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Modeling and Analysis 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.***

Keywords: Taguchi philosophy and genetic algorithm have been used for optimization. Genetic algorithm (GA) approach

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 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.

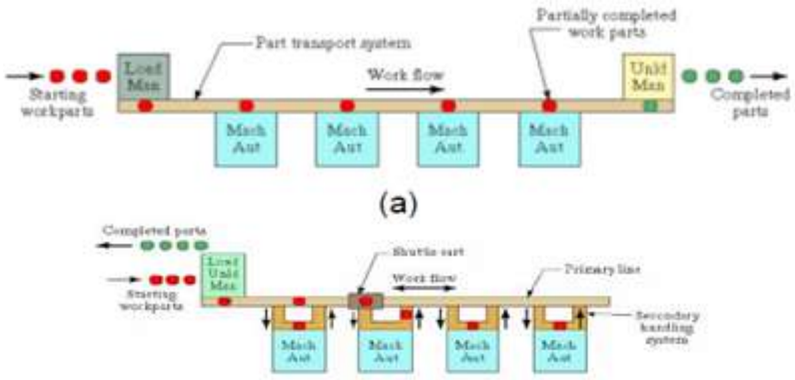

Figure 1 in line FMS layout

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.

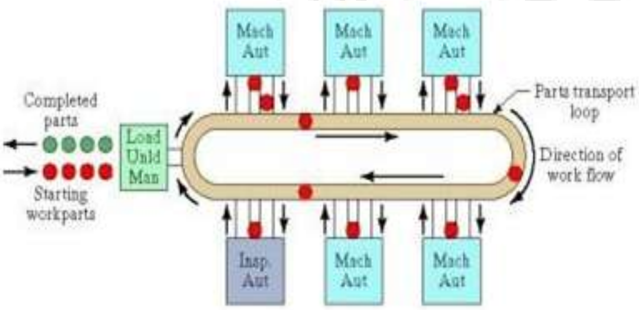

Figure 2: Loop FMS layout

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.

1.3 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.

1.5 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.

Genetic Algorithms works with a set of individuals, representing possible solutions of the task. The selection principle is applied by using a criterion, giving an evaluation for the individual with respect to the desired solution. The best-suited individuals create the next generation. It optimizes with both continuous and discrete variables efficiently. It doesn't require any derivative information. It searches from a wide sampling of the cost surface simultaneously. It handles a large no. of variables at a time. It optimizes variables with extremely complex cost surfaces. It provides a list of optimum variables, not just a single solution. Genetic algorithm has following steps

1) **Generate initial population** – in most of the algorithms the first generation is randomly generated, by selecting the genes of the chromosomes among the allowed alphabet for the gene. Because of the easier computational procedure it is accepted that all populations have the same number (N) of individuals.
2) Calculation of the values of the function that we want to minimize of maximizes.
3) **Check for termination of the algorithm** – as in the most optimization algorithms, it is possible to stop the genetic optimization by:

Value of the function: the value of the function of the best individual is within defined range around a set value. It is not recommended to use this criterion alone, because of the stochastic element in the search the procedure, the optimization might not finish within sensible time Maximal number of iterations: this is the most widely used stopping criteria. It guarantees that the algorithms will give some results within some time, whenever it has reached the extreme or not Stall generation: if within initially set number of iterations (generations) there is no improvement of the value of the fitness function of the best individual the algorithms stops.

4) Selection – between all individuals in the current population are chose those, who will continue and by means of crossover and mutation will produce offspring population. At this stage elitism could be used – the best n individuals are directly transferred to the next generation. The elitism guarantees, that the value of the optimization function cannot get worst (once the extreme is reached it would be kept).

5) Crossover – the individuals chosen by selection recombine with each other and new individuals will be created. The aim is to get offspring individuals that inherit the best possible combination of the characteristics (genes) of their parents.

6) Mutation – by means of random change of some of the genes, it is guaranteed that even if none of the individuals contain the necessary gene value for the General scheme of the evolutionary algorithms 8 extreme, it is still possible to reach the extreme.

7) New generation – the elite individuals chosen from the selection are combined with those who passed the crossover and mutation, and form the next generation. It works smoothly with both numerical and experimental data. it is well suited for parallel computing.

1.6 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.

2. 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. 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 fashion. However, as compared to the decomposed problem, the unified formulation did not produce significant improvement in make span to justify the additional computational effort required.

