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Analysis and Modeling of Flexible Manufacturing System

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ABSTRACT

Analysis and modeling of flexible manufacturing system (FMS) consists of scheduling of the system and optimization of FMS objectives. Flexible manufacturing system (FMS) scheduling problems become extremely complex when it comes to accommodate frequent variations in the part designs of incoming jobs. This research focuses on scheduling of variety of incoming jobs into the system efficiently and maximizing system utilization and throughput of system where machines are equipped with different tools and tool magazines but multiple machines can be assigned to single operation. Jobs have been scheduled according to shortest processing time (SPT) rule. Shortest processing time (SPT) scheduling rule is simple, fast, and generally a superior rule in terms of minimizing completion time through the system, minimizing the average number of jobs in the system, usually lower in-process inventories (less shop congestion) and downstream idle time (higher resource utilization). Simulation is better than experiment with the real world system because the system as yet does not exist and experimentation with the system is expensive, too time consuming, too dangerous. In this research, Taguchi philosophy and genetic algorithm have been used for optimization. Genetic algorithm (GA) approach is one of the most efficient algorithms that aim at converging and giving optimal solution in a shorter time. Therefore, in this work, a suitable fitness function is designed to generate optimum values of factors affecting FMS objectives (maximization of system utilization and maximization of throughput of system by Genetic Algorithm (GA) approach.

INTRODUCTION

In today's competitive global market, manufacturers have to modify their operations to ensure a better and faster response to needs of customers. The primary goal of any manufacturing industry is to achieve a high level of productivity and flexibility which can only be done in a computer integrated manufacturing environment. A flexible manufacturing system (FMS) is an integrated computer-controlled configuration in which there is some amount of flexibility that allows the system to react in the case of changes, whether predicted or unpredicted. FMS consists of three main systems. The work machines which are often automated CNC machines are connected by a material handling system(MHS) to optimize parts flow and the central control computer which controls material movements and machine flow. An FMS is modeled as a collection of workstations and automated guided vehicles (AGV). It is designed to increase system utilization and throughput of system and for reducing average work in process inventories and many factors affects both system utilization and throughput of system in this research system utilization and throughput of system has been optimized considering factors, which is discussed in next sections.

Flexible manufacturing system

A system that consists of numerous programmable machine tools connected by an automated material handling system and can produce an enormous variety of items. A FMS is large, complex, and expensive manufacturing in which Computers run all the machines that complete the process so that many industries cannot afford traditional FMS hence the trend is towards smaller versions call flexible manufacturing cells.

The primary goal of any manufacturing industry is to achieve a high level of throughput, flexibility and system utilization. System utilization computed as a percentage of the available hours (Number of the machines available for production multiplied by the number of working hours), it can be increased by changing in plant layout, by reducing transfer time between two stations and throughput, defined as the number of parts produced by the last machine of a manufacturing system over a given period of time. If the no of parts increases throughput also increases and also system utilization increases. Flexible manufacturing system consist following components Work station: work station consist computer numerical controlled machines that perform various operations on group of parts. FMS also includes other work station like inspection stations, assembly works and sheet metal presses.

In-line FMS layout

The machines and handling system are arranged in a straight line. In Figure 1(a) parts progress from one workstation to the next in a well-defined sequence with work always moves in one direction and with no back-flow. Similar operation to a transfer line except the system holds a greater variety of parts. Routing flexibility can be increased by installing a linear transfer system with bi-directional flow, as shown in Figure 1(b). Here a secondary handling system is provided at each workstation to separate most of the parts from the primary line. Material handling equipment used: in-line transfer system; conveyor system; or rail-guided vehicle system.

Open field FMS layout

It consists of multiple loops and ladders, and may include sidings also. This layout is generally used to process a large family of parts, although the number of different machine types may be limited, and parts are usually routed to different workstations depending on which one becomes available first.

Sequencing of jobs

The machines are arranged in a typical layout in a given FMS environment. The set of jobs are processed, those have different operations. According to their processing time, due dates these jobs scheduled to minimize make span. There are following rules selected from many existing priority scheduling rules to obtain optimum sequence. First-Come, First-Serve (FCFS) - the job which arrives first, enters service first (local rule). It is simple, fast, “fair” to the customer. And disadvantage of this rule is, it is least effective as measured by traditional performance measures as a long job makes others wait resulting in idle downstream resources and it ignores job due date and work remaining (downstream information).

Simulation modeling

“Simulation is the process of designing a model of real system and conducting experiments with this model for the purpose either of understanding the behaviors of the system or of evaluating various strategies (within the limits imposed by criterion or set of criteria) for the operation of the system”.

Genetic algorithm

Genetic Algorithms (GA) are direct, parallel, stochastic method for global search and optimization, which imitates the evolution of the living beings, described by Charles Darwin. GA is part of the group of Evolutionary Algorithms (EA). The evolutionary algorithms use the three main principles of the natural evolution: reproduction, natural selection and diversity of the species, maintained by the differences of each generation with the previous.

