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Analyzing and Improving the Performance of Flexible Manufacturing Systems

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Abstract**—** With the intense competition in the market, manufacturing managers are trying to optimize production times, improve product quality, increase product variety, and reduce production costs. Therefore, in the current market environment, these manufacturing environments must be designed, analyzed, and improved based on market challenges in order to survive and thrive in the industry. This paper presents a case study of a linear pallet system for moving parts on pallets in a flexible manufacturing system (FMS) shop. The objective of this study is to analyze the performance of the FMS and propose ways to improve its performance. To determine the current productivity and utilization of work space on the current FMS shop, the Bottleneck Model analysis method and its extension "Extended Bottleneck Model" are used. The proposed FMS that standardizes operations across workstations shows significant improvement in workstation utilization and production throughput.

Index Terms**—** Flexible Manufacturing System, Bottleneck, Busy servers, Workstations utilization, Performance analysis.

I. INTRODUCTION

The competitive business environment has placed new demands on manufacturing systems, including customized products (more variety) with on-time delivery, while emphasizing the traditional requirements of quality and competitive cost. Therefore, in order to survive in the global situation, the focus is on developing manufacturing systems that can meet all necessary requirements within a reasonable timeline and at a reasonable cost. The introduction of Flexible Manufacturing Systems (FMS) has enabled manufacturers to improve performance while flexibly producing customized products in medium batches. Flexible Manufacturing Systems (FMS) can be defined as a computer-controlled configuration of semi-independent workstations and material handling systems designed to efficiently produce a variety of part types in low to medium batches. It combines high flexibility with high productivity and low work-in-process inventory [1].

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Flexible Manufacturing System (FMS) is one of the most suitable manufacturing systems for the current manufacturing environment with short life cycles, customized products and diversified products due to its flexibility. The production process can be continuously improved to achieve performance, productivity and manufacturing advantages. The importance of continuous improvement in improving manufacturing efficiency cannot be overemphasized. It can be achieved by providing a control framework. This improvement can take the form of system optimization, variance reduction, throughput maximization, cost reduction, waste handling improvement, correction of inefficient processes, process simplification, responsiveness and reduction of setup time. Therefore, the necessary step must be to eliminate non-productive activities so that the main goals can be achieved as effectively as possible [2, 3]. Many limitations and obstacles prevent the production process from achieving its optimal production performance. These limitations are called bottlenecks. A manufacturing bottleneck is any situation in a factory floor that reduces productivity [4]. TOC believes that a bottleneck is the weakest link in the production system chain, affecting the entire production process. [5] There are many factors that constrain a production process, including raw materials, machines, personnel, processes, operating policies, etc. Many scholars view constraints from the perspective of the entire production system, including market constraints, capacity constraints, policy constraints, raw material constraints, etc. Constraints, process constraints, logistics constraints, behavioral constraints, and administrative constraints. But under all these constraints in the production process, machine capacity has a significant impact on output [6]. In order to continuously improve the production process, bottlenecks in the production system must be continuously identified, managed and controlled. The production system of a bottling plant is characterized by batch production, complex, high-speed automated processes and capital-intensive continuous processes, which require large investments in machinery and raw materials. However, these investments alone do not ensure financial growth for the company. Optimal utilization of machines and resources is necessary and can only be achieved by permanently using productivity tools to avoid bottlenecks. Of all types of bottlenecks, production bottlenecks play a huge role in reducing the capacity of the production line. This study focuses on investigating the problem of avoiding production bottlenecks in a linear pallet system used to move parts on pallets in an FMS with seven workstations, three machining stations, one inspection station, loading/unloading (2 servers), and transportation (1 shuttle).