2.1Taguchi 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 authors like Taguchi [24,25] and Ross [27] discovered analytical techniques to design highly efficient and cost effective experiments. The foundation of Taguchi's philosophy is the loss function concept. "*The quality of a product is the (minimum) loss imparted by the product to society from the time the product is shipped.*" [26].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. This design refers to design a process or a product in a way that it has minimal sensitivity to the external nuisance factors .Klien, I.E [28] has emphasized the importance signal-to-noise ratio analyses which was given by Taguchi to develop a design for Rayleigh surface acoustic wave (SAW) gas sensing device operated in a conservative delay-line configuration. Recently Chen [29] calculated signal-to-noise ratio on the basis of ANOVA. In this paper author has used 10 step methodologies as mention by koilakuntla [30] for deploying robust Taguchi design in process optimization of a molding operation by using MINITAB.

2.2 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].

This observation was first mathematically formulated by John Holland in 1975 in his paper, "Adaptation in Natural and Artificial Systems" [33]. Usually the algorithm breeds a predetermined number of generations; each generation is populated with a predetermined number of fixed length binary strings. These binary strings are then translated (decoded) into a format that represents suitable parameters either for some controller, or as output.

The product resulting from evolution (whether natural or simulated) is not simply discovered by a random search through the problem state space, but by a directed search from random positions in that space. In fact, according to

Goldberg, the simulated evolution of a solution through genetic algorithms is, in some cases, more efficient and robust than the random search, enumerative or calculus based techniques. The main reasons given by Goldberg are the probability of a multi-modal problem state space in non-linear problems, and that random or enumerative searches are exhaustive if the dimensions of the state space are too great [34].

An additional advantage of the genetic algorithm is that the problem solving strategy involves using "the strings' fitness to direct the search; therefore they do not require any problem-specific knowledge of the search space, and they can operate well on search spaces that have gaps, jumps, or noise" [35]. As each individual string within a population directs the search, the genetic algorithm searches, in parallel, numerous points on the problem state space with numerous search directions.

3. Methodology

In this research methodology has been adopted, 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

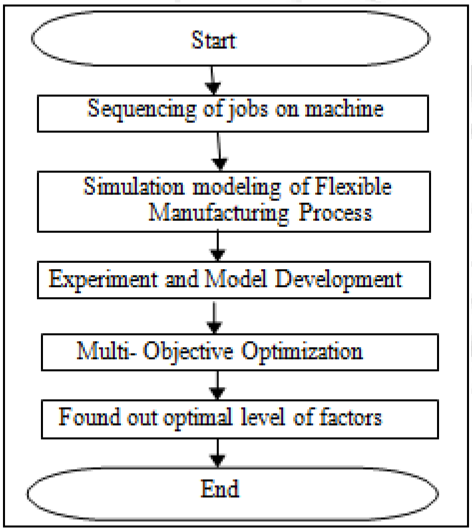

Figure 7: Flowchart of analysis of FMS

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	O21-O41-O23
M/C2	O12-O42-O32
M/C3	O31
M/C4	O11- O13-O33-O34
M/C4	O22

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.

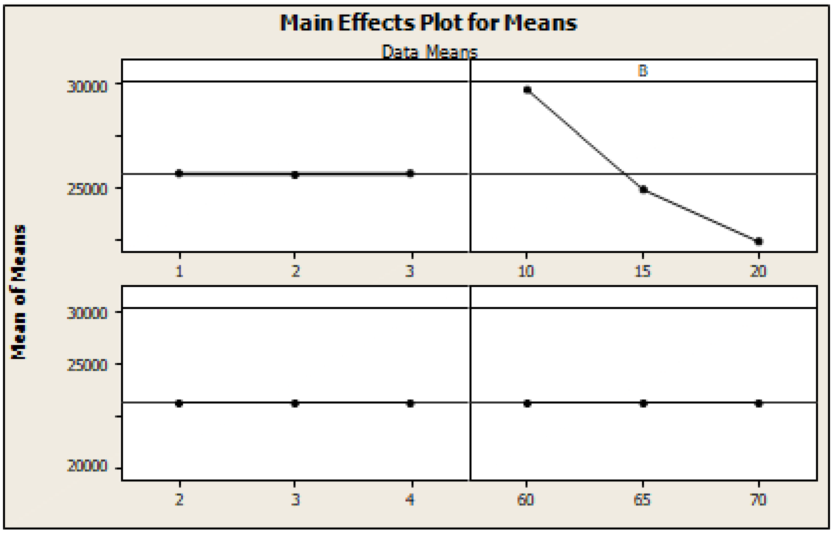

Figure 13: Main effect plot for means of throughput of system

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.

