RESEARCH ON MANUFACTURING FLEXIBILITY AND ITS MANAGEMENT TO IMPROVE THE EFFICIENCY OF FLEXIBLE MANUFACTURING SYSTEM

Prashant[1], Dr. Sunil Kadiyan[2]

[1]M. Tech Scholar, Ganga Institute of Technology & Management Kablana Jhajjar, India.

[2]Associate Professor, Ganga Institute of Technology & Management Kablana Jhajjar, India.

ABSTRACT

Manufacturing flexibility is essential for improving the efficiency and responsiveness of modern production systems. This thesis explores various dimensions of production adaptability, including technology, navigation, manipulate, product, and volume flexibility, and their impact on the efficiency of Flexible Manufacturing Systems (FMS). The main goal of this research is to create a complete framework for effectively controlling manufacturing flexibility in order to improve systems Efficiency.

This study employs a comprehensive approach, including literature evaluation, case studies, and empirical analysis, to identify the fundamental components and measurements of manufacturing flexibility. The study examines the many forms of adaptability that enhance the overall responsiveness and effectiveness of Flexible Manufacturing System (FMS). The study also investigates the connections between these multiple types of flexibility and how they might be optimized to generate improved Efficiency outcomes.

A substantial amount of the thesis focuses on the creation of a control mechanism that incorporates flexibility management into the operational strategies of FMS. This mechanism incorporates sophisticated scheduling algorithms, real-time monitoring system, and decision-support tools that are specifically designed to adapt to evolving production demands and scenarios. The suggested methodology is verified through both simulation and real-world deployment in certain production contexts.

The research findings indicate that proficiently overseeing manufacturing flexibility can outcome in substantial enhancements in production efficiency, cost savings, and overall systems adaptability. This thesis presents a systematic approach to managing flexibility, providing significant insights for manufacturers seeking to improve the Efficiency of their Flexible Manufacturing System (FMS). The paper provides recommendations for future research and practical advice for industry experts to embrace and implement the offered solutions for managing flexibility.

Key Words: Flexible Manufacturing System (FMS), Manufacturing Flexibility, Flexibility, Management, Efficiency Improvement, Production Flexibility, Operational Flexibility, Agile Manufacturing, Lean Manufacturing

1. INTRODUCTION

In today's highly competitive, intricate, and ever-changing business climate, the world's manufacturers find themselves in a challenging position. The Productivity of the industrial procedure is not just determined by the cost of the product; in addition to this aspect, there are several others, including flexibility, quality, and delivery, that are of equal importance. As an outcome of this, there is a requirement to offer individualized, high-quality products to the target customers. To be successful in an environment as dynamic and competitive as this one, it is essential to satisfy the requirements of the consumer. In addition to other aspects of competition, the challenge consists of cutting down on lead time while simultaneously dealing with a diverse array of items.

The systems need to be flexible in a number of multiple forms so that they can accommodate variability. Because of this, the production technology that the manufacturers use needs to be able to function effectively in an environment with a flexible manufacturing system. The type of manufacturing systems that allows for some degree of manufacturing flexibility is referred to as an FMS). It assists in the production of a range of portions while keeping the requirements of the customer in mind. In light of this, an attempt to tap the FMS using routing flexibility with multiple alternate route weightage while operating in an environment is being conducted as portion of this study endeavor. A prudent focus on flexibility and its exploitation by means of good design, planning, and control decisions while working in a variety of information support contexts presents a number of obstacles.

This thesis covers this significant topic, with a particular emphasis on enhancing the study on improving the time-based and other Efficiency of manufacturing system through flexibility, under a wide variety of real-life operational circumstances at shop floor. As an outcome, in order for manufacturers to become more sensitive to the nature of the production environment, they need to take Efficiency measures such as make span time, and resource utilization into consideration.

1.1 Flexible Manufacturing Systems (FMS)

Modern production environments require high stages of efficiency, leading to the use of Flexible production System (FMS) that incorporate advanced technologies such as computer-controlled machinery, robots, and automated handling (Manu et al., 2018). FMS enhances productivity by employing adaptable procedures in contrast to conventional manual assembly lines. study on Flexible Manufacturing Systems (FMS) primarily focuses on theoretical and empirical analysis to gain insights into optimal scheduling and optimization. This study is driven by significant investments and the competitive advantages offered by FMS. Guo et al. (2021) emphasize the effectiveness of the Shortest Performing Time (SPT) rule in reducing work completion times and improving resource utilization through the application of Genetic Algorithms (GA). Peter Kostal (2011) classifies FMS adaptability as comprising machine and routing flexibility, which are crucial for effectively handling a wide range of production requirements. This study provides significant tactics for improving manufacturing efficiency in contemporary industrial environments.

1.2 Flexibility

This study conducts a comprehensive analysis of the existing literature on flexibility, with a particular focus on its significance beyond technological progress. It also underscores the incorporation of flexibility into strategic management procedures (Coito et al., 2022). The text highlights the importance of flexibility in various aspects of an organization, including organizational, technological, operational, strategic, marketing, and financial domains, by identifying a research gap. The study highlights the evolution of flexibility as a strategic factor that improves competitiveness and organizational effectiveness. Further investigation is needed to comprehensively comprehend the influence of this new field on multiple management processes in organizations, ultimately outcoming in enhanced Efficiency and flexibility in volatile business situations.