II. LITERATURE SURVEY

- Kikolski (2016) Manufacturing companies consistently prioritize the improvement of their production processes by implementing various modifications at different phases. These modifications are essential in contemporary manufacturing due to the accelerated product life cycles prompted by fierce competition and evolving consumer demands.[7]
- Baldwin (2015) A bottleneck is characterized as a crucial component of a technical system that currently lacks viable alternatives or has very limited options. The efficiency of a process chain is contingent upon the capabilities of the machines involved in that chain, and those machines that significantly influence and restrict the overall performance more than others are referred to as bottlenecks.[8]
- Urban and Rogowska (2020) have identified two categories of bottlenecks that may arise within the production process. The first category exceeds the utilization threshold of performance limits, resulting in a deceleration of the flow of goods and materials, which imposes performance constraints on the entire production system. The second category pertains to the complete consumption of a specific resource, which poses a risk to production efficiency.[9]
- The effectiveness of a process chain is largely determined by the capacity of the machines involved, with those machines that most significantly hinder overall performance being referred to as bottlenecks (Tang, 2019; Roser et al., 2001).
- Kahraman, Rogers, and Dessureault (2020) assert that by effectively allocating resources, enhancing throughput, and reducing production costs, organizations can achieve substantial improvements when bottlenecks are identified swiftly and accurately.
- Chiang, Kuo, and Meerkov (2001) note that companies are employing various strategies to pinpoint bottlenecks that adversely affect production efficiency. The literature identifies three distinct methods for detecting bottlenecks: analytical, simulation-based, and data-driven approaches.

III. Overview of flexible manufacturing system

Flexible manufacturing systems (FMS) represent a category of manufacturing systems that can be rapidly adjusted to produce a variety of products. Over the past few decades, significant research has been undertaken by control theorists and engineers to model and analyze FMS. An FMS operates as a production system where discrete quantities of raw materials are processed and assembled using controlled machines, computers, and/or robots (Ruiz et al., 2009). Typically, it comprises a network of CNC machine tools, robots, material handling systems, automated storage and retrieval systems, along with computers or workstations. A standard FMS is capable of fully processing one or more components of a part family continuously, without the need for human intervention, and possesses the flexibility to adapt to evolving market demands and product variations without necessitating the acquisition of additional equipment. The term "flexible" encompasses various aspects, including machines, processes, products, routing, quantities, or outputs. The origins of the FMS concept can be traced back to British engineer David Williamson, who worked for Molins in the mid-1960s. [13]

A manufacturing system must exhibit three essential capabilities to achieve flexibility:

1) The capacity to recognize and differentiate between various incoming part or product styles processed by the system.
2) The ability to swiftly update operating instructions.
3) The capability for rapid modifications in structural design.

To qualify as flexible, automated systems must successfully undergo four evaluations:

a) The part variety evaluation.
b) The schedule adjustment evaluation.
c) The error recovery evaluation.
d) The new part evaluation.

Flexible Manufacturing Systems (FMS) have emerged as a significant advancement in manufacturing in recent years. They enable the production of diverse parts in a shorter timeframe and at reduced costs. In the contemporary market landscape, FMS facilitates the simultaneous fulfillment of growing demands for variety, volume, and speed.

FMS components can be classified into two primary categories:

- Hardware: This includes machine tools, handling systems, transport vehicles, test centers, robots, and similar equipment.
- Software: The software associated with FMS can be further divided into external functionalities and built-in features.

The case study discussed in this paper focuses on two forms of flexibility: mechanical flexibility and routine flexibility. A significant aspect of FMS is the evaluation of system performance. Enhancing FMS performance can lead to reduced labor costs, increased production efficiency, lower manufacturing expenses, greater flexibility, and shorter production lead times. The key performance indicators analyzed in this study were machine utilization and overall productivity. Machine utilization improves as the system processes a higher number of orders, with the bottleneck machine achieving 100% utilization. This utilization is quantified by comparing the operational hours of the system to the total available time. The design and assessment of an FMS system's performance is a multifaceted endeavor that necessitates comprehensive analysis.

IV. BOTTLENECK TECHNIQUE

Significant elements of Flexible Manufacturing System (FMS) performance can be articulated through a deterministic framework known as the bottleneck model, which was introduced by Solberg in 1981. While bottleneck models are characterized by their simplicity and intuitive nature, the deterministic methodology does present certain constraints. This model serves as a useful tool for generating preliminary estimates of FMS design parameters, including production rates and the number of workstations. The concept of a bottleneck highlights the existence of a maximum output limit within a production system when the product mix remains constant. This model is applicable to any production system exhibiting this bottleneck characteristic.[14]

4.1 Terms and symbols:

Part mix, a mix of the various parts or product styles produced by the system is defined by (p_j). The value of (p_j) must sum to unity:

$$\sum_j p_j = 1.0$$

The FMS has a number of distinctly different workstations (n) and (S_i) is the number of servers at the (*i*) workstation. Operation frequency is defined as the expected number of times a given operation in the process routing is performed for each work unit.

f_{ijk} = Operation frequency

For each part or product, the process routing defines the sequence of operations, the workstations where operations are performed, and the associated processing time.

