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The Simulation Optimization of a Flexible Manufacturing System with Arena

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***Abstract*— Flexible manufacturing system and its analysis consists of scheduling of the system and optimisation of flexible manufacturing system objectives. Scheduling and scheduling problems of incoming jobs into the system efficiently, maximizing system utilization and throughput of system. Jobs have been scheduled according to dispatching rule of shortest processing time (SPT) rule. Simulation helps to develop the virtual manufacturing system which can help to analysis manufacturing system with real boundary conditions of the manufacturing and help to improve the efficiency, improve the design of manufacturing system and which is directly related to the production rate and productivity. Simulation analysis is giving the facility to analysis the real problem of FMS by using numerical based analysis. Taguchi concept and Genetic algorithm have been used for optimization of the flexible manufacturing system with scheduling. Genetic algorithm has been used for optimisation of process parameter of FMS for shorter time with comparison of Taguchi method. Therefore, in this work, a suitable fitness function is designed for optimum values of factors affecting FMS objectives and maximization of system utilization with maximization of throughput of system.**

Keywords*— *Flexible manufacturing system, Scheduling, Automated Guided Vehicle, Genetic algorithm, ARENA

I. INTRODUCTION

A flexible manufacturing system (FMS) consists of Numerically Controlled (NC) machine, a Material handling system (MHS), and a computer controlled system for integrating the NC machine and the MHS. Flexible Manufacturing System emerged as a powerful tool one due to its large flexibility, which is essential to stay competitive in this highly excellent environment. Flexible Manufacturing System is a complex system consisting components like machine equipment tool, material handling system (AGV), storage and retrieval system. FMS for timely transfer of jobs between the workstation and the decisions include the design of flow path layout, traffic control and shortest processing time dispatching rules [1].

Scheduling is the process of adding start and finish time information to the job order dictated in the sequencing process. Sequencing process in turn, is defined as getting the order in which jobs are to be run on a machine. The sequence thus obtained determines the schedule, since we assume each job is started on the machine as soon as the job has finished all predecessor operations and the machine has completed all earlier jobs in the sequence, Bensana et al. [2].

SPT (Shortest Processing Time) – Select the job having minimum processing time, enter service first and advantages of this sequencing 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).

Simulation analysis is used to study the various control strategies before one can suggest an optimum solution for the given problem, hence simulation is used as a decision support system for real time scheduling of flexible manufacturing systems and is found to be an effective in design and operation of an flexible manufacturing system.

Arena is based on the SIMAN simulation language. It can be used for simulation in manufacturing, supply chain management, logistics, storing and other processes. Arena ensures a high degree of flexibility, various facilities for models of any level of complexity Gershwin et. al. [3] although simulation analysis is limited in some aspects, its popularity as a decision making aid is increasing in direct relation to the capability and accessibility of today's high speed digital computers.

Genetic Algorithms are the adaptive heuristic search and optimization techniques that mimic the process of evaluation this heuristic is routinely used in computing and Artificial Intelligence to generate useful solutions to optimization to search problems following the principle of survival of the fittest using techniques inspired by natural evolution: mutation, selection, reproduction and recombination [4].

II. LITERATURE REVIEW

A. Scheduling of jobs/machines

The objective of this model is to assign the 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 it is computationally expensive. The two sub-problems each have the same objective 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 and both problems become linear [5].

Shirazi et al. [6] developed a model which describes a simulation – based intelligent decision support system (IDSS) for real time control of a flexible manufacturing system (FMS) with machine and tool flexibility. They build the system design around the theory of dynamic supervisory control based on a rule-based expert system. Jerald et al. [7] discussed about simultaneously scheduling of jobs, Automated Guided Vehicles, Artificial Storage and Retrieval System in an FMS environment using artificial immune system approach in 2009. They considered a large variety problem with multiple objectives like minimizing penalty cost, minimizing machine idle time and minimizing the distance travelled by the Storage and Retrieval System; Ponnambalam et al. [8] developed a particle swarm optimization (PSO) algorithm in 2008 to solve machine loading problem in flexible manufacturing system (FMS) with objectives including minimization of system unbalance and maximizing system throughput in the presence of machining time and tool slots constraints.

