Performance Evaluation and Design of Flexible Manufacturing System: *A Case Study*

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ABSTRACT

This case study reflects results of a detailed simulation study in order to design and analyze a Flexible Manufacturing System. This paper aims at the performance enhancement of manufacturing system in Indian industry. An ample amount of literature review has been done to apprehend various factors affecting the performance of a manufacturing system which includes conceptual study of the machine & resource utilization, reducing time span, reducing in process inventories and improving control etc. The manufacturing company under focus of our research is operating on a traditional manufacturing system. With the intensifying global competition demands increased productivity in order to fulfil market demands for which the company should change to FMS. The research undertakes analysis of manufacturing systems of the gear manufacturing unit and hence attempts to provide solution to its prolonging problems. This research work will benefit other manufacturing industries as well. To conclude, simulation models are developed and the effect of seizing on the performance improvement is studied.

KEYWORD

FMS	Simulation
Machine	Productivity
Modeling	Workstation
System	Software

Preface

The manufacturing industry is the wealth of a country which showcases the prosperity of country. With the aggrandizing competition in global trade, these industries are facing dynamic environment. Such environment is characterized by the large amount of uncertainty caused due to rapid market changes, competitive prices and reduced product life cycles. All these factors have contributed to performance enhancement in automated industry. Traditional manufacturing systems lack the capability of meeting these requirements. These factors, thus, prompt the manufacturing industries to increase flexibility & productivity to stand in tough competition. The introduction of FMS (flexible manufacturing system) helps in improvises a manufacturing system. Flexible Manufacturing System (FMS) is a system which compiles production equipments actually coupled by a central sustainable system and logically structured under a host workstation. As the flexibility of a manufacturing system increases, the profit also increases because of improved quality. Productivity & flexibility have been the two conflicting objectives of production units. FMS tries to provide an optimization between improvising flexibility while maintaining the productivity of a medium scale mass production unit. While designing an FMS the focus should be on increasing the performance. Designing of FMS should always be apropos to the company's current production scenario which should focus on layout design, production capacity, material handling, level of automation, manpower, no of work stations etc. The earlier stages in designing of FMS should focus on deciding these parameters. The FMS hence designed should be able to justify performance improvement by meeting some set goals which include increased machine & resource utilization, reduced in process inventories, reduced time span, improved control etc. Performance is one of the main factors affecting the design, development & configuration of the FMS. Measurements, analytical models, and simulation models are alternative techniques for performance analysis. Analytical models were earlier used for analysing the performance of a manufacturing system. Nowadays, simulation based models are preferred over it so as to obtain accurate results for larger & complex calculations with fewer assumptions. FMS works on complex structure and dynamic character of real manufacturing units, hence using simulation techniques are used to analyse them. The simulation softwares provide an interface which can represent the real world by numbers & can be easily analysed & manipulated.

This case study is on a company which is based on traditional production system. The cutthroat market competition demands this company to convert into FMS in order to increase the productivity & meet market demands. The research attempts at analysing the manufacturing systems of the gear manufacturing unit and hence provides solution to its prolonging problems. Every manufacturing industry benefits from this research work. Performance analysis holds the key for improvement. Organisations adapt to the core concepts of research and hence benefit from it by following the standards and the goal set forth by modelling. The paper presents study of the existing system followed by designing & analysis of FMS. The paper is divided in the following sections: Section 2- Literature survey overview Section 3- Problem statement & Case Company's details Section 4- Design & analysis of FMS model Section 5- Comparison of results Section 6- Conclusion.

