Volume 2, Issue 8 August 2016 ISSN NO: 2454 - 7514

North Asian International Research Journal Consortium

North Asian International Research Journal Of Science, Engineering and Information Technology

Welcome to NAIRJC

ISSN NO: 2454 -7514

North Asian International Research Journal of Science, Engineering & Information Technology is a research journal, published monthly in English, Hindi. All research papers submitted to the journal will be double-blind peer reviewed referred by members of the editorial board. Readers will include investigator in Universities, Research Institutes Government and Industry with research interest in the general subjects

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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.

Key word- ***Flexible manufacturing system, Simulation, Genetic Algorithm etc.***

1. 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.

1.1. 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. 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 is a computer controlled manufacturing system, in which numerically controlled machines are interconnected by a material handling system and a master computer controls both NC machines and material handling system."[1]

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.

Automated Material Handling and Storage system: Work parts and subassembly parts between the processing stations are transferred by various automated material handling systems. Many automated material handling devices are used in flexible manufacturing system like automated guided vehicle, conveyors, etc. there are two types of material handling system

Primary handling system - establishes the basic layout of the FMS and is responsible for moving work parts between stations in the system.

Secondary handling system - consists of transfer devices, automatic pallet changers, and similar mechanisms located at the workstations in the FMS.

Computer Control System: It is used to control the activities of the processing stations and the material handling system in the FMS.

1.2. Flexible manufacturing system layouts

Flexible manufacturing system has different layouts according to arrangement of machine and flow of parts. According to part flow and arrangement of machine, layout of flexible manufacturing system are discussed below

1.2.1. In-line FMS layout

The machines and handling system are arranged in a straight line. In Figure1 (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.

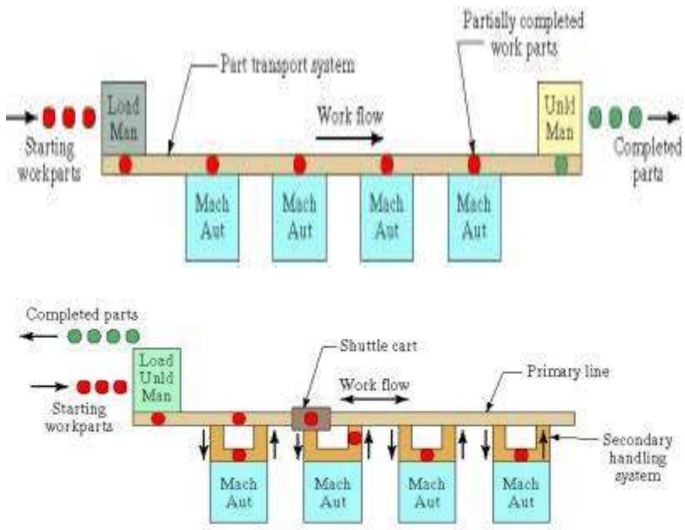

Figure 1 in line FMS layout

1.2.2. Loop FMS layout

Workstations are organized in a loop that is served by a looped parts handling system. In Figure 2, parts usually flow in one direction around the loop with the capability to stop and be transferred to any station.

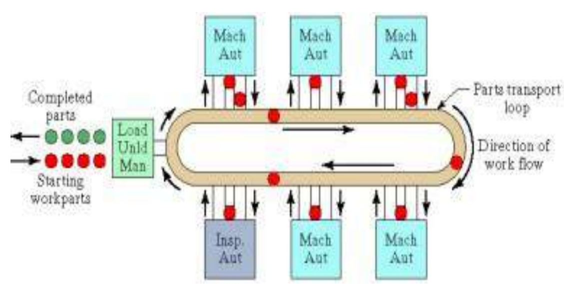

Figure 2: Loop FMS layout

Each station has secondary handling equipment so that part can be brought-to and transferred from the station work head to the material handling loop. Load/unload stations are usually located at one end of the loop.

1.2.3. Rectangular FMS layout

This arrangement allows for the return of pallets to the starting position in a straight line arrangement.

