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Analysis and Modelling of Flexible Manufacturing System

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Abstract - *Analysis and modelling 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). 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.*

Key Words:**FMS, Flexibility, Shortest Processing Time, Taguchi philosophy, FMS Factors , etc.**

1. INTRODUCTION

According to Stecke (1983) [1], an FMS is characterized as "an integrated, computer controlled complex arrangement of automated material-handling devices and numerically controlled (NC) machine tools that can simultaneously process medium-sized volumes of a variety of part types" 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. Today two or more CNC machines are considered a Flexible Manufacturing Cell (FMC), and two or more cells are considered a Flexible Manufacturing System (FMS).

Flexible manufacturing system consists these components (i) Work station (ii) Automated Material Handling and Storage system (iii) Primary handling system (iv) Secondary handling system (v) Computer Control System:

The different types of flexibility that are exhibited by manufacturing systems are given by (i) Machine Flexibility (ii) Production Flexibility (iii) Mix Flexibility (iv) Product Flexibility (v) Routing Flexibility (vi) Volume Flexibility (vii) Expansion Flexibility.

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

Stecke (1983) gave the first mathematical formula for grouping in FMS loading, as non linear 0-1 mixed integer programs (MIPs). A branch-and-bound algorithm was proposed by Berrada and Stecke (1986) [2] in order to balance the workloads on various machines. Avonts et al.(1988) [3] proposed a bi-standard target for the loading problem, i.e., equilibrating workloads and reducing visits to the workstations. Shanker and Srinivasulu (1989) [4] approached the machine-loading problem in a random FMS with the bi-standard target of meeting the finishing times of the jobs and equilibrating the workload amongst the machining centres. Swarnkar and Tiwari (2009) [5] approached the loading problem of a FMS having the bi-standard objectives of minimizing the system unbalance and maximizing the throughput, using a hybrid algorithm running on the principles of tabu search and simulated annealing (SA).

2. METHODOLOGY

The five steps, presented by Groover et al. (2010) [6], used to study and implement the operation are described as follows: Step1: Problem formulation. Step2: System description and modelling approach. Step 3: Building and re-building a model. Step 4: Verification and validation. Step 5: Model input and output.

After conducting several simulations‟ runs, the bottlenecks could be observed. Then, alternative scenarios are tested to determine the impact of them on the system. A further analysis is conducted using Opt Quest – one of simulation optimizer from ARENA software.

In this research methodology has been adopted as shown in figure 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 as discussed below

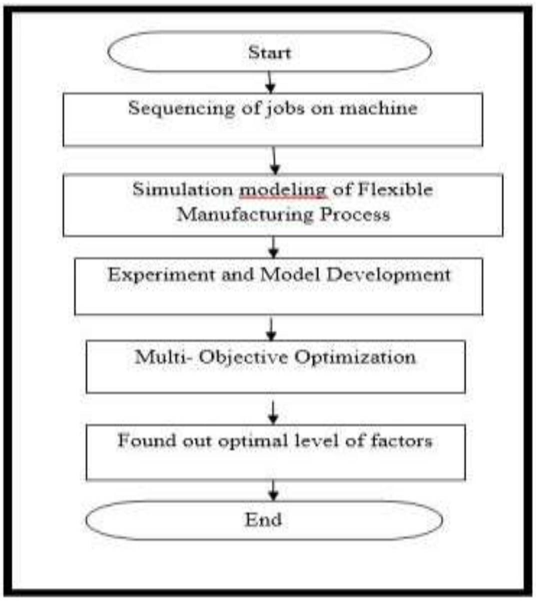

Figure 1: Flowchart of analysis of FMS

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.

Table 1: Processing time of each operation on each machine (min.)

Part/Machine	Operation	M/C 1	M/C 2	M/C 3	M/C 4	M/C 5
P_1 (n_1=3)	011	2	5	4	1	2
	012	5	4	5	7	5
	013	4	5	5	4	5
P_2(n_2=3)	021	2	5	4	7	8
	022	5	6	9	8	5
	023	4	5	4	5	5
P_3(n_3=4)	031	9	8	6	7	9
	032	6	1	2	5	4
	033	2	5	4	2	4
	034	4	5	2	1	5
P_4(n_4=2)	041	1	5	2	4	12
	042	5	1	2	1	2

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. Sequencing of operation of jobs on machines is shown in Table 2.

