Performance Enhancement of Flexible Manufacturing System Using Meta-Heuristics Hybrid Algorithm

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Abstract- The goal of today's manufacturing strategy is to maximize the benefits of flexibility. Only when a manufacturing system is completely controlled by FMS technology is this possible. A flexible manufacturing system is one in which there is some degree of flexibility that enables the system to adapt to changes, whether anticipated or unanticipated. This flexibility may be broken down into two main categories and various subcategories. The first is what is known as machine flexibility, which allows a machine to produce a variety of items. The second category is routing flexibility, which allows different computers to perform the same job. CNC machine tools, transport systems, and control systems are the three main components of flexible manufacturing systems. The so-called intelligent manufacturing systems represent a higher degree of flexible manufacturing systems. Petrinets are a form of modeling construct that may be used in a variety of situations, including data analysis, simulations, business process modeling, and other scenarios. This mathematical construct can aid in the planning of workflows or the presentation of data on complex systems. Six machines, six jobs are considered in the case study. The Petrinet concept is proposed to solve scheduling problems and compared with Scatter Search algorithm. The results are compared for case study (6 machines X 6 jobs) and it is observed that the Petrinet provides better result when compared with Scatter Search with respect to machine utilization. When comparing Petrinet to Scatter Search in terms of machine utilization, the results show that Petrinet outperforms Scatter Search.

Keywords – Flexible Manufacturing System, Machines, Scatter Search approach, Petrinet model, Machine utilization

I. Introduction

Flexible Manufacturing System (FMS) is an automated production environment in which numerous processes may run at the same time. Different items may be made at the same time, and shared resources are often used to save costs. The system is made up of machines that can perform a wide range of tasks on a set of parts. The unpredictable situation of today's market is requiring the manufacturing managers to develop the flexible manufacturing systems (FMS) to meet the difficulties imposed by worldwide competition, constantly changing consumer needs, speedy delivery to market and progress in technology Raj et al (2008) [1]. A simulation mechanism and a real-time control system are two major components of the scheduling mechanism. The simulation system assesses dispatching rules and chooses the most appropriate dispatching rule for each criterion. The real-time control system examines the system's performance value and monitors the shop floor on a regular basis. Until the difference between the real performance value and the value anticipated by simulation reaches a certain threshold, the specified dispatching rule is utilized Kim et al (1994) [2]. In a flexible manufacturing system (FMS), a scheduling challenge is made up of two interdependent tasks: loading and sequencing. The loading issue has two objectives: minimize system workload imbalance and minimize system imbalance and the number of late jobs, with restrictions such as the number of tools slots with duplications, unique job routing, non-splitting of tasks, and machine capacity Kripa, and Tzen (1985) [3].

A flexible manufacturing system (FMS) is concerned with the automated manufacture of various components in the medium range owing to its capacity to be flexible in nature. In a nutshell, it's a fully automated production system. This article provides an overview of prior work in the domain of FMS modeling as well as research and development for a better understanding of FMS. It is used to investigate work that is done in FMS utilizing various modeling approaches like as mathematics, artificial intelligence, hierarchical, multi-criteria decision-making, Petrinets, and simulation Yadav (2018) [4]. It is important to be flexible. There are two main categories and a number of subcategories. The very first is the so-called machine flexibility, which allows for the creation of a variety of products, falls into this category. The given machinery produces a variety of products. The second group is route flexibility allows for the execution of the same task through a variety of methods. machines. Typically, flexible manufacturing systems are made up of three components. CNC machine tools, transport system, and control system are the three main components. Flexible manufacturing systems at a higher level are represented by 'Intelligent manufacturing systems' Peter and Velisek (2010) [5]. Each component manufactured will be piece manufacturing, which means that just one piece of this component will be manufactured. Variability (for each component's size and form variations) will be rather broad. FMS's planning and control of the manufacturing process must be adjusted to account for this. The method of developing ground plans is discussed, for example, in references Peter et al (2010) [6]. . As a result of the lack of flexibility in reacting, the ability to respond to market needs (customers), and the competitiveness of Manufacturers are losing ground and are being outpaced by competitors. rivals with little or no experience in the machine business, but having the capacity to react quickly to consumer needs increased adaptability Mudriková and Štefan (2008) [7]. The results of an experimental study of operating methods for a computer-controlled flexible manufacturing system are presented. The system is actual, and it includes nine machines, an inspection station, and a centralized queuing space, all of which are linked by an automated material-handling mechanism. Policies for loading (assigning processes and tooling to machines) and real-time flow control are among the operational techniques explored. To evaluate the various options, a comprehensive simulation was used. The findings vary from those of traditional job shop scheduling studies, demonstrating that system performance is dependent on the loading and control tactics used to run this flexible manufacturing system Stecke and Solberg (1981) [8]. The most basic need for scheduling is to identify the target function for which the best schedule is wanted; one of the most generally utilized objectives is to complete the project in the shortest time possible. In the context of an FMS, the following goals are particularly significant (Smith et al (1986) [9]):