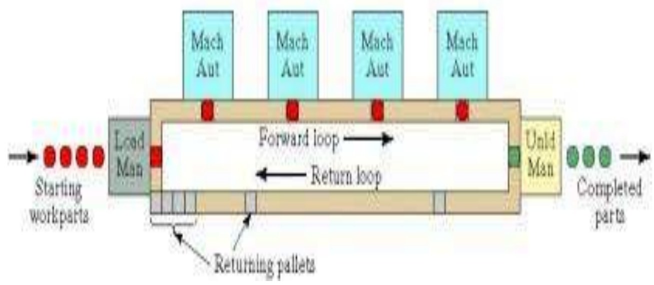

Figure 3: Rectangular FMS layout

1.3. 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).

Shortest Processing Time (SPT) - the job which has the smallest operation time enters service first (local rule). 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), and usually lower average job tardiness and disadvantages is, it ignores downstream, due date information, and long jobs wait (high job wait-time variance).

Earliest Due Date (EDD) - the job which has the nearest due date, enters service first (local rule) and it is simple, fast, generally performs well with regards to due date, but if not, it is because the rule does not consider the job process time. It has high priority of past due job and it ignores work content remaining.

Critical Ratio (CR) Rule - sequences jobs by the time remaining until due date divided by the total remaining processing time (global rule). The job with the smallest ratio of due date to processing time enters service first. The ratio is formed as (Due Date-Present Time)/Remaining Shop Time where remaining shop time refers to: queue, set-up, run, wait, and move times at current and downstream work centers. it recognizes job due date and work remaining (incorporates downstream information)but in this sequencing, past due jobs have high priority, does not consider the number of remaining operations.

Slack Per Operation - is a global rule, where job priority determined as (Slack of remaining operations) it recognizes job due date and work remaining (incorporates downstream information)

Least Changeover Cost (Next Best rule) - sequences jobs by set-up cost or time (local rule).it is simple, fast, generally performs well with regards to set-up costs. it does not consider the job process time, due date and work remaining.

1.4. 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". Definition has given by R.E. Shannon.

We simulate rather 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. Experimentation with the system is appropriate is inappropriate. A system is defined as a group of objects that are joined together some regular interaction or interdependence toward the accomplishment of some purpose. A system that does not vary with time is static whereas another one varies with time is dynamic system. A system consist following components

- Entity: An entity is an object of interest in the system.
- Attribute: AN attribute is a property of an entity. A given entity can process many attributes.
- Activity: An activity represents a time period of specified length

- State of a system: it is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study
- Event: An event is defined as an instantaneous occurrence that may change the state of the system
- Progress of the system: The progress of the system is studied by following the changes in the state of the system.

Simulation is a powerful problem solving technique. It can be used to experiment with systems which are not yet in existence, or with existing systems without actually altering the real system; and therefore offers valuable reductions in terms of time, cost, and risk involved in modeling systems, designing experiments and playing scenario analysis games.

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. Computer simulations are assuming the role of traditional experiments in many areas of business and scientific investigations as coding and running simulation models of large, complex real life systems (both in the manufacturing and service sectors) is becoming more and more profitable with the improving technology.

Generally, the real life systems we analyze are composed of closely interconnected sub-systems. There are various -seemingly independent- sources of information and multiple points of decision making. What is more, randomness is a very important, non-negligible factor in life: real systems are usually hierarchical, distributed, and contain a large number of relatively independent, but still implicitly coordinated decision makers operating under great uncertainty. The complexity of real world problems are such that in a lot of cases, the simplifying assumptions made by the corresponding analytic model might not be realistic, or the appropriately formulated model cannot be solved analytically.

When the uncertainty encountered in a system is sufficiently small, existing analytical methods can be suitably modified to cope with them: In fact, many of the algorithms dealing with stochastic systems are closely related to their counterparts in deterministic systems. However, when uncertainty is large, modifying existing algorithms is not enough: new paradigms have to be considered to take care of the random environment, and simulation modeling is a very promising alternative to capture the real stochastic behavior of the system under study.

2. OBJECTIVES OF RESEARCH

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. The objective of this research is to maximize machine utilization, maximizing throughput of system and optimize factors those affects system utilization and throughput of system by using taguchi philosophy and genetic algorithm.