Table 2: Sequencing of operation of jobs on machines.

M/Ck	Sequence of operation
M/C1	021-041-023
M/C2	012-042-032
M/C3	031
M/C4	011- 013-033-034
M/C5	022

For example operation O_{11} will be processed on machine 4 because machine 4 takes less processing time than other machine. Similarly for all operations of different jobs can be sequence on machine. Sequencing of operation of jobs on different machine is as shown in figure 2.

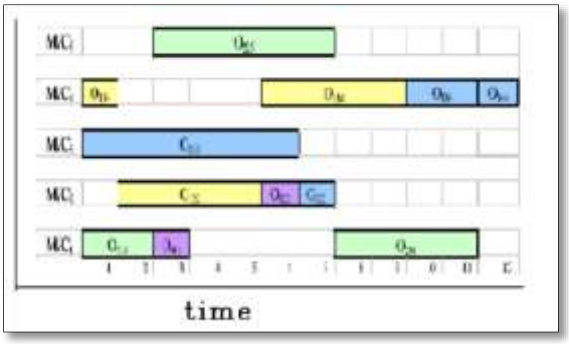

Figure 2: Gantt chart of operation on machines

Modelling 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 shown in Figure 3 graph at 3820 hours, which is almost smooth. It indicates the warm up period.

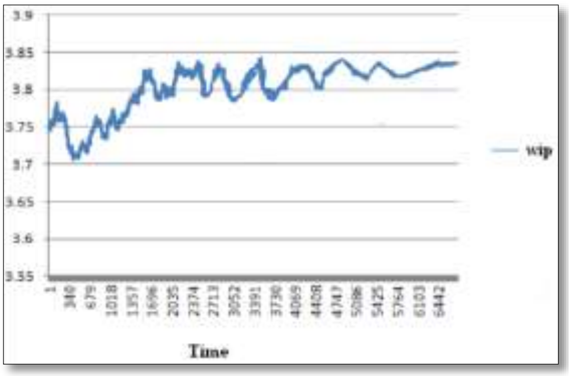

Figure 3: Graph between average work in process and time.

All the machines are scheduled as per the shortest processing time as shown in figure 4. Simulation model of small manufacturing system in figure 5.

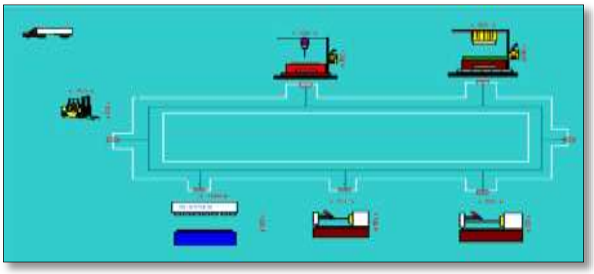

Figure 4: Small manufacturing system

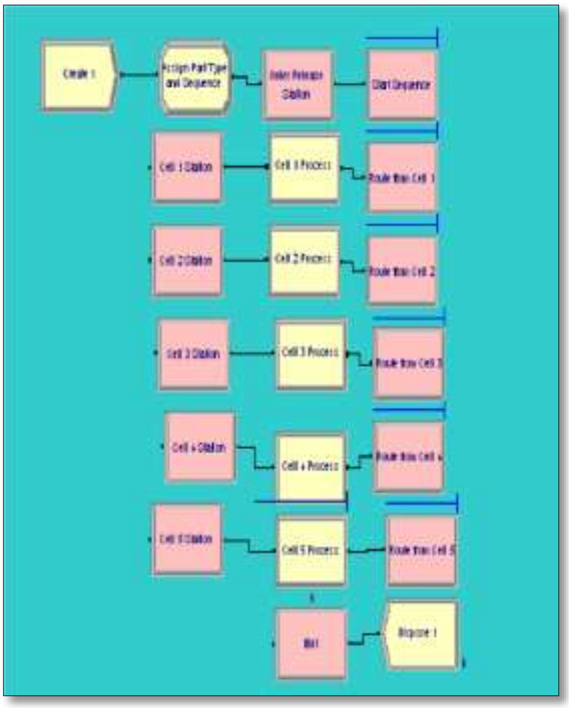

Figure 5: Simulation model of small manufacturing system

In this research we have used 5 work station and 5 machines those produces 4 part types having different operations. The processing time of operation is exponentially distributed as shown in table 1.