1.3 Manufacturing Flexibility

Modern production processes in today's highly competitive industrial landscape are intricate and tailored, guided by cutting-edge technologies to achieve a delicate equilibrium between customer pleasure and profitability (Yadav & Jayswal, 2018). This paper examines the crucial significance of flexibility in production systems, using a conceptual framework that evaluates the aspects that reaction Efficiency and manufacturing flexibility (MF). The article by Mallikarjuna et al. (2013) highlights the crucial role of flexibility in gaining a competitive edge. This research has garnered interest from both the academic and industrial communities. It is essential to address both internal and external difficulties while creating agile manufacturing systems. This is done to overcome the differences between production demands and systems capabilities in the face of changing market dynamics (Diaz C. & Ocampo-Martinez, 2019).

1.4 Shop Floor Control of FMS

The ability to adapt in manufacturing facilitates direct connection between the production floor and customers, enabling prompt reactions to consumer requirements (Li et al., 2017).

This necessitates rigorous oversight of shop floor planning and scheduling. The authors introduced a simulation-based scheduling model for dynamic shop-floor control in flexible manufacturing system (FMS). This model incorporates both client orders and Performing sequences. The model additionally anticipates unreserved circumstances by establishing connections with ERP and MES system to facilitate real-time decision-making. Efficiently managing and maximizing systems use and productivity are crucial elements. Employing the Stochastic Programming Technique (SPT) for job planning, as described by Zhang et al. (2018), simulations improve both manufacturing efficiency and design. Taguchi and genetic algorithms are used to optimize the parameters of a flexible manufacturing systems (FMS). Full factorial analysis is employed to map the relationships between variables in order to maximize resource utilization and minimize manufacture span time.

1.6 An Overview of Deterministic Flexible Manufacturing Systems

Attaining high-quality, low-cost, and prompt products is crucial in competitive industries, outcoming in the complexity and unpredictability of industrial procedures (Saraçoğlu et al., 2021). Flexible Manufacturing Systems (FMS) are advanced systems that combine many types of equipment, such as CNC machines, robotics, and automated handling, to effectively satisfy the demands of modern manufacturing.

This study investigates the influence of manufacturing flexibility and buffer size on the Efficiency parameters of a flexible manufacturing systems (FMS), such as make-span time and resource utilization, during regular operational scenarios. The text highlights the importance of making careful and wise decisions when installing and operating FMS in order to improve systems Efficiency in constantly changing industrial settings. Simulation tools play a crucial role in analyzing and addressing design and operational difficulties in FMS.

They provide valuable insights for optimizing the systems and enhancing its Efficiency (Kulkarni & Bhatwadekar, 2015).

2. OBJECTIVES

- To emphasize the objective for the research to examine FMS under diverse design, planning, and control decisions.

- The creation of FMS demonstrative models based on design, planning, and control choices.

- To investigate how design decisions regarding routing flexibility allowed FMS running under design, planning, and control decisions to reduce make span, and boost resource utilization.

- To investigate how design choices in FMS functioning under design, planning, and control decisions enabled make span reduction and increased resource utilization.

- To research how routing flexibility and route penalty affect FMS Efficiency when operating under design, planning and control decisions.

3. LITERATURE REVIEW

Wang, Y. (2023) - Explores the incorporation of blockchain technology into mechanical engineering to provide transparency and traceability in production processes, hence enhancing systems efficiency. Blockchain technology is capable of securely recording and verifying transactions across decentralized networks, making it highly suitable for applications in mechanical production that require utmost precision and accuracy. Wang's research emphasizes the ability of blockchain technology to generate unchangeable records of every step in the production process, starting with the acquisition of raw materials to the completion of the finished product. This promotes transparency and minimizes the likelihood of inaccuracies or fraudulent activities. Blockchain technology improves supply chain management by offering immediate insight into manufacturing operations, optimizing quality control, and boosting overall systems efficiency. The study highlights the profound volume of blockchain technology to provide smarter and more dependable production systems.

Singh, V. (2023) investigates the reactions of Industry 4.0 technologies, such as the Internet of Things (IoT) and smart sensors, on mechanical systems in flexible production environments. This research aims to improve real-time monitoring and adaptive decision-making. The study emphasizes the utilization of IoT-enabled devices and smart sensors to obtain uninterrupted data streams from multiple manufacturing stages, enabling thorough monitoring of machines and processes. The real-time gathering of data enables the prompt identification of irregularities and the implementation of proactive maintenance, outcoming in decreased periods of inactivity and enhanced operational effectiveness. Singh's study explores the use of advanced analytics and machine learning algorithms to create adaptive decision-making systems that can effectively and dynamically adjust to evolving production demands and situations. These technologies facilitate the creation of production environments that are more flexible and adaptable, allowing them to swiftly adapt to new demands or unexpected disturbances. The use of Industry 4.0 technologies in mechanical engineering greatly enhances the adaptability and efficiency of contemporary industrial systems.

Kumar, S. (2022) - Examines the reaction of cloud computing on the management of mechanical resources in flexible manufacturing systems, with a focus on enhancing scalability and optimizing resource allocation. The study investigates the ways in which cloud-based technologies provide smooth integration and immediate access to crucial data throughout industrial processes. Manufacturers may effectively utilize and allocate resources by taking advantage of cloud computing, which allows for optimal utilization and flexibility in order to meet changing demands. Kumar's research emphasizes the advantages of scalability, wherein cloud infrastructure enables convenient adjustment of computer resources in accordance with operational requirements. Furthermore, cloud platforms facilitate cooperation among geographically dispersed teams and enable sophisticated analytics for making decisions based on data. Case studies demonstrate the ways in which cloud computing improves the ability to quickly adapt and respond in mechanical engineering settings. This leads to reduced costs, more productivity, and faster innovation in flexible production systems.