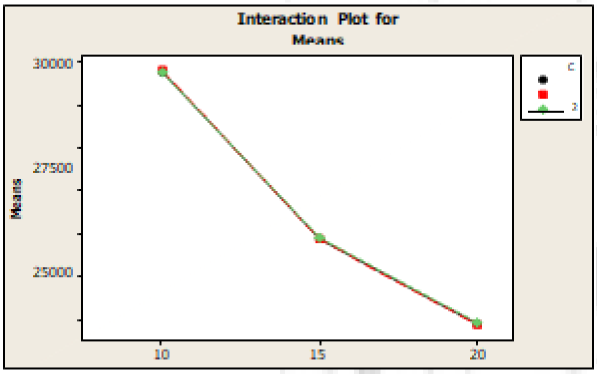

Figure 14: Interaction plots between demand arrival time (B) and no. of carts(C) for throughput Interaction plots for means between demand arrival demand time (B) and no. of carts gives that as arrival demand time increases throughput of system decreases there is very less effect of no. of carts on throughput according to this research in this problem.

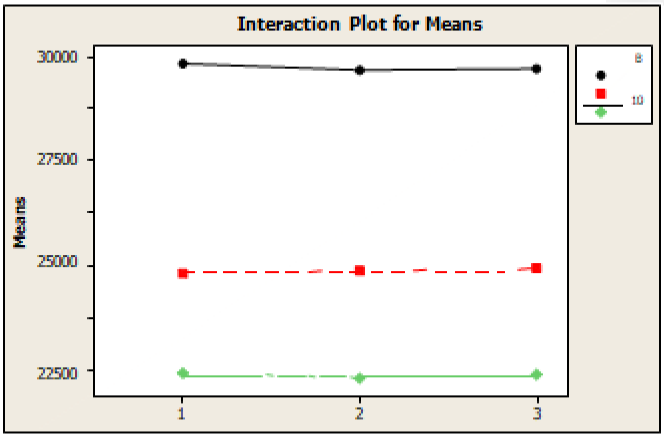

Figure 15: Interaction plots between and distance preference (A) and demand arrival time (B) for throughput

Interaction plots for means between demand arrival demand time (B) and distance preference (A) gives that as arrival demand time increases throughput of system decreases and when arrival demand time is 20 min., throughput maximum at level 1 means when the distance preference is smallest but when arrival demand time is 15 min., throughput maximum at level three means the distance preference is cyclical, and when arrival demand time is 10 min. and distance preference is smallest so throughput of system is maximum. It means as arrival time increases, throughput of system decreases

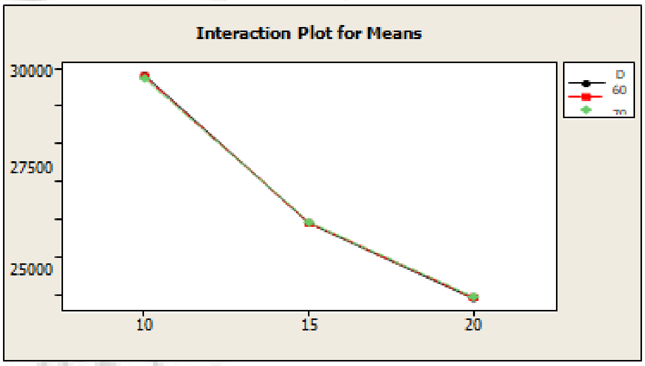

Figure 16: Interaction plots for means between demand arrival time (B) and velocity of carts (D) for system throughput

Interaction plots for means between demand arrival demand time (B) and velocity of carts (D) gives that as arrival demand time increases throughput of system decreases There is very less effect of velocity of carts on throughput according to this research in this problem.

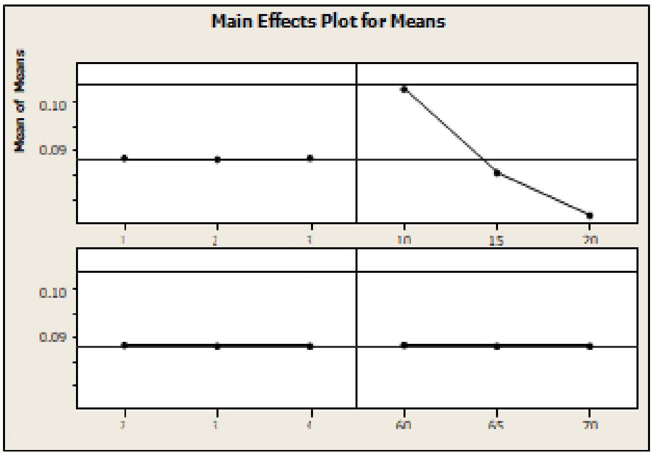

Figure 17: Main effect plot for means of system utilization

Main effect plot of system utilization shows that distance preference should be at first level means distance preference should be smallest for this simulated flexible manufacturing system for maximizing system utilization of system is maximum at demand time is 10 min. and no. of carts is 2 and velocity of cart is 60 feet/min.

5. Conclusion

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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