In this research, processing time taken as exponentially distributed. Arrival of demand also taken as exponentially distributed. It means that demand of part will come exponentially distributed here in this research, arrival demand time taken as 10, 15 and 20 minutes that means each demand come in 10, 15, 20 minutes and the parts will process according to given sequence.

3. EXPERIMENT AND MODEL DEVELOPMENT

From each factor at three level so the degree of freedom of each factor is 2, and three interaction of arrival demand time and other three factors (distance preferences, no. of carts, velocity of carts) so each interaction have 4 degree of freedom . Hence the total degree of freedom factors is 20. The degree of freedom of model should be equal to or greater than the total degree of freedom of factors. So in this research for precise results 'L_{27}'has been selected, and the process variables as 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, as shown in table 3 and table 4 respectively, and the system utilization of system should be carried out by following formula shown in equation 1.

$$System\ Utilization = \frac{\sum_{i=1}^{n} W_i}{n * 365 * 24}$$

Where i = No. of machine and n = Total no. of machine.

Here total no. of machine is five. System utilization for each treatment has been calculated by using above formula. Experimental design array for throughput and system utilization is shown in Table 3 and Table 4 respectively.

Table 3: Experimental design of L27 array for throughput.

Distance preference	Demand time	No. of Carts	Velocity of Carts	Throughput
Small	10	2	60	29586
Small	10	3	65	29733
Small	10	4	70	29552
Small	15	2	60	19463
Small	15	3	65	19586
Small	15	4	70	19812
Small	20	2	60	14870

Small	20	3	65	14778
Small	20	4	70	14976
Large	10	2	65	29373
Large	10	3	70	29284
Large	10	4	60	29380
Large	15	2	65	19844
Large	15	3	70	19623
Large	15	4	60	19749
Large	20	2	65	14595
Large	20	3	70	14670
Large	20	4	60	14594
Cyclical	10	2	70	29285
Cyclical	10	3	60	29595
Cyclical	10	4	65	29285
Cyclical	15	2	70	19875
Cyclical	15	3	60	19865
Cyclical	15	4	65	19770
Cyclical	20	2	70	14764
Cyclical	20	3	60	14732
Cyclical	20	4	65	14885

Table 4: Experimental design of L27 array for System utilization

Distance preference	Demand time	No. of Carts	Velocity of Carts	System utilization
Small	10	2	60	0.106313
Small	10	3	65	0.106346
Small	10	4	70	0.105746
Small	15	2	60	0.070139
Small	15	3	65	0.070316
Small	15	4	70	0.070486
Small	20	2	60	0.055483
Small	20	3	65	0.052751
Small	20	4	70	0.053747
Large	10	2	65	0.105842
Large	10	3	70	0.105249
Large	10	4	60	0.105111
Large	15	2	65	0.071236
Large	15	3	70	0.070445
Large	15	4	60	0.071466
Large	20	2	65	0.052381
Large	20	3	70	0.052368
Large	20	4	60	0.052429
Cyclical	10	2	70	0.10518
Cyclical	10	3	60	0.106638
Cyclical	10	4	65	0.105174
Cyclical	15	2	70	0.071295
Cyclical	15	3	60	0.071832
Cyclical	15	4	65	0.070563
Cyclical	20	2	70	0.052861
Cyclical	20	3	60	0.05335
Cyclical	20	4	65	0.054687

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. The function and the variable limits are given using following function. Equal weights are considered for all the responses in this multi-objective optimization problem. Hence W_1 and W_2 are equal to 0.5. The weighted moving average is given in equation 2.

$$Z_{Multi} = W_1 * \frac{Z_{system\ utilization}}{system\ utilization\ a_{max}} + W_z * \frac{Z_{throughput}}{Throughput_{max}} \quad (2)$$

Generally, when a Flexible Manufacturing System (FMS) is being planned, the objective is to design a system which will be efficient in the production of the entire range of parts. This cannot be achieved until the design, production planning, scheduling, and controlling stages work well. Depending on the required measure of scheduling performance, many different approaches to the scheduling problem can be generated. Scheduling methods can be classified into different approaches, such as combinatorial optimisation, artificial intelligence, simulation-based scheduling with dispatching rules, heuristics-oriented, and multi-criteria decision making. However, production scheduling in an FMS is usually very complicated, particularly in dynamic environments. Many manufacturing systems, therefore, need scheduling for dynamic and unpredictable conditions, so artificial intelligence and heuristic-based approaches have been considered in FMS scheduling.