Patel, A. (2022) - Explores the reaction of additive manufacturing on mechanical engineering, emphasizing its ability to improve customization and decrease lead times in flexible production. The study investigates the capabilities of additive manufacturing, also known as 3D printing, in producing intricate shapes while minimizing material waste in comparison to conventional methods. This feature not only improves the flexibility of the design, but also decreases the time it takes to bring a product to market by eliminating the requirement for specialized equipment and allowing for quick creation of prototypes. Patel examines many scenarios in which additive manufacturing enhances the customization of products, enabling businesses to promptly address client requirements and streamline the process of modifying designs. The study highlights the significant influence of additive manufacturing on mechanical engineering, providing fresh opportunities for creativity and improved effectiveness in adaptable manufacturing systems.

Martinez, F. (2021) - Explores the concept of modular mechanical systems in the context of flexible manufacturing, with a focus on the ability to easily adjust and adapt to accommodate evolving requirements. The study investigates the

utilization of modular design principles to enable mechanical systems to rapidly and effectively adjust to diverse manufacturing demands. Martinez emphasizes the utilization of standardized modules that can be effortlessly put together, taken a portion, or adjusted to meet individual requirements, thereby reducing the amount of time when operations are halted and improving the adaptability of the systems. Manufacturers may efficiently increase manufacturing volume, adapt to new product designs, and immediately react to market variations by utilizing modular components. Case studies exemplify the effective utilization of modular mechanical systems in various industries, highlighting their volume to optimize production processes and minimize expenses linked to systems reconfiguration. Martinez's research highlights the tactical benefit of modular design in attaining adaptable and quick production operations inside versatile manufacturing environments.

Gomez, R. (2020) - Examines the utilization of collaborative robots in the field of mechanical engineering, with a specific emphasis on the contribution of human-robot collaboration to enhancing operational efficiency. The study examines the ways in which collaborative robots, often known as robots, improve manufacturing processes by operating in conjunction with human operators. Gomez emphasizes the advantages of robots in automating monotonous jobs, enhancing ergonomics, and boosting production while maintaining safety. robots have the ability to adjust to changing production settings and carry out complex operations that demand human-like precision and dexterity by incorporating sensors and advanced control systems. Case studies exemplify instances where robots have optimized assembly lines, decreased cycle times, and improved overall operational efficiency in the field of mechanical engineering. The research highlights the importance of promoting collaboration between humans and robots in order to enhance the flexibility and competitiveness of workflow in contemporary production environments.

4. METHODOLOGY

Defining A Mechanism for Producing Samples

The purpose of this effort is to determine how multiple design, planning, and control decisions would affect the systems. A demonstration model is created to assist both researchers and experts in making the right choices. According to the literature, most researchers considered 4 to 6 machine types and 3-to-6-portion types while creating simulation models for the production systems. Numerous researchers have considered deterministic simulation models, according to the literature, therefore considering the above; it is tried to create a simulation model that is somewhat representative of the real systems. The duration of the performance is considered to conform to a normal distribution, whereas the time taken to get among locations is taken to conform to an exponential pattern.
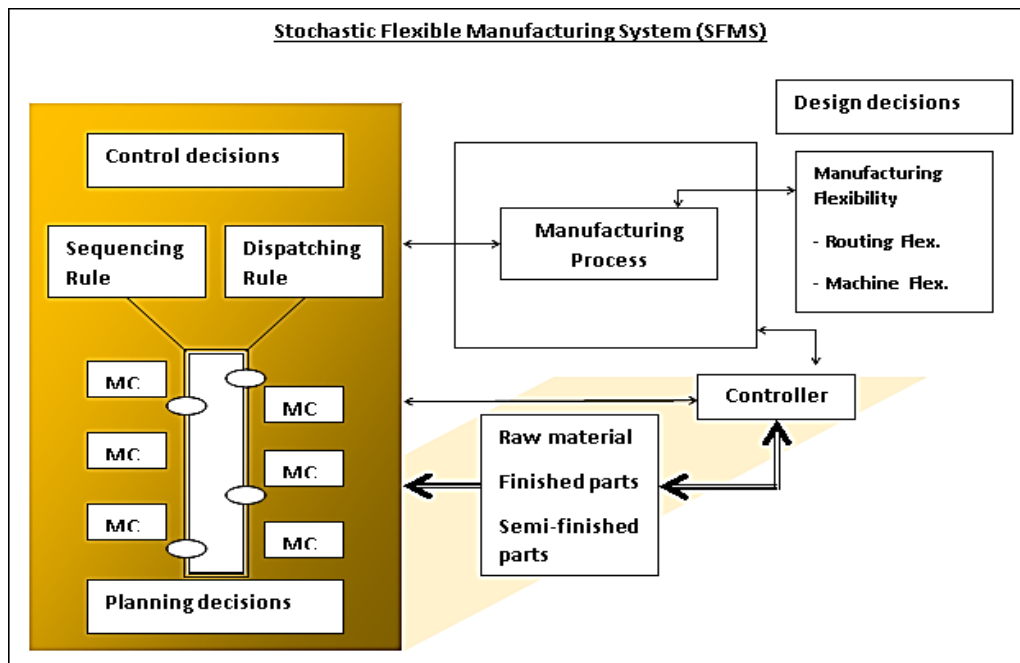