(a) Increasing system/machine utilization
(b) Meeting deadlines
(c) Increasing production rates
(d) Reducing in-process stocks
(e) Reducing setup and tool change times
(f) Reducing mean flow times
(g) Balancing machine utilizations

Scheduling that is well-planned gives a company a competitive advantage and the ability to innovate Customers will be satisfied if things are delivered on time. Initially, scholars saw the scheduling issue as a simple mathematical optimization issue, and their methods were based on the use of mathematical formulas. Enumerative methods and mathematical models are examples of models. programming, as well as linear programming approaches, etc. to get at the best result. The very first mathematical expression Stecke (1983) [10] provided a solution for the FMS-loading problem. Many researchers, including Stecke and Solberg (1981) [11], believed that carried performed a computer-controlled simulated study Nine machines make up a flexible production system. A centralized queue space, and an inspection station an automated material-handling device connects them. The findings vary from those of traditional jobshop scheduling studies, demonstrating the system's dependency. Performance of the specified loading and control schemes

to run this versatile production system. Persi and Solberg JJ (1981) [12] addressed the issue of enhancing the Using a machine to use a flexible manufacturing cell a top-down approach Sets of pieces that can be combined at a higher level Batches of data to be handled at the same time are determined. At the moment, Batches are sequenced, connected, and planned at lower levels. The purpose of this paper is to describe a study that looked into the impact of alternate operations on the performance of flexible manufacturing systems (FMS). An alternative operation could be directed, for example, to avoid a long queue and could be performed by a machine with less capability, incurring a time penalty. Three approaches for implementing alternative operations inside the FMS's hierarchical structure are designed, and test results are compared to performance attained with no alternative operations Wilhelm and Shin (1985) [13]. When developing a flexible manufacturing system (FMS), a visual interactive decision support framework is presented to assist the decision-maker, often senior management, in picking the best suitable technology and design. After deciding in principle to create an FMS, the framework may be employed in the pre investment stage of the planning process. To begin, both qualitative and quantitative criteria are employed to reduce the number of different system configurations under evaluation to a small number of the most appealing possibilities Antonie and Kuula (1991) [14]. Flexible manufacturing systems (FMSs), their design, and control have all been widely investigated in recent literature because to their expanding application in contemporary industry. The FMS scheduling challenge is one of the most serious challenges that has developed in this environment. This paper discusses a novel concept of an FMS system that is prompted by a real application that considers both machine and vehicle scheduling Jacek et al (1991) [15].

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II. MODELS

A. Petrinet Model

A Petrinet is a graphical, mathematical modeling tool that may be used to a wide range of systems. It's a potential tool for describing and investigating information processing systems that are concurrent, asynchronous, distributed, parallel, nondeterministic, or stochastic. Petri nets, like flow charts, block diagrams, and networks, may be used as a graphical tool for visual communication. This mathematical tool may be used to build state equations, algebraic equations, and other mathematical models that guide the behavior of systems. It's a type of directed graph with an initial state called the initial marking. In these nets, tokens are also used to replicate the system's dynamic and concurrent actions. Petrinets may be useful for both practitioners and theoreticians. As a consequence, they may be used to communicate effectively between practitioners and theoreticians. Practitioners may teach theoreticians how to make their models more systematic, while theoreticians may educate practitioners how to make their models more realistic. You must grasp both the modeled phenomena and the modeling methodology in order to apply the modeling approach successfully. The components are used in Petrinet modeling, and the schematic is shown in Fig. 1.

The fundamental operation of Petrinet is shown in Figure 1. The present location (P1) has one token and is ready to fire from it and move to the next location (P2) via transition (t1)

Where,

P - is a finite set of places;

T - {t1, t2… tn} → is a finite set of transitions

I - P × T → N is an input function that defines directed arcs from places to transitions, where N is a set of nonnegative integers;

O-T × P →N is an output function that defines directed arcs from transitions to places; and

M0 – P → N is the initial marking.