T_{ijk} = Processing time for operation.

The average workload, WL_i:

$$WL_i = \sum_{j=1}^{p} T_{ijk}\, P_j \quad \text{..............} \ ①$$

Where:

i : refers to the station,

j : refers to the part or product,

k : refers to the sequence of operations in the process routing.

The average of transport required completing the processing of a work part, n_t:

$$n_t = \sum_{j=1}^{p} n_v\, p_j - 1 \quad \text{..............} \ ②$$

The workload of handling system, WL_{n+1}:

$$WL_{n+1} = n_1\, T_{n+1} \quad \text{..............} \ ③$$

Where: T_{n+1} = Mean Transport time per move, min.

The FMS maximum production rate of all part, R_p^*, Pc/min:

$$R_p^* = \frac{S^*}{WL^*} \quad \text{..............} \ ④$$

Where: WL^* = workload min/Pc

S^* = Number of machines at the bottle-neck station

The part (j) maximum production rate, $R_{P_j}^*$, Pc/min:

$$R_{P_j}^* = P_j\,(R_p^*) = P_j\,(\frac{S^*}{WL^*}) \quad \text{..............} \ ⑤$$

The number of busy servers at each station, BS_i^*:

$$BS_i^* = R_p^*\,(WL_i) \quad \text{..............} \ ⑥$$

Mean utilization of a station (i), U_i^*:

$$U_i^* = \frac{WL_i}{S_i}(R_p^*) = \frac{WL_i}{S_i} \times \frac{S^*}{WL^*} = \frac{BS_i^*}{S_i} \quad \text{.........} \ ⑦$$

Average utilization of FMS including transport system:

$$\bar{U} = \frac{\sum_{i=1}^{n+1} U_i}{n+1} \quad \text{..............} \ ⑧$$

Where: $\bar{U}$: unweighted average of the workstation utilizations.

Overall FMS utilization, $\bar{U}_n$:

$$\bar{U}_n = \frac{\sum_{i=1}^{n} S_i\, U_i}{\sum_{i=1}^{n} S_n} \quad \text{..............} \ ⑨$$

The number of servers at each station *i*, S_i:

$$S_i = \text{minimum integer} \geq R_p^*\,(WL_i) \quad \text{..............} \ ⑩$$

4.2 Case study:

A linear pallet system is designed for the movement of parts on pallets within a Flexible Manufacturing System (FMS), comprising seven stations. These include three machining stations: a Horizontal Machining Center (HMC), a Multi-Turn Center (MTC), and a Multi-Tasking Machine (MTM), along with an inspection station, two load/unload servers, and a transport shuttle cart. Additionally, there is a part-storage unit featuring eight storage spaces. The system produces five distinct part styles, labeled A, B, C, D, and E, with their respective part-mix fractions detailed in Table 1. The processing sequence follows a numerical order corresponding to the stations, with cycle times provided. The time required to load and secure a part onto a pallet fixture at station 5 is indicated to the left of the slash, while the unloading time is shown to the right. The average transport time for parts is 1.2 minutes, and the time for an empty move is 0.6 minutes. Each transport move is accompanied by an empty move. Parts are conveyed on pallet fixtures from station 4 to the part-storage station 6, after which they proceed through their designated processing routes, return to storage, and are unloaded at station 4 as time allows, as illustrated in Figure 1.

Table (1): List of operations and process time on different machining centers.