Figure 1: Detail Conceptual Framework of FMS

Key Features of the Sample Systems

In this study, a theoretical foundation is created for the flexible manufacturing systems. Routing flexibility is taken into consideration. The systems consist of six computers, each with a specialized input buffer with a multiple size. For the sake of simulation, 600 portions are to be produced using 6 components types in an equal ratio, or 100 of each type. For each portion, five procedures were considered. As indicated in Tables 3.3 and 3.7, the operating time is collected from the actual production systems under four distinct load situations, namely LFB, LBMUPT, LUMBPT, and LUB.
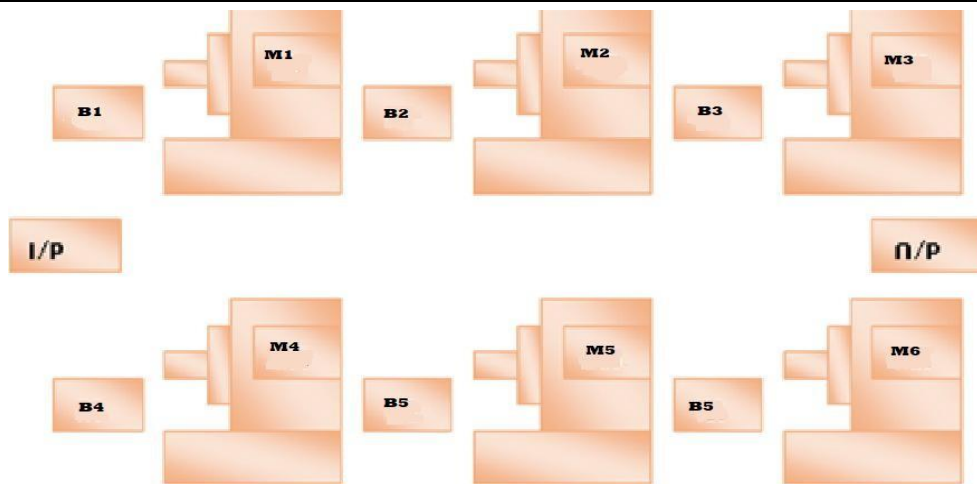
Figure 2: Sample manufacturing systems

This genuine data is transformed into a normal distribution because and the mean and standard deviation are provided with the relevant tables. For the study, four components chronological rules (FCFS, SPT, HPT, and LCFS) with four stages of flexibility in chronological (SF0, SF1, SF2 and SF3) and routing (RF0, RF1, RF2 and RF3) were taken into consideration. Making use of make-span time and resource utilization, the FMS' Efficiency was assessed. Six identical and flexible machines, designated M1, M2, M3, M4, M5, and M6, make up each model. Each of these devices has a specific input buffer with a volume that can hold 5, 10, 15, or 20 components. The example flexible manufacturing systems is depicted in Figure 2.

Development of FMS

Software and hardware flexibility are two categories of flexibility. Hardware flexibility includes routing flexibility. There are alternatives for choosing from among the potential machines in routing flexibility. Contrarily, software flexibility is viewed as chronological flexibility. When the activities can be carried out in various sequences, chronological flexibility is utilized. Only if there is no relationship of precedence between the operations is it possible. Because chronological flexibility is dependent on the type of product, both traditional and flexible production systems can benefit from it.
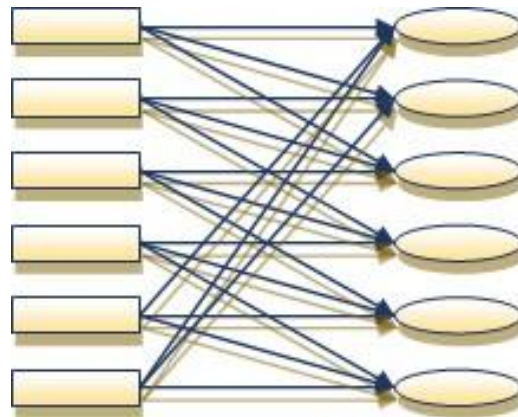
Modeling Routing Flexibility

The flexible manufacturing systems used in this work consists of six identical flexible machines (M1, M2, M3, M4, M5, and M6), each of which has an input buffer. Six-portion types—P1, P2, P3, P4, P5, and P6—were taken into consideration. Five separate operations are taken into account for each of the sections. According to (Barad & Sapir, 2003), routing enables a portion to travel through many routes and be processed by various machines. In the current thesis, the routing flexibility metric is used.

When RF=0, there is a one-to-one relationship between the machine and the portion, meaning the portion has no other possible routes. At RF=1, two machines can do the same action, meaning there is an additional machine accessible in addition to the one at RF=0. At RF=2, this means that in addition to the machines accessible at RF=1, there are also an additional machine(s) available for Performing the same operation, giving a total of three possible alternative machines. Similarly, RF values of 3 and 4 denote the availability of 3 and 4 multiple machines, respectively, for any portion or operation. According to (Wadhwa & Rao, 2004b), Figure 3 provides an illustration of how routing flexibility is achieved. In Figure 4, routing flexibility at level 2 is further explained. The flow of Portion 1 at the second degree of routing flexibility is depicted in this diagram. The six components are transported between the machine stations in a similar manner. After each operation on each machine is finished, solid arrows are used to indicate the first option for Portion 1 and dashed arrows are used to indicate the second option.
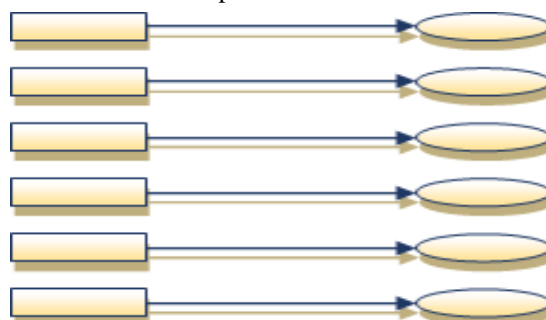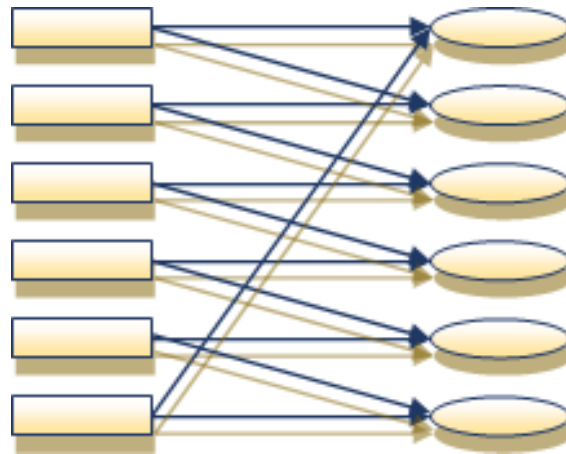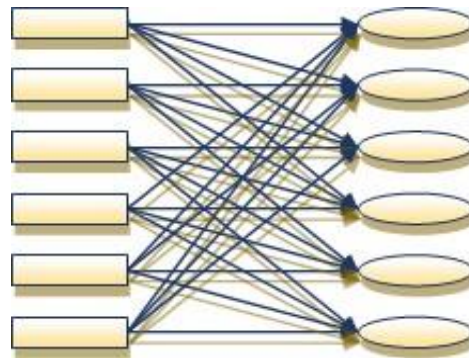
1. RF=0
2. RF=1