Chen and Chung [9] evaluated loading and unloading formulations and routing of the parts 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 et. al. [10] addressed the unique procedure to select the part mix and the routing of parts in a FMS. A LP model is used to select the part mix using cost differential from producing the part outside the FMS. The selected loading is then checked by a queuing model for utilization in an iterative manner. Hutchison et al. [11] provided a mathematical formulation of the random flexible manufacturing system scheduling problem, where random jobs arrive at the work station. Their formulation is a static one in which "n" jobs are to be scheduled on "m" machines.

B. Problem Description

Simulation and analysis of flexible manufacturing system (FMS) consists for scheduling of system and optimization of FMS is the main objectives of the research. Flexible manufacturing system scheduling problems are extremely complex when it comes to accommodate frequent variations in the part designs of incoming jobs in shop floor. Scheduling and scheduling related problems in the system will be efficiently, increase system utilization and throughput of system where machines are equipped with different tools and tool magazines but multiple machines can be assigned for single operation.

In this research work jobs have been scheduled according to dispatching rule for shortest processing time rule. Shortest processing time (SPT) dispatching 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 and downstream idle time which is directly related to the shop floor utilization which is directly related to the enchantment of production rate as reported in literature. Genetic algorithm have also used for optimization of flexible manufacturing system with scheduling to finding optimal solution for the FMS system.

III. METHODOLOGY

In this research methodology has been adopted as shown in Fig. (a), It starts with scheduling of job by using dispatching rules, and then according to scheduling a simulated small flexible manufacturing system has been developed. Anglani et al. [12] addressed about the process variables those affects FMS objectives were designed by using Taguchi Concept has been treated as input function for simulation model of FMS to generate the throughput and working hours for each machine per year.

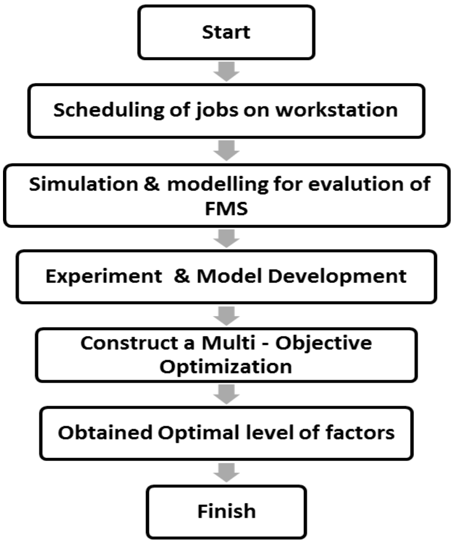

Fig. (a): Flow chart and analysis of FMS

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 3, in this research shortest processing time (SPT) dispatching rule has been used for scheduling.

TABLE – 1: Processing time of each operation on each machine (minutes)

Jobs/Machine	Operation	M/c 1	M/c 2	M/c 3	M/c 4	M/c 5
$J_1(n_1 = 3)$	O_{11}	2	5	4	1	2
	O_{12}	5	4	5	7	5
	O_{13}	4	5	5	4	5
$J_2(n_2 = 3)$	O_{21}	2	5	4	7	8
	O_{22}	5	6	9	8	5
	O_{23}	4	5	4	5	5
$J_3(n_3 = 4)$	O_{31}	9	8	6	7	9
	O_{32}	6	1	2	5	4
	O_{33}	2	5	4	2	4
	O_{34}	4	5	2	1	5
$J_4(n_4 = 2)$	O_{41}	1	5	2	4	12
	O_{42}	5	1	2	1	2

According to SPT rule, the job with having 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 [13].

TABLE – 2: Sequencing of operation on jobs at machines

M/C_n	Sequence of operation
M/C_1	O_{21} - O_{41} - O_{23}
M/C_2	O_{12} - O_{42} - O_{32}
M/C_3	O_{31}
M/C_4	O_{11} - O_{13} - O_{33} - O_{34}
M/C_5	O_{22}

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.

Simulation model for evaluation of FMS

In FMS, the Automated Guided Vehicle system (AGVs) is an excellent choice for MHS because of its automation of loading and unloading, flexibility in path movement, ease of modification of the guide-path network and computer control. AGVs can be used in two different ways – The first approach is to attach a part to the AGV that helps to execute all manufacturing processes by carrying the part from station to station. AGVs has been used for transfer parts from one station to other station and in Fig. (b) shows logical data module those has been used in simulation modeling .