Part Style (j)			A	B	C	D	E
Part-Mix Fraction P_j			0.15	0.2	0.15	0.3	0.2
Station (j)	**Operation**	**Server (s_j)**	$T_{c/A}$	$T_{c/B}$	$T_{c/C}$	$T_{c/D}$	$T_{c/E}$
1	HMC	2	25	35	18	29	
2	MTC	1	20		15	23	33
3	MTM	1	28	23	40		16
4	Insp.	1	15	8	10	7	11
5 (n+1)	Load/Unload	2	10/4	12/6	10/5	9/4	11/5
6 (n+2)	Transport	1	1.2/0.6	1.2/0.6	1.2/0.6	1.2/0.6	1.2/0.6
7 (n + 3)	Part storge	8	NA	NA	NA	NA	NA

Part (A): Load → HMC → MTC → MTM → Insp. → Unload
Part (B): Load → HMC → MTM → Insp. → Unload
Part (C): Load → HMC → MTC → MTM → Insp. → Unload
Part (D): Load → HMC → MTC → Insp. → Unload
Part (E): Load → MTC → MTM → Insp. → Unload

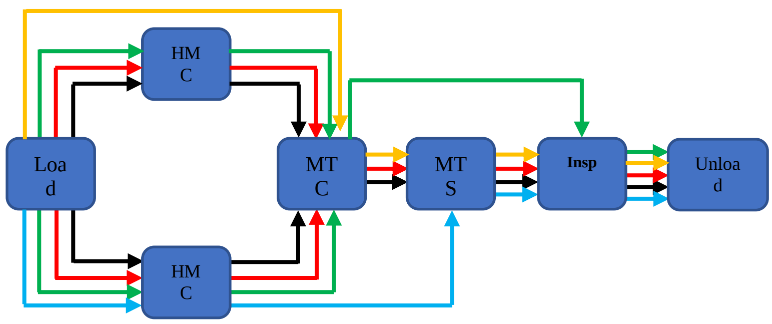

Fig. 1: Block diagram of considered FMS of case study

V. RESULTS AND DISCUSSION

The performance analysis of FMS with various resources is presented in this section.

5.1. Identification 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. from equation number (1,2,3) the average workload, WL_i is:

$$WL_i = \sum_{j=1}^{p} T_{cij}\, P_j \quad \ldots\ldots\ldots\ldots\ldots \text{①}$$

$WL_i = (T_{c/A}) * (P_A) + (T_{c/B}) * (P_B) + (T_{c/C}) * (P_C) + (T_{c/D}) * (P_D) + (T_{c/E}) * (P_E)$

WL_1 = (0.15)*(25) + (0.2)*(35) + (0.15)*(18) + (0.3)*(29) + (0.2)*(0)

= 22.15 min/pc = 0.369 hr/pc

WL_2 = (0.15)*(20) + (0.2)*(0) + (0.15)*(15) + (0.3)*(23) + (0.2)*(33)

= 18.75 min/pc = 0.313 hr/pc

WL_3 = (0.15)*(28) + (0.2)*(23) + (0.15)*(40) + (0.3)*(0) + (0.2)*(16)

= 18 min/pc = 0.3 hr/pc

WL_4 = (0.15)*(15) + (0.2)*(8) + (0.15)*(10) + (0.3)*(7) + (0.2)*(11)

= 9.65 min/pc = 0.161 hr/pc

WL_5 = (0.15)*(10+4) + (0.2)*(12+6) + (0.15)*(10+5) + (0.3)*(9+4) + (0.2)*(11+5)

= 15.05 min/pc = 0.251

$$WL_6 = WL_{n+2} = n_t\, T_r + n_g\, T_g \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{②}$$

$$\text{Where: } n_t = \sum_{j=1}^{p} n_v\, p_j - 1 \quad \ldots\ldots\ldots\ldots\ldots \text{③}$$

n_v = visited stations 4 → 6 → 1 → 2 → 3 → 4 → 6 → 4 ⇒ n_v = 6

$n_t = \sum_{j=1}^{p} n_v\, p_j - 1 = (6 * 0.15 + 6 * 0.2 + 6 * 0.15 + 6 * 0.3 + 6 * 0.2) - 1 = 5$

WL_6= (5)*(1.2) + (5)*(0.6) = 9 min = 0.153 hr

WL_7= N/A

The bottleneck station is identified by the largest WL/s ratio:

$$\text{Bottleneck station} = \frac{WL_i}{S_i} \quad \ldots\ldots\ldots\ldots\ldots \text{④}$$

For station 1, $R_p^* = \frac{WL_1}{S_1} = \frac{0.369}{2} = 0.185$

For station 2, $R_p^* = \frac{WL_2}{S_2} = \frac{0.313}{1} =$ **0.313** …. Bottleneck station

For station 3, $R_p^* = \frac{WL_3}{S_3} = \frac{0.3}{1} = 0.3$

For station 4, $R_p^* = \frac{WL_4}{S_4} = \frac{0.161}{1} = 0.161$

For station 5, $R_p^* = \frac{WL_5}{S_5} = \frac{0.251}{2} = 0.126$

For station 6, $R_p^* = \frac{WL_6}{S_6} = \frac{0.15}{1} = 0.15$

For station 6, NA

The bottleneck station refers to the station that has the maximum workload for each server. The summary of the calculated values of the six stations are given in Table 2.