3. 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 as discussed below

3.1 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	M/C 2	M/C 3	M/C 4	M/C 5
P1 (n1=3)	O_{11}	2	5	4	1	2
	O_{12}	5	4	5	7	5
	O_{13}	4	5	5	4	5
P2(n2=3)	O_{21}	2	5	4	7	8
	O_{22}	5	6	9	8	5
	O_{23}	4	5	4	5	5
P3(n3=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
P4(n4=2)	O_{41}	1	5	4	4	2
	O_{42}	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.

Table 2: Sequencing of operation of jobs on machines

M/Ck	Sequence of operation
M/C1	O_{21}-O_{41}-O_{23}
M/C2	O_{12}-O_{42}-O_{32}
M/C3	O_{31}
M/C4	O_{11}- O_{13}-O_{33}-O_{34}
M/C5	O_{22}

For example operation O11 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 8

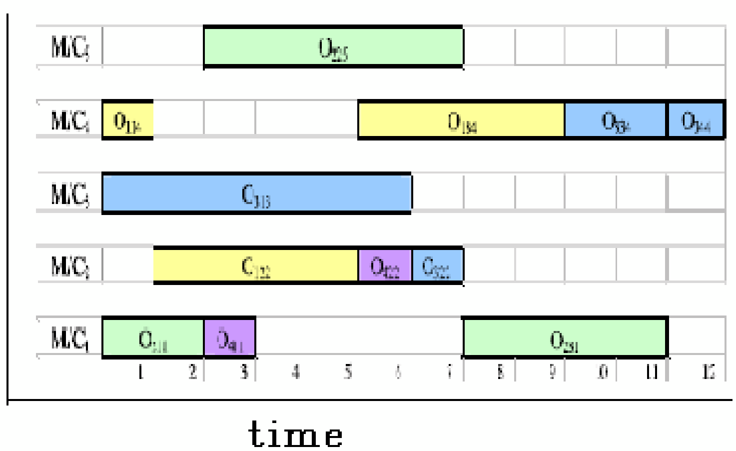

Figure 8: Gantt chart of operation on machines.

3.2 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. So it is the warm up period.

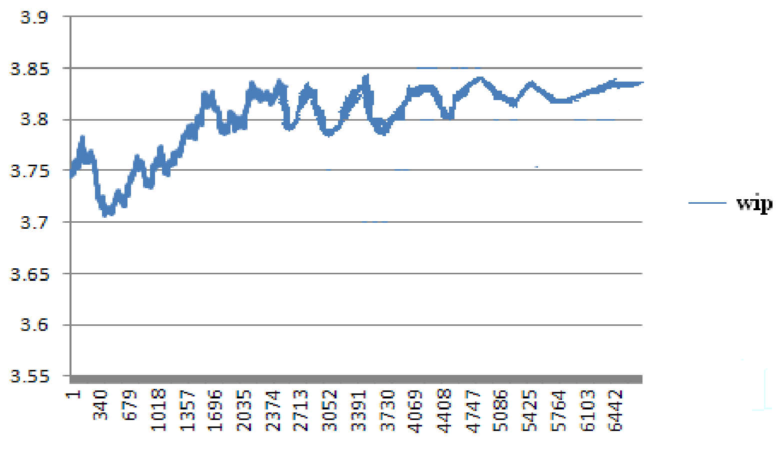

Figure 9: Graph between average work in process and time

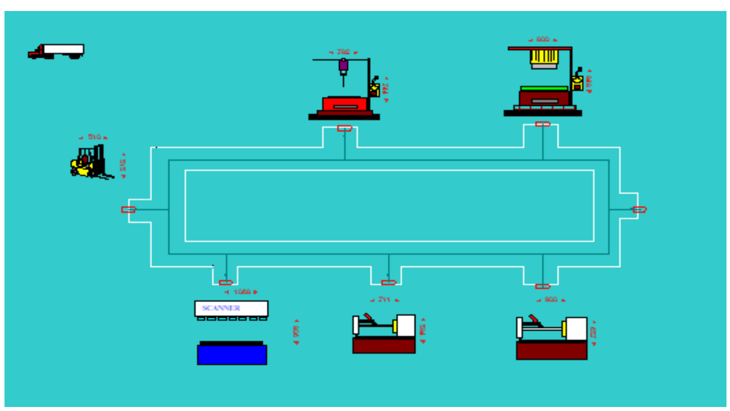

Figure 10: Small manufacturing system

AGVs has been used for transfer parts from one station to other station and in figure shows logical data module those has been used in simulation modeling.