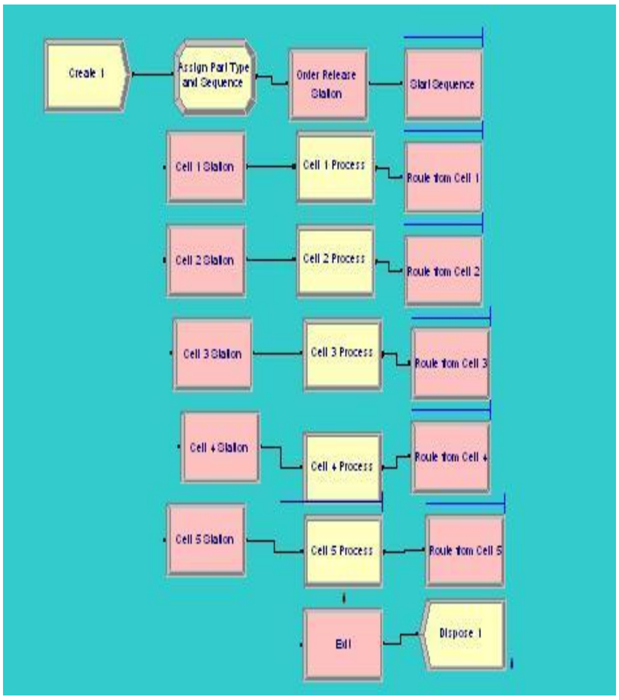

Fig. (b): Simulation model of small manufacturing system

In this work, 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.

A. Experiment and model development

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 6 and table 7 respectively, and the system utilization of system should be carried out by following formula –

$$\text{System Utilization} = \frac{\sum_{i=1}^{n} Wi}{n \times 24 \times 365}$$

Where i = Number of machine

n = Total number of machine

Here total number of machine is five. System utilization for each treatment has been calculated by using above formula.

B. Optimization

Optimization of system utilization and throughput has been done by genetic algorithm. Regression equation generate by taguchi concept for system utilization and throughput were used as fitness function for genetic algorithm and genetic algorithm gives the optimize value. We have taken w_1 & w_2 is equal to 0.5 because it is least value that function is not governed means process is not possible hence we taken w_1 & w_2 are equal to 0.5 [14].

$$Z_{\text{multi}} = w_1 \times Z_{\text{system utilization}} / \text{System utilization}_{\text{max.}} +$$

$$w_2 \times Z_{\text{throughput}} / \text{Throughput}_{\text{max}}$$

IV. 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..

A. Experimental and Design analysis

In this research L_{27} array has been used as discussed in this 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.

TABLE 3: Experimental design of L_{27} array for throughput

Distance preference	Demand time	No. of AGV's	Velocity of AGV's	Throughput
Small	10	2	60	30567
Small	10	3	65	30714
Small	10	4	70	30533
Small	15	2	60	18484
Small	15	3	65	18567
Small	15	4	70	18813
Small	20	2	60	15850
Small	20	3	65	15759
Small	20	4	70	15967
Large	10	2	65	28364
Large	10	3	70	30275
Large	10	4	60	30380
Large	15	2	65	18835
Large	15	3	70	18624
Large	15	4	60	18739
Large	20	2	65	15586
Large	20	3	70	15690
Large	20	4	60	15575
Cyclical	10	2	70	30276
Cyclical	10	3	60	30596
Cyclical	10	4	65	30264
Cyclical	15	2	70	18854
Cyclical	15	3	60	18846
Cyclical	15	4	65	18780
Cyclical	20	2	70	15795
Cyclical	20	3	60	15753
Cyclical	20	4	65	15865

TABLE 4: Experimental design of L_{27} array for System utilization

Distance preference	Demand time	No. of AGV's	Velocity of AGV's	System Utilization
Small	10	2	60	0.10534
Small	10	3	65	0.10535
Small	10	4	70	0.10577
Small	15	2	60	0.08142
Small	15	3	65	0.08042
Small	15	4	70	0.08048
Small	20	2	60	0.06547
Small	20	3	65	0.06278
Small	20	4	70	0.07373
Large	10	2	65	0.10865
Large	10	3	70	0.10526
Large	10	4	60	0.10456
Large	15	2	65	0.06523
Large	15	3	70	0.06039
Large	15	4	60	0.06235
Large	20	2	65	0.06285
Large	20	3	70	0.06326
Large	20	4	60	0.05256
Cyclical	10	2	70	0.10569
Cyclical	10	3	60	0.10676
Cyclical	10	4	65	0.10416
Cyclical	15	2	70	0.08239
Cyclical	15	3	60	0.08352
Cyclical	15	4	65	0.08045
Cyclical	20	2	70	0.06287
Cyclical	20	3	60	0.06345
Cyclical	20	4	65	0.06478