Table (2): values of the six stations

Part Style (j)		**A**	**B**	**C**	**D**	**E**	**WL_i (hr)/pc**	**WL_i / S_i (hr)**
Part-Mix Fraction P_j		**0.15**	**0.2**	**0.15**	**0.3**	**0.2**		
Station (j)	**Servers (Sj)**	**$T_{c/A}$ (hr)**	**$T_{c/B}$ (hr)**	**$T_{c/C}$ (hr)**	**$T_{c/D}$ (hr)**	**$T_{c/E}$ (hr)**		
1	**2**	**25**	**35**	**18**	**29**		**0.369**	**0.185**
2	**1**	**20**		**15**	**23**	**33**	**0.313**	**0.313**
3	**1**	**28**	**23**	**40**		**16**	**0.3**	**0.3**
4	**1**	**15**	**8**	**10**	**7**	**11**	**0.161**	**0.161**
5 (n + 1)	**2**	**0.233**	**0.3**	**0.25**	**0.217**	**0.267**	**0.251**	**0.126**
6 (n + 2)	**1**	**0.18**	**0.15**	**0.18**	**0.15**	**0.15**	**0.15**	**0.15**
7 (n + 3)	**8**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

Analysis of the ratio of peak workload to number of servers indicated that the MTC station was a bottleneck station that limited the capacity of the FMS under investigation as shown in figure (2).

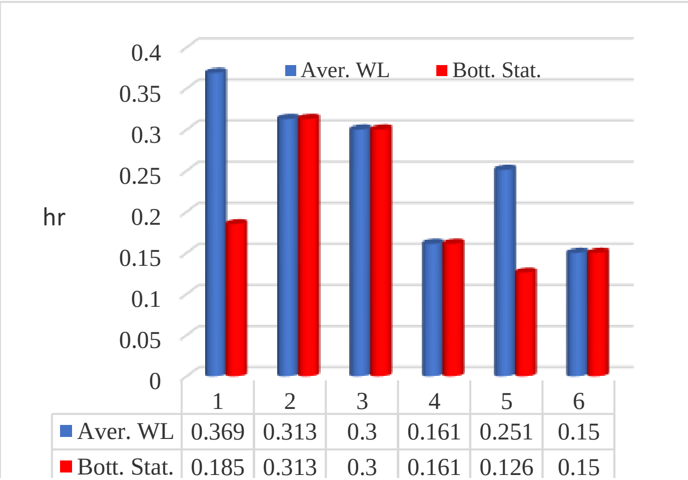

Fig. 2: Ratio of peak workload to number of servers

5.2 Maximum Production Rate of all Parts:

The bottleneck station restricts the maximum production rate for all parts and it can be calculated by:

$$R_p^* = \frac{S^*}{WL^*} \text{ .... ④}$$

Where: S^*= Number of servers at bottleneck station = 1 server

WL^* = Work load at bottleneck station = 0.313 hrs.

$$R_p^* = \frac{S^*}{WL^*} = \frac{1}{0.313} = 3.195 \text{ pc/hr}$$

The summary of the calculated values of the six stations are given in Table 3.