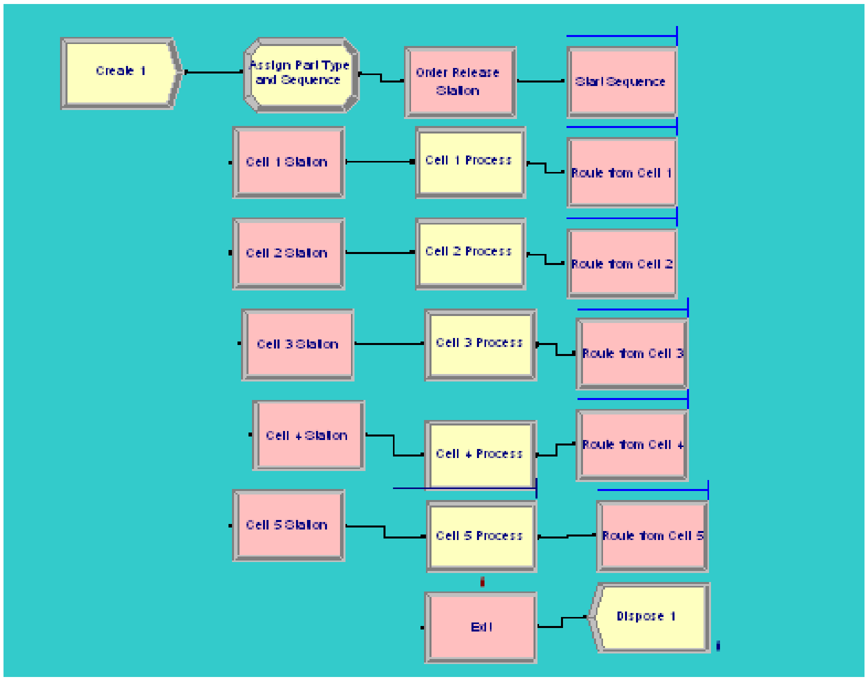

Figure 11: Simulation model of small manufacturing system

To build a FMS model and to carry out simulation runs with Arena, a user performs the following steps:

1. Construction of a basic model. Arena provides the model window flowchart view, which is a flowchart-style environment for building a model. The user selects and drags the flowchart module shapes into the model window and connects them to define process flow of the model.
2. Adding data to the model parameters. The user adds actual data (e.g., processing times, resource demands, others) to the model. This is done by double-clicking on module icons and adding data.
3. Performing a simulation run of the model. The user runs the simulation and examines the results.
4. Analysis of the simulation results provided by the automatic reports of Arena. The user can expand the statistics.
5. Modifying and enhancing the model according to the user needs

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.

3.3 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.
3. No. of carts(X3) = No. of carts used in simulation, here in simulation three levels of no. of carts were assumed 2, 3 and 4.
4. Speed of carts (feet/min.) (X4)=it's the speed of carts or AGVs, which is also affects the FMS objectives. Here in this thesis three level of speeds were assumed 60, 65 and 70.

From above 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 'L27'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

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

Where i = No. of machine

n = Total no. of machine

Here total no. of machine is five. System utilization for each treatment has been calculated by using above formula.

Table 3: Experimental design of L27 array for throughput.

Distance preference	Demand time	No. of Carts	Throughput
Small	10	2	29586
Small	10	3	29733
Small	10	4	29552
Small	15	2	19463
Small	15	3	19586
Small	15	4	19812
Small	20	2	14870
Small	20	3	14778
Small	20	4	14976
Large	10	2	29373
Large	10	3	29284
Large	10	4	29380
Large	15	2	19844
Large	15	3	19623
Large	15	4	19749
Large	20	2	14595
Large	20	3	14670
Large	20	4	14594
Cyclical	10	2	29285
Cyclical	10	3	29595
Cyclical	10	4	29285
Cyclical	15	2	19875
Cyclical	15	3	19865
Cyclical	15	4	19770
Cyclical	20	2	14764
Cyclical	20	3	14732
Cyclical	20	4	14885

Table 4: Experimental design of L27 array for System utilization.