The objective functions that are used to approach the loading problem in this dissertation are: Minimization of SU, Maximization of Throughput & A union of minimization of SU and the maximization of Throughput In order to minimize the complexities, the following assumptions are made when analyzing the FMS loading problem.

Proposed Methodology

Let us deliberate and evaluate the number of decision variables and constraints for a typical machine loading problem. Assuming, say,

Number of jobs (J) = 6

Number of operations for each job (O_j) = 2

Number of machines (M) = 4

Then,

Total number of decision variables = J*((M*O) + 1) = 54

Total number of constraints = J +M + M + J*O = 26

Thus, there can be a fairly large number of combinations in which operations of the part type can be assigned on the different machines while satisfying all the technological and capacity constraints. These operation–machines allocation combinations are evaluated using two common performance measures: system unbalance and throughput.

However, the values of system unbalance and throughput vary for each assigned job sequence, as some jobs may eliminated in each sequence since they do not satisfy the technological and capacity constraints. Hence a number of job sequences need to be evaluated to find the optimal job sequence, by considering the minimum SU and maximum throughput. Take for instance, a loading problem with 8 jobs.

Number of possible job sequences = 8! = 40320

The computational burden would be too high, and the possibility of finding an optimal solution extremely faint in such a situation.

Thus, while creating the proposed algorithm, the number of iterations was fixed, and could be changed if needed. The computational effort was significantly lessened, and the chance of finding an optimal solution was increased.

Proposed Algorithm

Step 1: Input the total number of available machines, jobs, batch sizes, tool slots on each machine, operations of all jobs (both essential and optional), and the processing time of each operation of every job.

Step 2: Input the number of iterations (n), where (i=1,….,n) (the number of job sequences to be generated).

Step 3: Get the initial sequence (i=1) and do the following:

First, load the essential operation on the machine if and only if the available machining time and available tool slots on the machine is greater than the time and the tool slots required by the essential operation ; otherwise, reject the job. Then, load the optional operation on the machine if and only if the available machining time and tool slots on the machine is greater than the time and the tool slots required by the optional operation on the basis of the machine having the maximum available time ; otherwise, reject the job.

Step 4: Terminate if the maximum number of iterations is reached (i=n). Otherwise, go to step 2.

JOB	BATCH SIZE	OPERATION NUMBER	MACHINE NUMBER	UNIT PROCESSING TIME	TOOL SLOTS NEEDED
1	15	1	4 2	10 12	2 2
2	10	1 2	1 3	20 35	1 2
3	12	1	1	22	3
4	9	1	3 2	25 25	1 1
5	16	1 2	4 2 3 1 4	30 25 27 16 16	2 1 2 1 1 1
6	11	1	2	21	3

4. RESULTS AND DISCUSSIONS

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 6. According to this sequence make span is 12 min.

Table 6: Sequencing of Operation on jobs

M/Ck	Sequence of operation
M/C1	O21-O41-O23
M/C2	O12-O42-O32
M/C3	O31
M/C4	O11- O13-O33-O34
M/C4	O22

In this research L_{27} 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 L_{27} array in taguchi philosophy following plots and regression equations obtained.

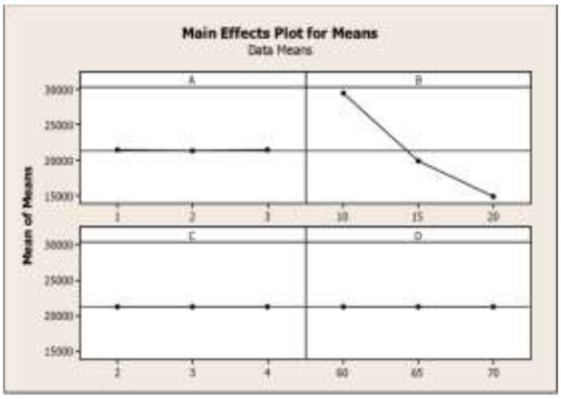

Figure 6 - Mean chart of the process

Main effect plot for means of throughput shows that distance preference should be at first level means distance preference should be smallest for this simulated flexible manufacturing system for maximizing throughput of system and throughput of system is maximum at demand time is 10 min. and no. of carts is 4 and velocity of cart is 65 feet/min.

5. 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.

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