Table (3): maximum production rate

Station(j)	Servers (Sj)	WL_i (hr)/pc	WL_i / S_i (hr)	R_p^* (pc/hr)
1	2	0.369	0.185	
2	1	0.313	**0.313**	3.195
3	1	0.3	0.3	
4	1	0.161	0.161	
5 (n + 1)	2	0.251	0.126	
6 (n + 2)	1	0.15	0.15	
7 (n + 3)	8	NA	NA	NA

Correspondingly, part production rate for the separate stations (of part type j) can be found out by:

Correspondingly, part production rate for the separate stations (of part type j) can be found out by:

$$R_{p_j}^* = P_j \,(R_p^*) = P_j \left(\frac{S^*}{WL^*}\right) \text{ .... ⑤}$$

For part style A,

$R_{pA}^* = P_A \; R_p^* = 0.15 * 3.195 = 0.479$ pc/hr

For part style B,

$R_{pB}^* = P_B \; R_p^* = 0.2 * 3.195 = 0.639$ pc/hr

For part style C, $R_{pC}^* = P_C \; R_p^* = 0.15 * 3.195 = 0.479$ pc/hr

For part style D, $R_{pD}^* = P_D \; R_p^* = 0.3 * 3.195 = 0.959$ pc/hr

For part style E, $R_{pE}^* = P_E \; R_p^* = 0.2 * 3.195 = 0.639$ pc/hr

5.3 The number of busy servers at each station:

The number of busy servers at each station can be calculated by:

$$BS_i^* = R_p^* \,(WL_i) \text{ .... ⑥}$$

For station 1, $BS_1^* = R_p^* \,(WL_1) = 3.195 * 0.369 = 1.181$

For station 2, $BS_2^* = R_p^* \,(WL_2) = 3.195 * 0.313 = 1$

For station 3, $BS_3^* = R_p^* \,(WL_3) = 3.195 * 0.3 = 0.960$

For station 4, $BS_4^* = R_p^* \,(WL_4) = 3.195 * 0.161 = 0.515$

For station 5, $BS_5^* = R_p^* \,(WL_5) = 3.195 * 0.251 = 0.803$

For station 6, $BS_6^* = R_p^* \,(WL_6) = 3.195 * 0.15 = 0.490$

For station 7, NB

Table (4): Part production and busy servers at each

Station (j)	Servers (Sj)	WL_i (hr)/pc	WL_i / S_i (hr)	R_p^* (pc/hr)	BS_i^*
1	2	0.369	0.185		1.181
2	1	0.313	**0.313**	3.195	1
3	1	0.3	0.3		0.960
4	1	0.161	0.161		0.515
5 (n + 1)	2	0.251	0.126		0.803
6 (n + 2)	1	0.12	0.15		0.490
7 (n + 3)	8	NA	NA	NA	NA

5.4 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^*). Average utilization (U_i^*) is given as the product of the ratio of workload per server and the maximum production rate (R_p^*)

$$U_i^* = \frac{WL_i}{S_i}\,(R_p^*) = \frac{WL_i}{S_i} \text{ X } \frac{S^*}{WL^*} = \frac{BS_i^*}{S_i} \text{ .... ⑦}$$

For station 1, $U_1^* = \frac{BS_1^*}{S_1} = \frac{1.181}{2} = 0.590$

For station 2, $U_2^* = \frac{BS_2^*}{S_2} = \frac{1}{1} = 1$

For station 3, $U_3^* = \frac{BS_3^*}{S_3} = \frac{0.960}{1} = 0.960$

For station 4, $U_4^* = \frac{BS_4^*}{S_4} = \frac{0.515}{1} = 0.515$

For station 5, $U_5^* = \frac{BS_5^*}{S_5} = \frac{0.803}{2} = 0.401$

For station 6, $U_6^* = \frac{BS_6^*}{S_6} = \frac{0.490}{1} = 0.490$

For station 7, NA

Table (5): Part production, busy servers and utilization at each station

Station (j)	Servers (Sj)	WL_i (hr)/pc	WL_i / S_i (hr)	R_p^* (pc/hr)	BS_i^*	U_i^*	U_i^* (%)
1	2	0.369	0.185		1.181	0.590	59.0
2	1	0.313	0.313	3.195	1	1	100
3	1	0.3	0.3		0.960	0.960	96.0
4	1	0.161	0.161		0.515	0.515	51.5
5 (n + 1)	2	0.251	0.126		0.803	0.401	40.1
6 (n + 2)	1	0.12	0.12		0.490	0.490	49.0
7 (n + 3)	8	NA	NA	NA	NA	NA	