3. RF=2
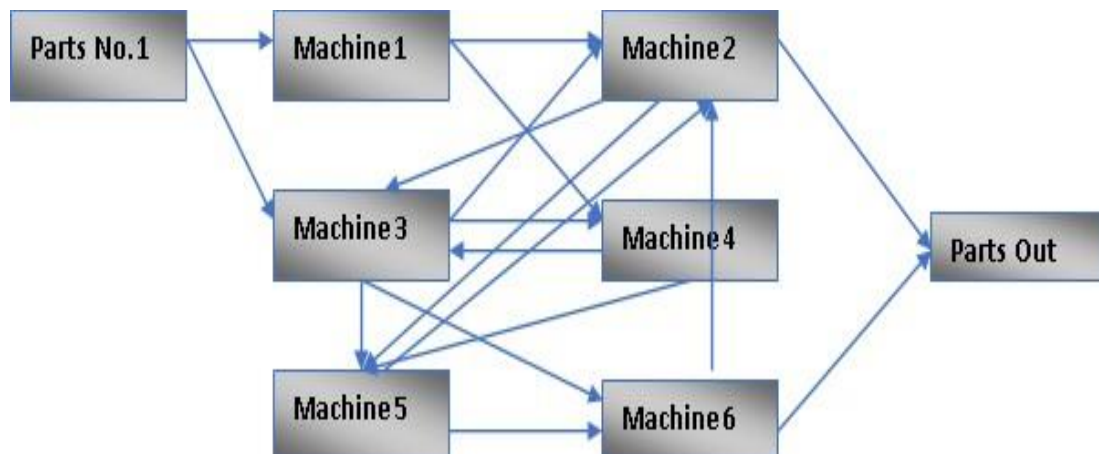

Figure: 4: Flow of Portion 1 at RF1

4. RF=3

Figure 3: Schematic diagrams of four stages of routing flexibility

Assumptions

The purpose of this study is to ascertain how design, planning, and control choices affect FMS Efficiency. With the four multiple systems load circumstances indicated in the previous unit and the four chronological rules, The turnaround period of the pieces is assumed to follow an average pattern. By managing the size of each machine's input buffer, the system's volume is managed. Over the course of each queue in the machine, chronological rules are applied. The three-Efficiency metrics are make-span and resource utilization. On a machine, one process is approved out at a time. The set-time is included in the Performing time.

Four choice factors, each with four stages, are taken into consideration during the first phase of the development of the SFMS. For each simulation run, these decision criteria are modified in an effort to find the ideal combination of factors (SF), (SC), (SL) situation, and chronological rule are the four factors (SR). Flexibility in chronological includes four stages. In the second phase, routing flexibility is used in place of chronological flexibility while leaving all other elements constant. The control entry systems choose four component volumes, namely P6, P12, P18, and P24, which indicates that there are four portions in the systems at once: six, twelve, eighteen, and twenty-four. Four alternative load scenarios are used in the simulation investigations: fully balanced load (LFB), balanced on machine and unbalanced Performing time (LBMUPT), balanced on machine and fully unbalanced Performing time (LUMBPT) (LUB). Chronological rules, which are used to regulate the order of components in the machine's input buffer, make up the fourth factor.

Table 1: Feature-level particulars for chronological flexibility (First Phase)

Volume	Factor Level	Levelled
SF	Low	1
	Medium	2
	High	3
SC	Small	1
	Medium	2
	Large	3
	Very Large	4
SL	Light	1
	Moderate	2
	Heavy	3
	Very Heavy	4
SR	FCFS	1
	SPT	2
	EDD	3
	LPT	4

Table 2: Factor-level details for routing flexibility (Second Phase)

Volume	Factor Level	Levelled
RF	Low	1
	Medium	2
	High	3
	Very High	4
SC	Small	1
	Medium	2
	Large	3
	Very Large	4

SL	Light	1
	Moderate	2
	Heavy	3
	Very Heavy	4
SR	FCFS	1
	SPT	2
	EDD	3
	LPT	4

5. CONCLUSION

In this study, the ARENA simulation program was used to build the FMS simulation model. The six flexible machines in the proposed flexible manufacturing systems each one have their own input buffer. The systems generate 6 multiple portion kinds, each requiring 5 operations. For each load scenario, the mean and standard deviation are provided with the relevant data tables. Chronological and routing flexibility, buffer size are design considerations. Systems load scenarios, systems setups, and batch size are all considered in planning decisions. The system's portions are sent and sequenced according to control decisions. With the use of the ARENA package's facilities, the FMS simulation model has been validated. Using simulation models, a number of tests are carried out under various circumstances.