LITERATURE REVIEW

Scheduling of flexible manufacturing system

Han et al. [8] presents the setup and scheduling problem in a special type of flexible manufacturing system, where all the machines are of the same type, and tools are 'borrowed' between machines and from the tool crib as needed. In their model, there were limited tools. The objective of their model is to assign tools and jobs to machines so that the 'borrowing' of tools is minimized while maintaining a 'reasonable' workload balance. This is a nonlinear integer programming problem, and is computationally expensive. To solve the problem efficiently, the authors propose to decompose the problem. The two sub-problems each have the same objective as shown above. But the constraints are divided. The first problem finds an optimum tool allocation, given the job allocation. The second problem finds an optimal job allocation, given the tool allocation. Phrased in this way, both problems become linear. The first problem is a capacitated transportation problem, and the second is a generalized assignment problem. It is suggested to solve the two problems iteratively. The flexible manufacturing system investigated by Han et al., is special.

All machine tools are assumed identical. hence, the jobs remain at one machine, and the tools are moved to the machines as needed. Kimemia and Gershwin [9] report on an optimization problem that optimizes the routing of the parts in a flexible manufacturing system with the objective of maximizing the flow while keeping the average in-process inventory below a fixed level. Operation has different processing time for different machines in cell. Network of queues approach is used. The technique showed good results in simulation. Chen and Chung [10] evaluate loading formulations and routing policies in a simulated environment. Their main finding was that flexible manufacturing system is not superior to job shop if the routing flexibility is not utilized. Avonts and Van Wassenhove [11] present a unique procedure to select the part mix and the routing of parts in a FMS.

Hutchison et al. [12] provide a mathematical formulation of the random FMS scheduling problem, where random jobs arrive at the FMS. Their formulation is a static one in which N jobs are to be scheduled on M machines. The objective is to minimize the make span. They present a mixed integer 0-1 programming formulation.

Sarin and Chen [17] approach the loading problem from the viewpoint of machining cost. Computational methodologies to solve the integer programming formulation are proposed. Ram et al. [18] consider this problem as a discrete generalized network and present a branch and bound procedure. Co et al. [19] have suggested a four pass approach to solve the batching, loading and tool configuration problems of random FMS. In this approach, compatible jobs are batched together using integer programming. The solution is then improved upon in three further stages. Jaikumar and Van Wassenhove [20] propose a hierarchical planning and scheduling decomposition of FMS operation problems. In the first level, an aggregate production model is used. This is a linear programming model that chooses parts to be produced in a FMS during the next planning period.

Mathematical models in the literature are not efficient for reasonably sized problems. Further, they make simplifying assumptions which are not always valid in practice. The assumptions, of course, change with the models: some models assume automatic tool transport, some others will neglect delays caused by automated guided vehicles (AGV), still others will assume that tool magazines, pallets and fixtures do not constrain the models in any way, and so on. The models also take a static view of the shop floor.

Taguchi Philosophy

Taguchi technique is step by step approach to identify causal relationship between design factors and performance, which results to increased quality performance into processes and products at development as well as production level. Taguchi's technique used by a many industries to optimize their process design, through identifying independent and dependent variables with the help of identified factors and factor levels. Design of Experiment is an approach that facilitates analytically alters in number of inputs and output variables and examines the impact on response variables.

The main reason behind loss is not only non–conformance of products, rather loss increases further if one of the parameter deviates from specification (objective value/ reading/ degree).Quality should be implanted to products. The author also pointed that quality is best accomplished by increasing accuracy and the cost of quality should be calculated as a function of the divergence from the desired specifications. The robust design concept given by Taguchi can be realized with design of experiments.

Genetic Algorithm

A genetic algorithm is simply a search algorithm based on the observation that sexual reproduction, and the principle of survival of the fittest, enables biological species to adapt to their environment and compete effectively for its resources. While it is a relatively straight forward algorithm, the algorithm is an effective stochastic search method, proven as a robust problem solving technique [31] that produces better than random results [32].

METHODOLOGY

In this research methodology has been adopted as shown in figure 3.1, it starts with scheduling of job by using sequencing rules, and then according to scheduling a simulated small flexible manufacturing has been developed. The process variables those affects FMS objectives were designed by using Taguchi philosophy has been treated as input function for simulation model of FMS to generate the throughput and working hours for each machine per year and then system utilization and throughput has been optimized.

Sequencing of jobs on machines

In this research, four part types and five machines has been used. Processing time for each operation on different part types on different machines are as shown in table 1, in this research shortest processing time sequencing rule has been used for scheduling.

According to shortest processing time rule, the job with the shortest processing time is processed first and here each operation can processed on each machine with different processing time. Operation on part will be processed on that machine which machine takes less processing time for operation.

Modeling of flexible manufacturing system

In this research, five machines and four different part types has been used. As shown in figure 3.4 there are five machines, and in this model, simulation has been run for 1 year with 3820 hours warm up period which is calculate by using Welch's method. According to this method we obtained moving average of work in process then plot graph and at 3820 hours, this graph almost smooth.