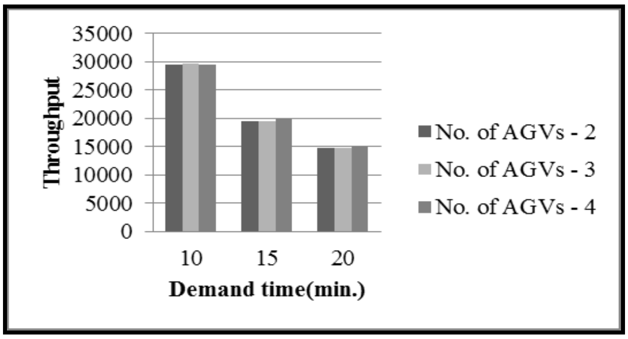

Fig. (c): Interaction plots between demand arrival time and no. of AGVs for throughput

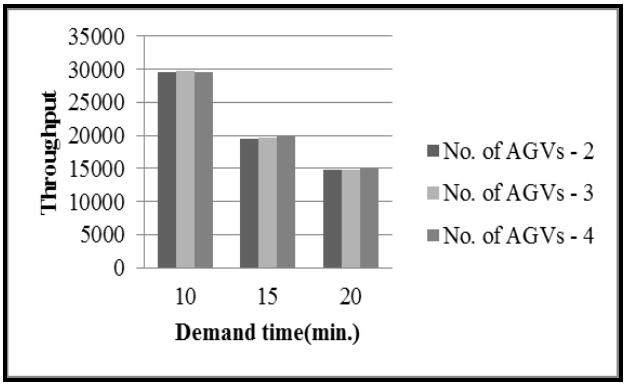

Fig. (d): Interaction plots between distance preference and demand arrival time for throughput

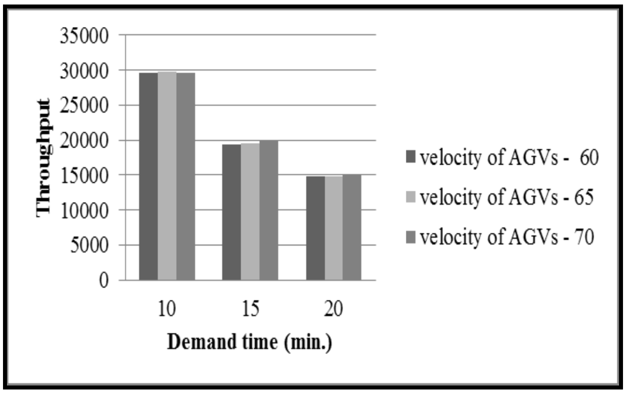

Fig. (e): Interaction plots between demand arrival time and velocity of AGVs for system throughput

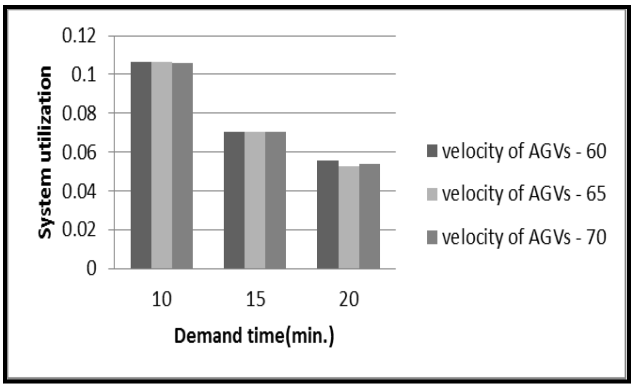

Fig. (f): Interaction plots between demand arrival time and velocity of AGVs for system utilization

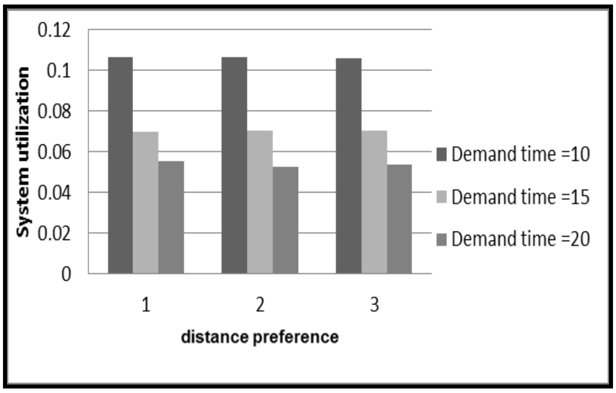

Fig. (g): Interaction plots between and distance preference and demand arrival time for system utilization