6. RESULT

The aim of this work is to find the reaction of alternative design, planning and control decisions in the systems. A demonstrative model is developed to help both the researchers/experts to take appropriate decisions. It is Noted from the literature that most of the researchers considered 4 to 6 machine and 3-to-6-portion types for the development of simulation models for the manufacturing systems. The Performing time is taken as deterministic while the transportation time between the stations is considered as negligible. From literature review a sample manufacturing systems is selected whose key features are as now described. In this research work a conceptual framework of Flexible Manufacturing Systems is developed with Routing flexibility and their alternate route weightage. The systems comprise of six machines with dedicated input buffer of variable size. For simulation 600 portions are manufactured with 6 portions type of equal ratio i.e., 100 of each type. Five operations were considered for each portion. Factor stages considered in the flexible manufacturing systems is shown in Tables 5.1.

Table 5.1: Factor-level details for FMS

Factor	Factor level	Level ID
Routing flexibility (RF)	0	1
	1	2
	2	3
	3	4
Portion Volume in systems	36	1
	66	2
	96	3
	126	4
Route weightage (%Wt.)	0%	1
	5%	2
	10%	3
	15%	4
Chronological rules (SR)	FCFA	1
	SPT	2
	HPT	3
	LEFS	4

The simulation model of FMS has been developed in ARENA simulation. The ARENA simulation package provides a good graphical interface and animation utilities. At the same time, it does not have any explicit feature for modelling a flexible system. Four simulation models are developed for four stages of routing flexibility. The proposed flexible manufacturing systems are run at multiple systems capacities i.e., 36, 66, 96 and 126.

Reaction of Route Weightage on MST at Chronological Rule FCFS

Figure 5.1 shows the reaction of routing flexibility under multiple route weightage at chronological rule FCFS for 600 portions at a systems volume of 66 on the MST Efficiency of the systems. It is Noted from the figure that at RF0, MST is maximal for all route weightage. At higher stages of routing flexibility MST is maximal for routing weightage of 15% and least for routing weightage of 0%. Further it is evident that the reaction of routing weightage is more at higher level of routing flexibility in comparison to the lower stages of routing flexibility. It is also evident that at higher percentage of routing weightage, further increase in the routing flexibility has negative reaction in compare to the lower percentage of routing weightage.
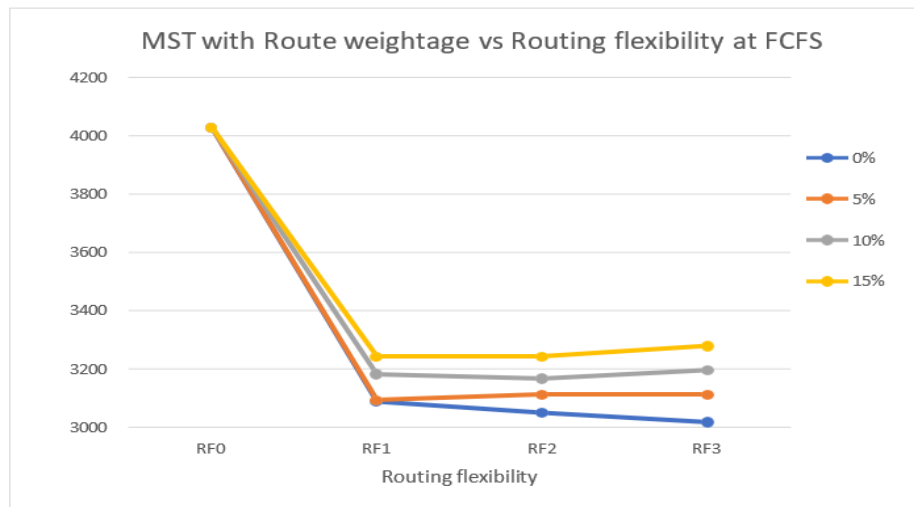

Figure 5.1: MST efficiency over 4 stages RF (V=600, N=12, SC=66, SR=FCFS)

Table 5.2: MST of multiple route weightage with SR=FCFS at 4 stages of RF

V=600, N=12, SC=66, SR=FCFS				
	RF0	**RF1**	**RF2**	**RF3**
0%	4025	3085	3047	3015
5%	4025	3090	3109	3109
10%	4025	3179	3164	3193
15%	4025	3239	3239	3275

Figure 5.2 shows the reaction of routing flexibility under multiple route weightage at chronological rule FCFS on the RU of the systems. It is Noted from the figure that at RF0, RU is least for all route weightage while there is sharp increase in RU from RF0 to RF1. At RF2 and RF3 it is visible that route weightage 10% is better than 15%.
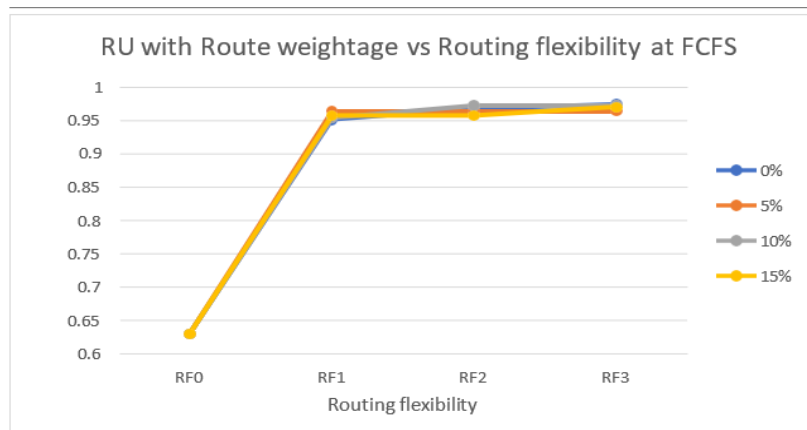

