have been suggested and developed for designing and control of AGVs in different situations by various researchers. But, countries like India, where labor is very cheap, hesitate to adopt these AGVs because of their costly and complex controlling techniques. Production managers generally argue that when human labor is cheaply and conveniently available then, why to go for such complicated material handling systems. Human labor is highly flexible and does not require special control algorithms. In such an environment, automated material handling systems, present a big barrier in the implementation of a complete FMS.

13. Discussion

The introduction of FMS should focus more on the efficient functioning of the firm as a whole rather than enhancement of operations in a particular department. At all levels it is acknowledged that AGV activities will be strategic significance for the firm. FMS provide and automated material handling is an expansive concept. It will provide solutions to manufacturing industries in order to survive in the competitive

global market. In addition various components like AGV and AS/RS need to be integrated into the FMS domain to provide a complete solution to the manufacturing industries.

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