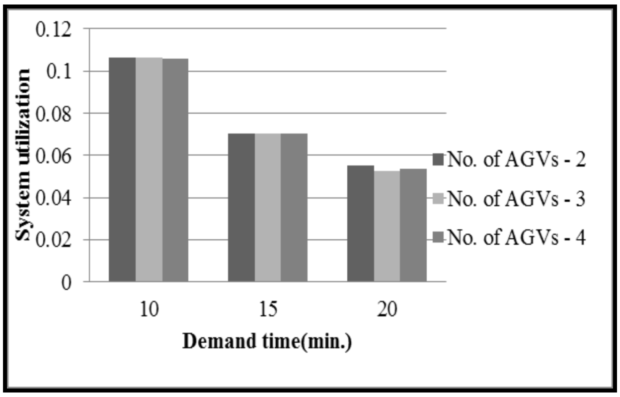

Fig. 4(h): Interaction plots between demand arrival time and velocity of AGVs for system utilization

TABLE 5: Response table for means for throughput

Level	I	II	III	IV
1	0.08681	0.10573	0.08675	0.08697
2	0.08628	0.08086	0.08659	0.08659
3	0.08684	0.06334	0.0676	0.08638
Delta	0.00065	0.06239	0.00018	0.00071
Rank	3	1	4	2

As shown in response table gives that demand time is more influencing factor than other factors. Than velocity of AGVs affects the system utilization and distance preference is very less influencing factor for system utilization.

TABLE 6: Response table for system utilization

Level	I	II	III	IV
1	21378	30457	22194	21319
2	21236	18732	23118	21318
3	21340	15761	22633	21315
Delta	20895	15670	38956	20233
Rank	2	1	3	4

B. Optimization

In this research, system throughput of system and system utilization both are optimized by genetic algorithm, using genetic algorithm following results obtained as shown in table 5 and table 6 respectively for maximum throughput.

Throughput = 43321 – 17 × distance preferences (X_1) – 1469 × arrival demand + 19 × number of AGVs (X_3) + 0.1 × velocity of AGVs (X_4)

TABLE 7: Factor and their level for maximizing throughput through genetic algorithm

Factors	Level	Value
Distance presence	Level 1	Smallest distance
Demand arrival time	Level 1	10 minutes
No. of AGVs	Level 3	4
Velocity of AGVs	-	69.384

Throughput obtained by value of above factor in simulation is 30013.

System utilization = 0.159 + 0.00001 × distance preferences (X_1) – 0.00534 × arrival demand time (X_2) – 0.00067 × number of AGVs (X_3) – 0.000060 × velocity of AGVs (X_4)

TABLE 8: Factor and their level for maximizing system utilization through genetic algorithm

Factors	Level	Value
Distance presence	Level 1	Smallest distance
Demand arrival time	Level 1	10 minutes
No. of AGVs	Level 3	4
Velocity of AGVs	-	61.396

System utilization obtained by value of above factor in simulation is 0.2081%.

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.

Using an above following combined function attained which is optimized by using genetic algorithm –
Z_{multi} = 0.5 × [1.49155 – 0.0000938× X(1) distance preferences – 0.049155 × X(2) arrival demand time + 0.0006566 × X(3) no. of carts + 0.0005628 × X(4) velocity of carts] – 0.5 × [1.4642 – 0.0005717×X(1) distance preferences – 0.049406 × X(2) arrival demand time + 19 × X(3) no. of carts + 0.0006390 × X(4) velocity of carts]

Table 9: Factor and their level for maximizing throughput and system utilization through genetic algorithm

Factors	Level	Value
Distance presence	Level 1	Smallest distance
Demand arrival time	Level 1	10 minutes
No. of AGVs	Level 3	4
Velocity of AGVs	-	61.396
Throughput	-	30019
System utilization	-	0.1081%

C. Conclusion

A simulation modeling and optimization of FMS objectives for evaluating the effect of factors such as demand arrival time, no. of AGVs, velocity of AGVs, and distance preference between two work stations used in system. System utilization and throughput both are affected by these factors. It is observed that from comparing the result maximum percentage of utilization is 10% against of throughput parameters. 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.

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