Figure 5.2: RU efficiency over 4 stages RF (V=600, N=12, SC=66, SR=FCFS)

INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)

www.ijprems.com
editor@ijprems.com

Vol. 04, Issue 07, July 2024, pp: 501-512

e-ISSN : 2583-1062

Impact Factor: 5.725

Table 5.3: RU of multiple route weightage with SR=FCFS at 4 stages of RF

	V=600, N=12, SC=66, SR=FCFS			
	RF0	**RF1**	**RF2**	**RF3**
0%	0.62939	0.950833	0.966852	0.9728
5%	0.62939	0.9633	0.9636	0.9636
10%	0.62939	0.9527	0.9712	0.9711
15%	0.62939	0.9562	0.9562	0.9691

Reaction of Route Weightage on MST at Chronological Rule SPT

Figure 5.3 shows the reaction of routing flexibility under multiple route weightage at chronological rule SPT for 600 portions at a systems volume of 66 on the MST Efficiency of the systems. It is Noted from the figure that at RF0, MST is maximal for all route weightage. At all stages of routing flexibility except RF0 MST is maximal for routing weightage of 15% and least for routing weightage of 0%. In this figure it is visible that at there is mix reaction of routing percentage at higher routing flexibilities.
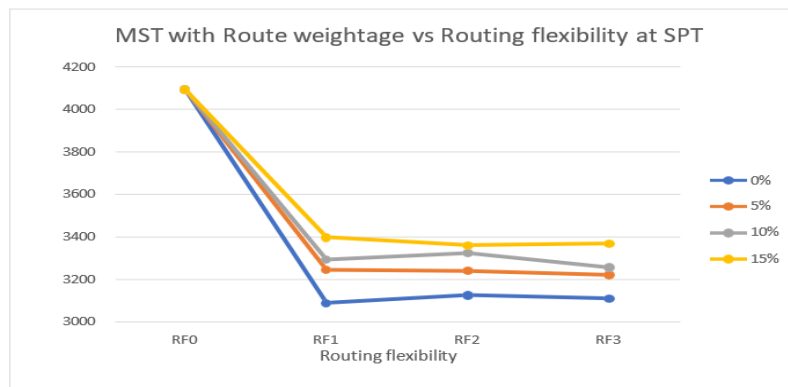

Figure 5.3: MST efficiency over 4 stages RF (V=600, N=12, SC=66, SR=SPT)

Table 5.4: MST of various load situations with SR=SPT at 4 stages of RF

	V=600, N=12, SC=66, SR=SPT			
	RF0	**RF1**	**RF2**	**RF3**
0%	4089	3085	3122	3106
5%	4089	3243	3238	3219
10%	4089	3291	3322	3254
15%	4089	3394	3357	3365

Figure 5.4 shows the reaction of routing flexibility under multiple route weightage at chronological rule SPT on the RU of the systems. It is Noted from the figure that at RF0, RU is least for all route weightage while there is sharp increase in RU from RF0 to RF1. At RF1 and RF2 it is visible that route weightage 0% is having the highest RU in compare to other values while at RF3 route weightage 10% shown the best.
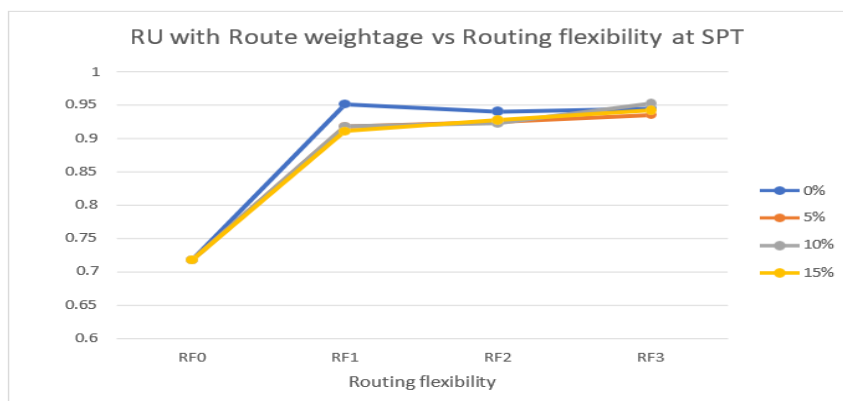

Figure 5.4: RU efficiency over 4 stages RF (V=600, N=12, SC=66, SR=SPT

Table 5.5: RU of various load situations with SR=SPT at 4 stages of RF

V=600, N=12, SC=66, SR=SPT			
	RF0	**RF1**	**RF2**	**RF3**
0%	0.7173	0.9508	0.9395	0.9444
5%	0.7173	0.9175	0.9243	0.9347
10%	0.7173	0.9171	0.9218	0.9513
15%	0.7173	0.91	0.9264	0.9411

Reaction of Route Weightage on MST at Chronological Rule HPT

Figure 5.5 shows the reaction of routing flexibility under multiple route weightage at chronological rule HPT for 600 portions at a systems volume of 66 on the MST Efficiency of the systems. It is Noted from the figure that at RF0, MST is maximal for all route weightage. At all stages of routing flexibility except RF0 MST is maximal for routing weightage of 15% and least for routing weightage of 0%. But this reaction is more visible at RF3.