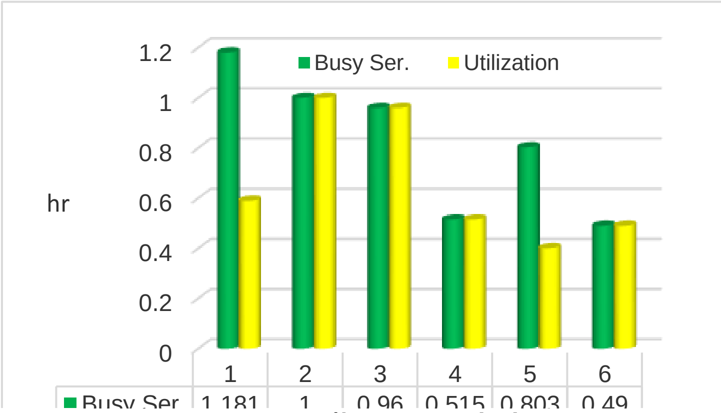

Fig. 3: Ratio of busy servers and utilization station

Average utilization of the processing stations is given as:

$$U_n^* = \frac{\sum_{i=1}^{n} S_i U_i^*}{S_n} = \frac{BS_n^*}{S_n} \quad \ldots\ldots\ldots\ldots\ldots \text{⑨}$$

$$= \frac{1.181 + 1 + 0.960 + 0.515}{2 + 1 + 1 + 1} = \frac{3.656}{5}$$

$$U_n^* = 0.7312 = 73.12\ \%$$

Average utilization of all stations except storage:

$$U_n^* = \frac{\sum_{i=1}^{n} S_i U_i^*}{S_n} = \frac{BS_n^*}{S_n}$$

$$= \frac{1.181 + 1 + 0.960 + 0.515 + 0.803 + 0.490}{2 + 1 + 1 + 1 + 2 + 1} = \frac{4.949}{8}$$

$$U_n^* = 0.6186 = 61.86\ \%$$

Table (6): Summary of the calculated values of the six stations

Part Style (j)		A	B	C	D	E
Part-Mix Fraction Pj		0.15	0.2	0.15	0.3	0.2
Station (j)	Servers (Sj)	$T_{c/A}$(hr)	$T_{c/B}$(hr)	$T_{c/C}$ (hr)	$T_{c/D}$(hr)	$T_{c/E}$ (hr)
1	2	25	35	18	29	0
2	1	20	0	15	23	33
3	1	28	23	40	0	16
4	1	15	8	10	7	11
5 (n + 1)	2	14	18	15	13	16
6 (n + 2)	1	0.18	0.15	0.18	0.15	0.15
7 (n + 3)	8	NA	NA	NA	NA	NA

WL_i (hr)/pc	WL_i / S_i (hr)	R_p^* (pc/hr)	BS_i^*	U_i^*	Un*
0.369	0.185		1.181	0.591	61.853
0.313	0.313	3.200	1.000	1.000	
0.300	0.300		0.960	0.960	
0.161	0.161		0.515	0.515	
0.251	0.125		0.803	0.401	
0.153	0.153		0.490	0.490	
NA	NA		NA	NA	

5.5 Proposed Flexible Manufacturing System:

5.5.1 Sizing the FMS

The findings of the analysis indicate that while resource allocation is functioning effectively, the distribution of workload is flawed. Consequently, the ideal number of servers has been established, and the Flexible Manufacturing System (FMS) has been designed to ensure an equitable distribution of workload and to address any bottlenecks present in the system under examination. To achieve this balance, the number of servers will be increased from 8 to 11. Following the addition of these servers, the operational and performance metrics will be evaluated in comparison to those of the current system.

5.5.2 Production rate of proposed manufacturing system

The enhanced manufacturing system's maximum productivity is constrained by the material handling system, which serves as a bottleneck within the overall process. To determine the maximum productivity of the proposed Flexible Manufacturing System (FMS), the same methodologies and equations utilized for assessing the productivity of current systems were employed. Similar to the calculations performed for the existing system, the newly proposed system is capable of attaining a maximum production rate of 6.218 parts per hour.

5.5.3 Utilization of workstation for the proposed manufacturing system

Average utilization is defined as the duration a specific workstation is operational rather than idle. This metric is determined by multiplying the maximum production capacity by the ratio of workload to the number of servers. The findings are presented in Table (7).