2. Literature Review

The desirable qualities needed in a manufacturing system to have a speedy reaction against today's varying market needs form the basic structure of FMS. Flexible manufacturing system is used for manufacturing of a variety of products of medium sized volume using computer for central control, CNC tools for operation and automated handling of material [Browne et al[i]., 1998]. Better quality, high flexibility and an increase in productivity are its basic features [Womack[ii], 1990]. Flexible Manufacturing System (FMS) is a compilation of production equipments actually coupled by a central sustainable system and logically structured under a host workstation. The most vital element of a production system is Flexible Manufacturing System due to its ability to conform to a change three times as compared to an ordinary job shop. Performance of a system is largely influenced by the loading and control strategies [Stecke[iii], 1983; Solberg[iv], 1981].To implement an FMS, a well planned designing with controlling strategies is required [Gowan Jr., & Mathieu[V], 1996]. Similar NC machines form the main constituents of an FMS, forming a well connected network by a transportation system that is automated in nature. A dedicated computer called FMS cell computer is allotted for each process. A chief impact on operation of an FMS is achieved by the hardware used for transferring of tools to/from the central storage to the tool magazine automatically while the operation is taking place [Edghill, & Davies[vi], 1985; Jaikumar[vii], 1986]. FMS is an emergent technology which is appropriate for mid-variety, mid-volume type of production and comprises of multipurpose NC machines [Sridharan[viii], 2007]. As compared to the traditional manufacturing systems which are used for higher volume and lower part variety, an FMS has the ability of managing a wide variety of products simultaneously in small to medium size lots at a higher efficiency. This system processes any part within the specified capacity belonging to a specific part family according to an encoded plan. It functions in such a way that the change over time is minimum and there is a lesser human intervention [Chan, & Chan[ix], 2004]. Productivity and flexibility are the two conflicting objectives of production Ability to produce a greater number of products distinct in nature in a job shop is referred to as flexibility while high production rate closely resembling an assembly line in its operation, is referred to as Productivity. The two decisions related to FMS operation are categorized as pre-release and post-release. Pre-release decisions are taken before FMS begins its operation and is related to the tools and parts' collection. While the system is in operation, Post-release decisions indicate the sequence of parts and their routing [Stecke[iii], 1983]. Given the current condition in the manufacturing industry, the focus has shifted towards increasing the flexibility with the available resources while maintaining high utilization of the resources. Flexibility is a system's capability to produce a variety of products with an acceptable excellence while modifying the resources to do so [Sethi, & Sethi[x], 1992].It is the capability of a system to cope up with variation by dynamically exploring the choices [Wadhwa, & Rao[xi], 2000]. Flexibility is of two types-Process and Product flexibility. The property of a company to perform adequately under varied operating conditions is referred to as Process flexibility while product flexibility deals with manufacturing of wide variety of a particular product [Benjaafar, & Ramakrishman[xii], 1996]. To make decision making procedure effective, there are eight types of flexibilities namely routing flexibility, product flexibility, volume flexibility, process flexibility, machine flexibility, operation flexibility, production flexibility and expansion flexibility [Browne et.al[i]., 1984]. Increase in flexibility ensures maximum resource utilization [Shnits et al.[xiii], 2004]. An FMS is said to be effective if it is capable of dealing with any change in the volume, mix, nature or activity timing and this capability is referred to as flexibility [Correa, & Slack[xiv], 1996]. Designing of FMS is related to control and physical aspects. Control aspects deal with defining the rules of scheduling and algorithms defining the way in which a system can function while the physical aspect deals with selection of the types of machines depending upon the time taken for its processing, transportation, material handling, loading unloading etc. As the machinery involved in FMS is quite costly, the layout should be selected bearing in mind the various options of layouts. The layout of machines deals with the problem of arrangement of machinery is in such a way that there is a minimum transfer time taken by materials between them. To evaluate the other layouts in a system, the minimum distance between machines, the transporting path etc are to be considered apart from the other factors like distance and time. The results on the layouts of FMS are evaluated and aspects vital in the designing of an FMS layout are identified [Kouvelis, & Kiran[xv], 1989]. As an experimental inspection of an FMS, the number of completed parts was a measure of system performance. Researchers have been constantly in improving performance of an FMS [Wadhwa, S. et al.[xvi], 2005; Chan, F.T.S.[xvii], 2003]. Deterministic models are also used by some researchers to approximate the performance of an FMS by estimating parameters of the system like utilization of resources; rate of production etc during the initial stages itself. A commonly accepted mathematical model for evaluation of performance parameters was given by [Solberg[iv], 1981; Mejabi[xviii], 1988]. For intricate systems, researchers have proposed the use of Simulation as it provides a simplified method of modelling of complex systems while representing the real world system. Simulation modelling is very useful in problems like scheduling, routing etc, which are faced while functioning of a system. There are two types of difficulties involved with FMS. Design problem is concerned with choosing the appropriate FMS components, while operational problem is concerned with the utilization aspects in an FMS. Both these aspects are considered in this paper. Analyzing the existing FMS using analytical models and an alternative FMS model devised to improve the performance characteristics. A simulation model has been designed which identifies the machine as blockage point apart from calculating the parameters of performance of the new FMS. As an advice to increase the production rate and to ensure better resource utilization, some strategies for up gradation are also suggested to the company.