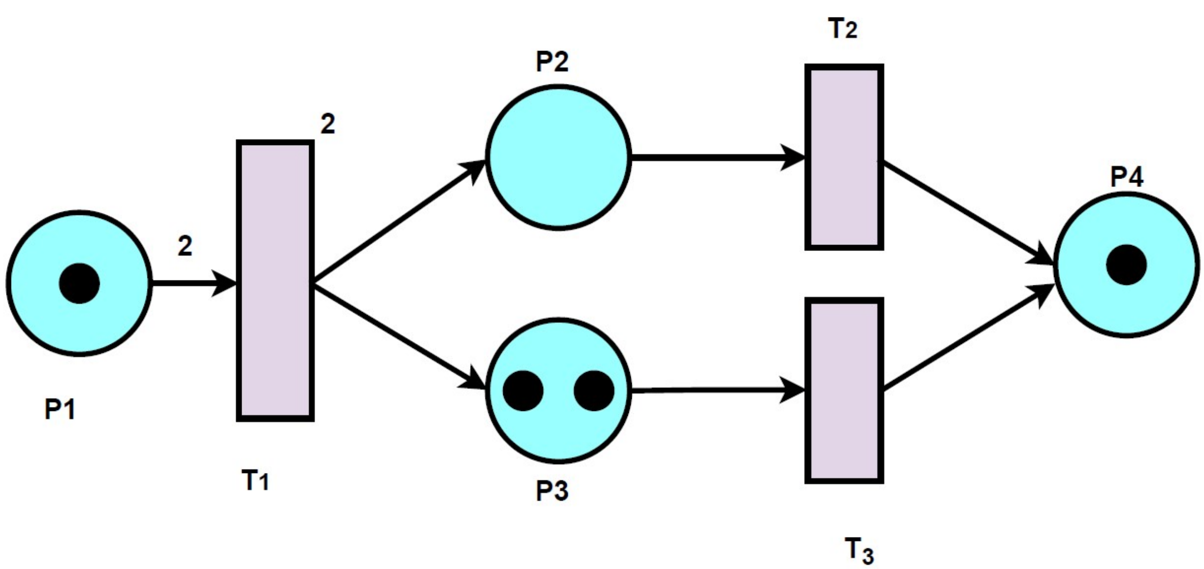

Figure1. Petrinet work Model

The use of Petrinets to model and analyze a flexible manufacturing system (FMS) cell is discussed. To accomplish the hierarchy and preservation of critical system attributes, top-down refinement, system decomposition, and modular composition principles are applied throughout the process. These qualities, which include liveness, boundedness/safety, and reversibility, ensure that the system is stable, deadlock-free, and cyclic. In addition, a timed Petrinet analysis for cycle time is shown. A reduction approach is used to transform the timed Petrinet into an equivalent timed marked graph. The cycle time for annotated graphs is then calculated using the normal approach Zhou et al (1993) [16]. A flexible manufacturing system (FMS) is a manufacturing system that is highly interconnected. Its components have a complicated relationship. Because mathematical programming methodologies for highly complex systems are difficult to solve, FMS simulation is commonly utilized to examine its performance measurements. Modeling and performance analysis have been investigated in relation to FMS. The idea and implementation of Petrinets for monitoring and analyzing FMS performance metrics are presented in this study. AweSim, a Visual Slam software program, was also used to simulate the system. The bottleneck methodology, which is another well-defined mathematical methodology, has also been used to compare and verify the simulation findings. FMS as an example has been considered, and its Petrinet model, AweSim model, and mathematical model have all been built. The performance of the system has been assessed using a variety of metrics. It has also been discovered that simulation approaches make analyzing the complicated flexible manufacturing system simple Tamimi et al (2012) [17]. The use of PNs to simulate and control production systems is explored. Top-down, bottom-up, and a hybrid technique combining the two are briefly discussed as PN synthesis approaches for industrial control. The mutual exclusion theory and hybrid approach are summarized. This synthesis approach ensures that the final net has the desired features of liveness, boundedness, and reversibility. The FMS and the network of computers that control the components are described. The controlled automated production system is a one-sixth size physical model of a shop that conducts both machining and assembly processes. Two machining workstations with robotic loading and unloading, a robotic assembly workstation, a materials transportation system, raw material and finished product inventory storage, and an automated storage and retrieval system are all included in the system. This manufacturing system's PN model is designed using a hybrid technique. There are examples of top-down and bottom-up synthesis structures, as well as choice-synchronization structures. A supervisory control PN description language and PN execution method are described Zhou et al (1992) [18]. The total performance of an FMS, which consists of a carousel layout surrounded by production and assembly cells capable of delivering a range of numerous goods, is modelled, simulated, and analyzed in this work. Variations in input parameters such as mean machining and assembly time, material loading and unloading time, number of operations between failures, repair time, parts inter-arrival time, conveyor speed, and buffer capacity have been proved to have a significant impact on system performance. The findings show that colored Petrinet tools may be used to model, simulate, and evaluate a carousel-configured multiple-product flexible manufacturing system Zahid and Aized (2020) [19]. The quantitative features of lead time and throughput were assessed by Da et al. (2016) [20]. In addition to Petrinets, Time Petrinets are a subclass of PNs. Petrinets toolbox simulation in MATLAB. Mohamed et al. (2013) [21] conducted a thorough comparison of conventional and alternative methods. Petrinets in various colors Petrinets (PN) and colored Petrinets (CP) are two types of nets are both general graphical and ideal design tools. A production system is simulated, verified, and specified. CPN, on the other hand, is a common expansion of the standard Petrinet with an additional The inclusion of color symbolizes tokens for large-scale modeling. However, it has complicated production methods and is capable of producing concise analysis, direct data manipulation, and thorough analysis description. Aized et al. (2007) [22] [23] developed a colorful Petrinet-based FMS model to explore the cycle time changes and throughput of multistaged, multi-lined, and variable product FMSs that include assembly, machining station with inspection units, and routing flexibility. Optimization of the addressed system has been done using DoE and RSM in combination with CPN tools to achieve effective performance.