Distance preference	Demand time	No. of Carts	System Utilazation
Small	10	2	0.106313
Small	10	3	0.106346
Small	10	4	0.105746
Small	15	2	0.070139
Small	15	3	0.070316
Small	15	4	0.070486
Small	20	2	0.055483
Small	20	3	0.052751
Small	20	4	0.053747
Large	10	2	0.105842
Large	10	3	0.105249
Large	10	4	0.105111
Large	15	2	0.071236
Large	15	3	0.070445
Large	15	4	0.071466
Large	20	2	0.052381
Large	20	3	0.052368
Large	20	4	0.052429
Cyclical	10	2	0.105180
Cyclical	10	3	0.106638
Cyclical	10	4	0.105174
Cyclical	15	2	0.071295
Cyclical	15	3	0.071832
Cyclical	15	4	0.070563
Cyclical	20	2	0.052861
Cyclical	20	3	0.05335
Cyclical	20	4	0.054687

3.4 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 W1 and W2 are equal to 0.5.

$$Z_{Multi} = w_1 * \frac{Z_{system\ utilization}}{system\ utilizationa_{max}} + w_2 * \frac{Z_{throughput}}{Throughput_{max}}$$

4. RESULTS AND DISCUSSIONS

4.1. 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.

Table 5: Sequencing of Operation on jobs

M/Ck	Sequence of operation
M/C1	O_{21}-O_{41}-O_{23}
M/C2	O_{12}-O_{42}-O_{32}
M/C3	O_{31}
M/C4	O_{11}- O_{13}-O_{33}-O_{34}
M/C5	O_{22}

4.2. 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.

Table 6: Response table for means for throughput

Level	A	B	C	D
1	0.07681	0.10573	0.07675	0.07697
2	0.07628	0.07086	0.07659	0.07659
3	0.07684	0.05334	0.0766	0.07638
DELTA	0.00056	0.05239	0.00016	0.0006
RANK	3	1	4	2

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

Table 7: response table for system utilization

Level	**A**	**B**	**C**	**D**
1	**21373**	**29453**	**21295**	**21315**
2	**21235**	**19732**	**21318**	**21317**
3	**21340**	**14763**	**21334**	**21316**
DELTA	**138**	**14690**	**39**	**2**
RANK	**2**	**1**	**3**	**4**

4.3. 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 4.4 and table 4.5 respectively for maximum throughput

Throughput = 43321 - 17*distance preferences (X1) - 1469 *arrival demand + 19* no. of carts (X3) + 0.1 * velocity of carts (X4)

Table 8: factor and their level for maximizing throughput through genetic algorithm

Factors	Level	Value
Distance preference	Level 1	Smallest distance
Demand arrival time	Level 2	10 minutes
No. of carts	Level 3	4
Velocity of cart		- 69.495

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

System utilization = 0.159 + 0.00001 *distance preferences (X1) - 0.00524*arrival demand time (X2) - 0.00007 * no. of carts (X3) - 0.000060 * velocity of carts (X4)

Table 9: factor and their level for maximizing throughput through genetic algorithm

Factors	**Level**	**Value**
Distance preference	**Level 1**	**Smallest distance**
Demand arrival time	**Level 2**	**10 minutes**
No. of carts	**Level 3**	**4**
Velocity of cart		**- 62.495**

System utilization obtained by value of above factor in simulation is 0.1071%

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 W1 and W2 are equal to 0.5.

$$Z_{Multi} = w_1 * \frac{Z_{system\ utilization}}{system\ utilization_{max}} + w_2 * \frac{Z_{throughput}}{Throughput_{max}}$$

Using above function a following combined function obtained which is optimized by using genetic algorithm and gives results as shown in table 4.6

ZMulti = 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)-
0.75*(1.4642 - 0.0005717 * X(1) distance preferences -0.49406 * X(2) arrival demand time +19 * X(3) No. of carts +0.0006390 * X(4) Velocity of carts)

Table 10: factor and their level for maximizing throughput and system utilization through genetic algorithm

Factors	Level	Value
Distance preference	Level 1	Smallest distance
Demand arrival time	Level 2	10 minutes
No. of carts	Level 3	4
Velocity of cart		- 62.495
Throughput		30018
System utilization		0.1085%

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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