Experiment and model development

Small manufacturing system modeled in this thesis is taken from [2]. Which consists five work stations and five machines and there is four parts produced by these machines. Every work station consist one machine. Here we have used four factors which affects the objective of FMS: these factors and there levels are as follows:

1. Distance preference (X1): distance preference means what distance between two stations. It can be smallest distance between two stations or largest distance between two stations or the distance in cyclic order as shown in figure. So the level of distance preferences is smallest distance(S), largest distance (L), cyclic distance (C).
2. Arrival (demand) time (min.) (X2): it's the time of arriving demand of parts. Here for in simulation three levels of demand time were assumed 10 min., 15min. and 20 min.

Optimization:

Optimization of system utilization and throughput has been done by genetic algorithm. Regression equation generate by taguchi philosophy for system utilization and throughput were used as fitness function for genetic algorithm and genetic algorithm gives the optimize value of factors for maximizing throughput and system utilization discuss in next chapter. Apart from the single objective functions considered for this problem, a combined function is also used to perform the multi-objective optimization for the FMS parameters.

RESULTS AND DISCUSSIONS

Scheduling

In this research, Shortest Processing Time (SPT) has been used. In Shortest Processing Time (SPT), the job which has the smallest operation time enters service first (local rule). SPT rule is simple, fast, generally a superior rule in terms of minimizing completion time through the system, minimizing the average number of jobs in the system, usually lower in-process inventories (less shop congestion) and downstream idle time (higher resource utilization), and usually lower average job tardiness. Scheduling of flexible manufacturing system according to SPT rule is as shown in table 5. According to this sequence make span is 12 min.

Experimental design

In this research L27 array has been used as discussed in previous chapter. When the process variable designed by using Taguchi philosophy has been treated as input function for simulation model of FMS to generate the working hours for every machine per year, and also gives the throughput of system. According to objective of FMS throughput and system utilization are larger is better. So using larger is better in L27 array in taguchi philosophy following plots and regression equations obtained.

Interaction plots for means between demand arrival demand time (B) and no. of carts (C) gives that as arrival demand time increases throughput of system decreases there is very less effect of no. of carts on system utilization according to this research in this problem.

CONCLUSIONS

In this research, we presented a simulation modeling and optimization of FMS objectives for evaluating the effect of factors such as demand arrival time, no. of carts used in system, velocity of carts, and distance preference between two stations. System utilization and throughput both are affected by these factors. System utilization and throughput is more affected by demand arrival time comparatively other three factors. Distance preference also affects throughput and system utilization. For both system utilization and throughput distance preference should be smallest. And as the demand arrival time increases both system utilization and throughput of system decreases. No of carts and velocity of carts are less affected.

REFERENCES

[1] Groover, M. P., (2012), Fundamentals of modern manufacturing, materials, processes, and systems, Edition: 4, Publisher: John Wiley & Sons, pp. 935

[2] Groover, M. P., (2010) "Automation, Production Systems and Computer Integrated Manufacturing", Edition: 3,

Pearson Education. pp. 235
[3] Avonts, L.H. and Wassenhove, L.N., (2009), the part mix and routing mix problem in FMS: a coupling between an LP model and a closed queuing network. International Journal of Production Research, Vol. 26, pp. 1891-1902.
[4] Akella, R., Choong, Y., and Gershwin, S.B., (1998), Performance of hierarchical production scheduling policy. IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 7, pp. 215-217.
[5] Barr, A.B., and Feigenbaum, E.A., (2008), The Handbook of Artificial Intelligence, Vol. 1, pp. 343
[6] C.B. and Mize, J.H., (2009), an object-oriented framework for operating flexible manufacturing systems. Proceedings: International Conference on Object-Oriented Manufacturing Systems, pp. 346-351. 32
[7] Bensana, E., Bel, G., and Dubois, D., (2010), OPAL: A multi-knowledge-based system for industrial job-shop scheduling. International Journal of Production Research, Vol. 26, pp. 795-819.
[8] Berrada, M., and Stecke, K.E., (2011), A branch and bound approach for machine load balancing in flexible manufacturing systems. Management Science, Vol. 32, pp. 1316-1335.
[9] Bourne, D.A., and Fox, M.S., (2012), Autonomous manufacturing: automating the job-shop. IEEE Computer, Vol. 17, pp. 76-86.
[10] Gershwin, S.B., (2010), Hierarchical flow control: a framework for scheduling and planning discrete events in manufacturing systems. Proceedings of the IEEE, Vol. 77, pp. 195-209.
[11] Chen, Y.J., and Askin, R.G., (2013), A multiobjective evaluation of flexible manufacturing system loading heuristics. International Journal of Production Research, Vol. 28, pp. 895-911.
[12] Avonts, L.H. and Wassenhove, L.N., (2010), the part mix and routing mix problem in FMS: a coupling between an LP model and a closed queuing network. International Journal of Production Research, Vol. 26, pp. 1891-1902.