3. Problem Statement & Company Details

The company under consideration is located in Uttar Pradesh State of India. It manufactures various kinds of three wheelers. The company is ISO 9001:2000 and ISO 14001 certified and has established its name in international markets. The company integrates departments for design, development, manufacture & sales. The company has a large market in India as well as overseas. The manufacturing division is divided into assembly line, foundry line, machine shop etc. Various parts are manufactured in the machine shop including shafts, cylinders, gears etc. This case study is on manufacturing of gear. The line for gear manufacturing process includes machines like hobbing, turning, gear shaving etc. The company is a progressive company and is willing to invest in R&D. The company's vision of growing into a globally competitive company & meeting the increasing & different needs of customers have created a need to switch on to new type of manufacturing systems from current traditional type. The paper focuses on analysing the current manufacturing setup which is based on cellular technology & propose a new flexible manufacturing system using simulation techniques. This analysis & design will help in performance improvement of the company by studying various parameters on which performance depends.

The study started with the data collection which was done by preparing a questionnaire & distributing it to various people involved in the line for manufacturing of gears. The line is responsible for production of two types of gears Gear 1 & Gear 2. The FMS study is carried out on production of these two gear types & is a standard batch type manufacturing case. The gear manufacturing process is carried out in 10 steps which include chamfering, facing, turning, hobbing, shaving of the initial blank. The manufacturing process of the two gears in detail is given as under:

3.1 Gear-1 processing

The total time taken in production of one piece of gear one is 2279 seconds. The detailed description is given in Table-1

Table 1. Processing description of Gear-1

S. No	OPERATION DESCRIPTION	M/C DESCRIPTION	Cycle Time in Sec.
1.	OD Chamfer, Face, OD Turn, Face, Chamfer etc.	Mini Chucker	330
2.	Turn Second side face and chamfer OD	Mini Chucker	300
3.	Spline Broaching	Broaching	250
4.	Washing	Washing M/c	150
5.	Spline Deburring	Manual	150
5.	Final turning	PTC Lathe	300
6.	Burr Chamfering	Manual	100
7.	Hobbing	Hobbing M/c	149
8.	Teeth Chamfering	Cham. M/c	100
9.	Oil Grooving	Hyd.Press	150
10.	Shaving	Shaving M/c	300
	Total Time		2279

3.2 Gear-2 processing

The total time taken in production of one piece of gear one is 2195 seconds. The detailed description is given in Table-2.

Table 2. Processing description of Gear-2

S. No	OPERATION DESCRIPTION	M/C DESCRIPTION	Cycle Time in Sec.
1.	OD Chamfer, Face, OD Turn, Face, Chamfer etc.	Mini Chucker 1	288
2.	Turn Second side face and chamfer OD	Mini Chucker 2	240
3.	Spline Broaching	Broaching	250
4.	Washing	Washing M/c	150
5.	Spline Deburring	Manual	113
5.	Final turning	PTC Lathe	250
6.	Burr Chamfering	Manual	150
7.	Hobbing (10 Jobs)	Hobbing M/c	149
8.	Teeth Chamfering	Cham. M/c	155
9.	Oil Grooving	Hyd.Press	150
10.	Shaving	Shaving M/c	300
	Total Time		2195

4. Performance Analysis and Modelling of Case system

Profitability and survival of a manufacturing firm depends upon accommodating fluctuating product demands, day-to-day technological advancements, and competition from and among different firms. Flexibility plays a vital role for operation in such a scenario. Modeling and performance analysis of manufacturing systems helps decision makers at higher levels to conduct an economic feasibility analysis for expansion/diversification or modification of the system. Also, this could help in installing a new manufacturing system with a substantial reduction in the number of machines, floor space, inventory level, throughput and lead time and also high quality products, with a greater flexibility to respond to the market needs. To meet the objective, various manufacturing flexibilities need to be measured to evaluate and select a desired flexible manufacturing system. There are various universal mathematical models available to perform deterministic study and therefore may be utilized. It is felt that better study of an existing system would also help in improving performance and in designing operational parameters of a new FMS. Getting the motivation from the earlier studies it was decided to adopt a well recognized mathematical model proposed by [Solberg[iv], 1981] and further modified by [Mejabi[xviii], 1988]. These models have been duly verified and validated in the literature to provide primary estimates of operational parameters such as production rate, workstation load etc. The considered research case involves the assessment and analysis of performance of a flexible manufacturing system at operational level under various parameters. Primary step may be to identify the various such parameters that can affect performance of the system.