Table (7): Summary of the calculated values of the six stations after optimization

Station (j)	Servers (Sj)	$T_{c/A}$ (hr)	$T_{c/B}$ (hr)	$T_{c/C}$ (hr)	$T_{c/D}$ (hr)	$T_{c/E}$ (hr)	WL_i (hr)/pc	WL_i / S_i (hr)	R_p^* (pc/hr)	BS_i^*	U_i^*	Un*
Part Style (j)		A	B	C	D	E						
Part-Mix Fraction Pj		0.15	0.2	0.15	0.3	0.2						
1	3	25	35	18	29	0	0.369	0.123		2.295	0.765	87.405
2	2	20	0	15	23	33	0.313	0.156	6.218	1.943	0.972	
3	2	28	23	40	0	16	0.300	0.150		1.865	0.933	
4	1	15	8	10	7	11	0.161	0.161		1.000	1.000	
5 (n + 1)	2	14	18	15	13	16	0.251	0.125		1.560	0.780	
6 (n + 2)	1	0.18	0.15	0.18	0.15	0.15	0.153	0.153		0.951	0.951	
7 (n + 3)	8	NA	NA	NA	NA	NA	NA	NA		NA	NA	

The total utilization of the proposed system was determined using the specified equation, resulting in an enhancement of utilization from 61.851% to 87.405%. The eleventh column of Table 7 illustrates the utilization rates of the workstations, indicating that the proposed or modified Flexible Manufacturing System (FMS) facilitates improved workstation utilization. The following figure compares the utilization of the proposed FMS with that of the current FMS resources.

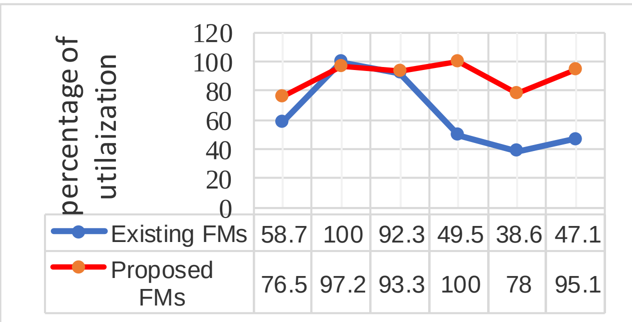

Fig.4.Existing Vs Proposed FMSs Utilization

The comparison of the existing and proposed FMS corresponding to the production rate, total number of servers, and overall utilization is represented in the table (8).

Table 8: Performance of FMS (Existing Vs. Proposed)

S/N	Performance Parameters	Existing (FMs)	Proposed (FMs)
1	No of servers	08	11
2	Overall utilization	61.860	87.414
3	Production rate	3.200 parts/hr	6.218parts/hr

VI. CONCLUSIONS

This paper presents the application of quantitative methods: the Bottleneck Model and the Extended Bottleneck Model to evaluate the production performance of the FMS based on real data through a case study. Using the two models, various operating and performance parameters were calculated and compared with the performance of the proposed FMS. The study showed that the workload per server of the existing system for the MTC Multi-Turn Center is higher. This is evident from the fact that the machine utilization of this station is 100%. Therefore, the turning center is identified as the station that limits the production speed of the existing system and is classified as the bottleneck station.

The workstation utilization has also been investigated in the study and the results showed that resources are underutilized due to uneven workload distribution. To improve the performance of the existing system, it is important to move the bottleneck station to another less important station and propose a new FMS that properly distributes the load among each station. The improvement is achieved by adding three servers to the existing system and proposing a new FMS. The proposed system shows promising improvements in all operational performance indicators, including production rate and overall utilization. The modified FMS improved the overall workstation utilization by 25.55% and the production rate by 3,018 pieces per hour.

While the research results are important for managers in measuring performance and making decisions, analytical approaches to determining the performance of a system assume certainty regarding all system parameters such as processing time, production rate, and product demand, whereas in real applications, these parameters constantly change over time and the planning period changes. Therefore, the prospects for future research in the field of FMS are to develop probabilistic models for analyzing the performance of FMS and to propose ways to improve its performance. Another limitation of this paper is that it does not include financial analysis, therefore, including financial analysis in the study is another research topic that needs to be expanded.

VII. REFERENCES

Fig. 4:

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