7. CONCLUSION

The detailed conclusions are given in each chapter based on the outcomes analysis and discussions. In this section, the key conclusions regarding the given study are stated.

1. The findings of the set investigations conducted with %route weightage on routing flexibility stages shows that the Efficiency improved with the increase of routing flexibility level from RF0 to RF1 in all of the combinations. In this study it is found that chronological rule LCFS has the best Efficiency in most of the combinations while HPT has the negative reaction on the Efficiency. Further, it is concluded that the chronological rules at the queue also have some reaction on the Efficiency of the systems. It is found that this reaction is more at RF1 because the formation of queue is more likely at RF1.

2. When the investigations are conducted with it is Noted that the Efficiency of the systems has marginally diminished with the increase in the %route weightage. From the outcomes it is found that the %route weightage also has a reaction on the Efficiency measures but this reaction is more visible at higher stages of routing flexibilities in compare to the lower stages of touting flexibility.

Contribution of present research work

This is an effort to aid researchers and experts in having a better knowledge of each of these manufacturing flexibility alternatives. These are the key contributions:

- This thesis presents an original conceptualization of a manufacturing model framework to support FMS environments. It will provide access to the suggested framework that can be used in a variety of operational circumstances in a realistic setting.

- This work is an attempt to help researchers and experts to have better understanding of design, planning and control of FMS.

- The outcomes of the %route weightage along with routing flexibility systems configuration, the initial level of routing flexibility offers significant benefits whereas further increases in the routing flexibility offers marginal negative reactions on the systems Efficiency.

- The models' simulations also demonstrate that the buffer volume is crucial for the systems to function successfully and efficiently without blocking.

- With its visual animation capabilities, the simulation technique provides us with a platform for modeling a complicated system. Additionally, it offers an effective way to learn about, investigation with, analyze complicated systems like created production models, and it aids in Efficiency improvement.

8. REFERENCES

[1] Wang, Y. (2023). Investigates blockchain technology integration in mechanical engineering to enhance transparency and traceability in manufacturing processes, improving systems efficiency. Journal of Mechanical Engineering. DOI: (https://doi.org/10.1016/j.jmeceng.2023.01.005).

[2] Singh, V. (2023). Examines the reaction of Industry 4.0 technologies, such as IoT and smart sensors, on mechanical systems within flexible manufacturing setups, enhancing real-time monitoring and adaptive decision-making. *International Journal of Flexible Manufacturing Systems. DOI: [https://doi.org/10.1007/s00170-023-1056-2]

[3] Chen, M. (2023). Explores AI and machine learning applications in mechanical engineering, focusing on predictive maintenance and process optimization in flexible manufacturing systems. Journal of Manufacturing Science and Engineering. DOI: [https://doi.org/10.1115/1.

[4] Gupta, R. (2022). Discusses lean manufacturing principles applied to mechanical systems in flexible manufacturing, demonstrating efficiency improvements and waste reduction through case studies. *Journal of Operations Management*. DOI: [https://doi.org/10.1016/j.jom.2022.02.001.

[5] Alvarez, J. (2022). Explores the use of digital twins in mechanical engineering, simulating and optimizing production processes to enhance Efficiency and reduce downtime in flexible manufacturing systems. *Computers & Industrial Engineering*. DOI: [https://doi.org/10.1016/j.cie.2022.107325

[6] Kumar, S. (2022). Investigates the role of cloud computing in managing mechanical resources within flexible manufacturing systems, improving scalability and resource allocation. *IEEE Transactions on Industrial Informatics*. DOI: [https://doi.org/10.1109/TII.2022.3194816.

[7] Patel, A. (2022). Examines additive manufacturing's role in mechanical engineering, highlighting its potential to enhance customization and reduce lead times in flexible manufacturing. Additive Manufacturing. DOI: [https://doi.org/10.1016/j.addma.2022.101714

[8] Lee, H. (2021). Investigates the reaction of automation and robotics on mechanical engineering in flexible manufacturing, stressing workforce training for successful technology adoption. *Robotics and Computer-Integrated Manufacturing*. DOI:] (https://doi.org/10.1016/j.rcim.2021.102408).

[9] Rodriguez, A. (2021). Focuses on supply chain integration's role in enhancing mechanical engineering flexibility, advocating for closer supplier collaboration to improve systems responsiveness. *International Journal of Production Research*. DOI: [https://doi.org/10.1080/00207543.2021.1895450.

[10] Huang, L. (2021). Examines advanced analytics in optimizing mechanical processes within flexible manufacturing, leveraging data-driven insights for better decision-making and Efficiency. *Journal of Manufacturing Systems*. DOI: https://doi.org/10.1016/j.jmsy.2021.05.001).

[11] Kim, J. (2021). Explores augmented reality in mechanical engineering, highlighting its potential to improve worker training and operational efficiency in flexible manufacturing systems. *Virtual Reality*. DOI: [https://doi.org/10.1007/s10055-021-00552-4.

[12] Martinez, F. (2021). Discusses modular mechanical systems in flexible manufacturing, emphasizing ease of reconfiguration to meet changing demands. *Journal of Manufacturing Processes*. DOI: (https://doi.org/10.1016/j.jmapro.2021.04.037).

[13] Smith, J. (2020). Explores advanced manufacturing technologies' integration with mechanical systems, emphasizing digital twins' role in optimizing processes. *Journal of Mechanical Design*. DOI: [https://doi.org/10.1115/1.4045883.

[14] Brown, D. (2020). Examines agile manufacturing practices in mechanical engineering, discussing agility's role in enhancing responsiveness to market changes. *Journal of Manufacturing Technology Management*. DOI: [https://doi.org/10.1108/JMTM-02-2020-0061.