4.1 Operational parameters

Average Workload

Various performance parameters are analyzed by calculating the average workload for each work station of FMS which is denoted by *WLi* and is the mean total time spent by a part at a machining station. It is used to identify the bottleneck station in the system if any.

$$WLi.(\min) = \sum_j \sum_k tijk\ fijk\ Pj$$

WLi = average workload for station *i (Min)*, *tijk* = Processing time for operation *k* in process plan *j* at station *i (Min)*, *fijk* = operation frequency for operation *k* in part *j* at station *i*, *pj* = part-mix fraction for part *j*. The average workload calculated for various workstations of case FMS is summarized in table 3.

Table 3. Average workload for workstations

S No.	Machine	Average Workload (sec)
1	Mini Chucker 1	309
2	Mini Chucker 2	270
3	Broaching	250
4	Washing M/c	150
5	Manual	131.5
6	PTC Lathe	275
7	Manual	125
8	Hobbing M/c	149
9	Cham. M/c	127.5
10	Hyd.Press	150
11	Shaving M/c	300

Estimation of Bottleneck Station

Bottleneck station refers to the station having the maximum workload per server. For an FMS, it can be found out by finding the ratio of largest workload to the no. of servers.

Bottleneck station = Largest workload to no. of server ratio, i.e. $WLi/_{si}$

Table 4. Calculation of various parameters

S No.	Machine	Average Workload (sec)	No. of Servers	Bottle neck station? Workload/no. of servers
1	Mini Chucker 1	309	10	30.9
2	Mini Chucker 2	270	9	30
3	Broaching	250	6	41.66667
4	Washing M/c	150	5	30
5	Manual	131.5	5	26.3
6	PTC Lathe	275	6	45.83333
7	Manual	125	7	17.85714
8	Hobbing M/c	149	3	49.66667
9	Cham. M/c	127.5	4	31.875
10	Hyd.Press	150	4	37.5
11	Shaving M/c	300	2	**150**

4.2 FMS Performance Measures

Various performance evaluation studies are mentioned in literature and they have used performance measures like average flow time, [Chan F.T.S.[xvii], 2003], machine utilization, system utilization etc. Here popular performance measures have been used i.e. Production Rate of all parts, Production Rate of each Part Type, Average Utilization of Workstations, manufacturing lead time and mean waiting time experienced by a part at the stations.

Maximum Production Rate of all Parts

The bottleneck station restricts the maximum production rate for all parts and it can be calculated by finding the ratio of s* (No. of servers at bottleneck station) to WL* (Workload at Bottleneck Station).

$$Rp*\left(Pc./_{Min}\right)=\frac{s*}{WL*}$$

Correspondingly, part production rate for the separate stations (of part type j) can be found out by multiplying R*p and the corresponding part mix ratios (Pj).

$$Rpj*=pj(Rp*)=pj\frac{s*}{WL*}$$

By using the above formula, maximum production rate for all parts is calculated to be 0.00666667 Pc. /hr. for our case.

Utilization of each Workstation

The mean utilization of each workstation is the time for which the servers are working at the station(excluding the ideal time). The utilization will be 100% for the bottleneck station (at *R*p)*.Mean utilization *Ui* is given as the product of the ratio of workload per server and the maximum production rate(*R*p)*

$$Ui = \frac{WLi}{si}(Rp*) = \frac{WLi}{si}\frac{s*}{WL*}$$

Average station utilization (*Uav*) can also be calculated by finding the average utilization value for all the stations. The transport system value also needs to be taken into consideration.

$$\mathbf{Uav} = \frac{\sum_{i=1}^{n+1} \mathbf{Ui}}{\mathbf{n+1}}$$

Table 5. Station utilizations

Machine	Station Utilization	
	NUM	%
Mini Chucker 1	0.206	20.6
Mini Chucker 2	0.2	20
Broaching	0.277778	27.7778
Washing M/c	0.2	20
Manual	0.175333	17.5333
PTC Lathe	0.305556	30.5556
Manual	0.119048	11.9048
Hobbing M/c	0.331111	33.1111
Cham. M/c	0.2125	21.25
Hyd.Press	0.25	25
Shaving M/c	1	100

Overall FMS utilization

This is a vital measure for performance measurement and can be computed by taking into account the average number of servers for each station (*n*) and not considering the transport system. The overall FMS utilization in this case has been calculated as 24.44809%.

$$\boldsymbol{Uoverall} = \frac{\sum_{i=1}^{n} \boldsymbol{siUi}}{\sum_{i=1}^{n} \boldsymbol{si}}$$

4.3 Proposed FMS: Sizing and Other Issues

The analysis of the existing system in the company has been done in the previous section 4 on the data collected. Using the mathematical models, various performance parameters have been calculated. The results showed that the performance of current system is not at the optimum level. The competition in global market coerced the management of company to invest in achieving a better & productive system and was willing to see our designs. A new FMS was designed by following normal procedure based on the inputs received. The sizing of FMS, layout selection etc was done using a mathematical models from the literature. After the calculation, the performance of proposed system is assessed by the simulation models. The simulation models have been developed in SIMAN based software package ARENA version 12.0 and results verified.

Sizing of proposed FMS

With the help of the mathematical models suggested by [Mejabi[xviii], 1988; Solberg[iv], 1981], we can calculate the number of servers required & realize a specified production rate. Such estimations done in the initial stages of FMS design helps to decide the size of the system. The part mix, process sequence, and process times, the number of servers at each station *i* can be calculated as given in table 6.

Table 6. No. of Servers in Proposed FMS Workstations

Workstations (Description)	No. of Servers (Proposed)
Mini Chucker 1	2
Mini Chucker 2	2
Broaching	2
Washing M/C	1
Manual	1
Ptc Lathe	2
Manual	1
Hobbing M/C	1
Cham. M/C	1
Hyd.Press	1
Shaving M/C	2

4.4 Calculation of Performance Measures of proposed FMS

On the lines of initial sizing calculations, done in the previous section we can estimate the performance measures for the new FMS. The mathematical model described in section 4 can be used to calculate important performance parameters like increased station utilization, overall system utilization, maximum production rate etc. Various performance parameters of proposed FMS and increased utilizations are shown in Table 7 and 8.

Table 7. Performance Parameters of proposed FMS

S.No.	Performance Parameters	Estimated Value
1	Maximum Production Rate (Pcs./Hr)	23.30097
2	Most Utilized Station	100
3	New Bottleneck Station	MINI CHUCKER 1
4	Overall Utilization of System (%)	90.4935

Table 8. Increased Station Utilization in proposed FMS

Stations Utilization	(%)
Mini Chucker 1	100
Mini Chucker 2	87.37864
Broaching	80.90614887
Washing M/c	97.0873786
Manual	85.11327
PTC Lathe	88.99676
Manual	80.90615
Hobbing M/c	96.44013
Cham. M/c	82.52427
Hyd.Press	97.08738
Shaving M/c	97.08738

5. Software model development: simulation modelling of proposed FMS

Simulation modeling is a prototype used to attain a simplified depiction of an intricate system while generating performance parameters of the system. Various simulation software used are Arena, Pro-Model etc but the simulators incorporating system information is advantageous over the others. It is beneficial and less time consuming to use simulation modeling in place of the mathematical models particularly in cases where compound problems are involved. This will aid in determining and substantiate the key performance parameters. For performance of complex systems, ARENA has found a large application in the literature, therefore ARENA 11.0 professional was used for modeling. For the proposed FMS, a model was prepared and simulated to achieve the performance parameters and system's response in real life situations. The simulation results when compared for different parameters with the results obtained from the deterministic model varied between 5-7%.

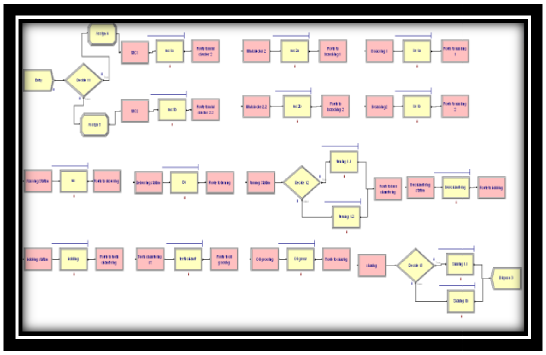

Figure 1. Arena model window

6. Results & Discussions

In the previous section we have presented the performance analysis of existing system and proposed system. Case calculations (Average workload, system utilizations, bottleneck, number of servers etc) are presented in table 3,4,5,6,7 and 8. Initially maximum workload on each workstation has been taken out and it is found that the average workload on shaving station is 300(min) with the total number of servers 2, on this basis the ratio of average workload to server comes out to be 150 (maximum in all stations) which clearly indicates that the shaving station is creating a bottleneck in the processing of gears. To improve the performance it is required either to shift the bottleneck to any other station or neutralize the effect of the bottleneck. So, a new system has been proposed and the bottleneck has been shifted to mini chucker1station with the sufficient number of servers to meet the workload requirement. The mean utilization of the workstations is also another important performance measure. The utilization of each station for the existing system has been calculated and is summarized in table 5. It is observed that most of the stations are underutilized (like mini chucker1, mini chucker 2, washing m/c, manual) whereas some are highly loaded (100% utilized like shaving) and because of this only the overall performance of the system is very less. To overcome this problem the seizing of the proposed system is done. For the optimum number of servers for each workstation have been done and presented in table 6. Comparison between the old and proposed system's station utilization and the number of servers is shown.

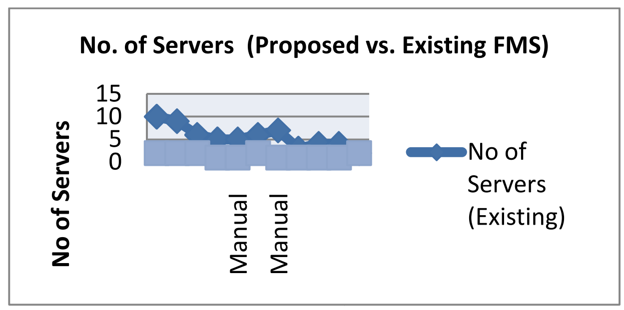

Figure 2. No. of servers (existing vs proposed)

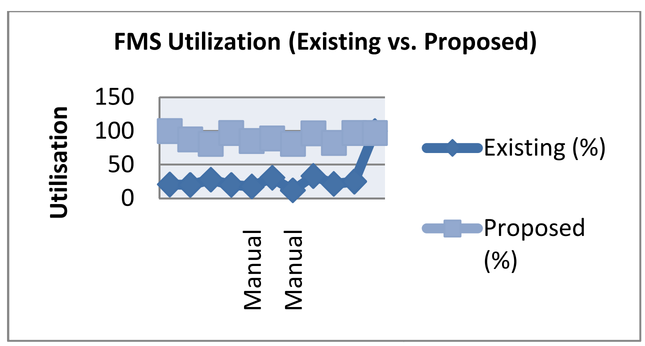

Figure 3. FMS utilization (Existing Vs Proposed)

A comparison chart of all the parameters (station utilization, maximum production rate, bottleneck etc) showing performance improvement (verified with simulation) is presented in table 9.

Table 9. Comparison Chart of Performance Parameters of FMS (Proposed vs. Existing)			
S No.	Performance Parameters	Proposed	Existing
1	Maximum Production Rate (Pcs./Hr)	23.30097	24
2	Most Utilized Station	100	100
3	New Bottleneck Station	MINI CHUCKER 1	Shaving Machine
4	Overall Utilization of System (%)	90.4935	24.4481

Conclusion

The evaluation of performance parameters in this case study is based on a universally accepted mathematical model given by [Solberg[iv], (1981); Mejabi[xviii], (1988)]. The performance parameters of the manufacturing firm's present conventional manufacturing system were calculated analytically. A new FMS model is then proposed by reducing the number of servers to an optimum number. The new FMS model shows an improved machine utilization and reduced workload per machine. In the present system, Shaving, a very important gear manufacturing operation, was the bottleneck station. It had the maximum workload per server and 100% machine utilization amongst all the operations. The aim of the new designed FMS was thus to reduce the workload on Shaving machine & shift the bottleneck station to a less significant station. According to the new model, Mini chucker was classified as the new bottleneck station. In order to have a better machine utilization, the workload has been redistributed in the proposed FMS. Machine utilization, witnessed a significant increase from 11 to 30% to 80 to 100% in the proposed model.

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