B. Scatter Search

Scatter search (SS), unlike other evolutionary strategies, provides for a wider study of the search space by raising the intensity and diversifying the search space. It also uses an adaptive memory strategy to avoid developing or integrating duplicate answers at various stages of the problem. In this paper, a meta-heuristic methodology known as scatter-search (SS) is used to optimize the scheduling of flexible manufacturing systems by taking into account several goals, such as lowering the machine's idle time and lowering the overall penalty cost for missing the due date.

In contrast to other evolutionary procedures, scatter search (SS) allows for a broad exploration of the search space through intensification and diversification. It also has a unifying principle for joining solutions, and it makes use of adaptive memory to avoid generating or incorporating duplicate solutions at different stages of the problem. Various meta-heuristic strategies are utilized in this study to solve three distinct sizes of scheduling issues that were collected from the literature. The findings acquired by the scatter-search approach are compared to the results acquired by the different known meta-heuristic approaches. For all three problems, the proposed framework produces better results, with an average deviation of 16.67 percent from the best results obtained by other methods Saravanan and Noorul Haq (2008) [24]. The results of a novel evolutionary method termed scatter search are contrasted in this research study for the identical benchmark tasks performed by the aforementioned writers. In scheduling issues such as flow shop scheduling, the scatter-search method works better Noorul haq and Saravanan (2007) [25]. In this study, a meta-heuristic methodology known as Scatter-Search (SS) is used to optimize the scheduling of flexible manufacturing systems with the goal of decreasing the makespan with machine failure. It allows for a broad investigation of the search space through intensification and diversification, as well as a unifying concept for linking solutions, and it uses adaptive memory to prevent producing or integrating duplicate solutions at different phases of the issue. This methodology is compared to static scheduling in a comparative study Krishnan et al (2013) [26].

Flexible Manufacturing Systems (FMSs) are cutting-edge products that are integrated with manufacturing systems. It is made up of two or more robots with machining cells and computer-controlled automated guided vehicles (AGVs). By reducing retracing distance and distance traveled by Automated Guided Vehicles, this article emphasizes the necessity of employing loop architecture and planning in FMS (AGV). The Improved Scatter Search Method is a hybrid meta heuristic algorithm utilized in this work (ISSA) Chinnusamy et al (2020) [27].

The various methods for improving the solutions range from simple local searches to a highly complex method. A somewhat simple strategy is a local search based on a set of basic movements consisting of choosing an improving move until no such basic move exists. Improving moves are fundamental movements that result in a solution with improved values for the goals. The Scatter Search meta heuristic strategy includes deciding how to update the reference set while the search is ongoing. A halting condition for the entire search phase is also included in the meta heuristic. The reference set is then filled with a selection of great, efficient solutions as a result of the technique. Since the best solution selected was changed the last time, the most typical stopping criteria are based on allowing a total maximum computing time or a maximum computational effort.

III. CASE STUDY

For the production process, the researchers Udhayakumar and Kumanan (2012) [28], Noorul et al (2003) [29], Krishnan et al (2009) [30] designed a U-shaped production model as shown in figure 2 with six machines, six products, two load/unload stations, and one Automated Guided Vehicle (AGV) employed. Table 1 shows the setup specifics. Table 2 lists the operation sequence numbers for each component. Table 3 shows the manufacturing model's operating time for each separate machine.

Table - 1 Configuration of FMS

Sl.No	Layout Type	No. of Machines	No. of Parts	Load / Unload Stations	No. of AGV
1	U Loop	06	06	02	01

Table - 2 Operation sequence for Case Study

Sl.No	Part Type	Operation Sequence					
		1	2	3	4	5	6
1	P1	M3	M1	M2	M4	M6	M5
2	P2	M2	M3	M5	M6	M1	M4
3	P3	M3	M4	M6	M1	M2	M5
4	P4	M2	M1	M3	M4	M5	M6
5	P5	M3	M2	M5	M6	M1	M4
6	P6	M2	M4	M6	M1	M5	M3

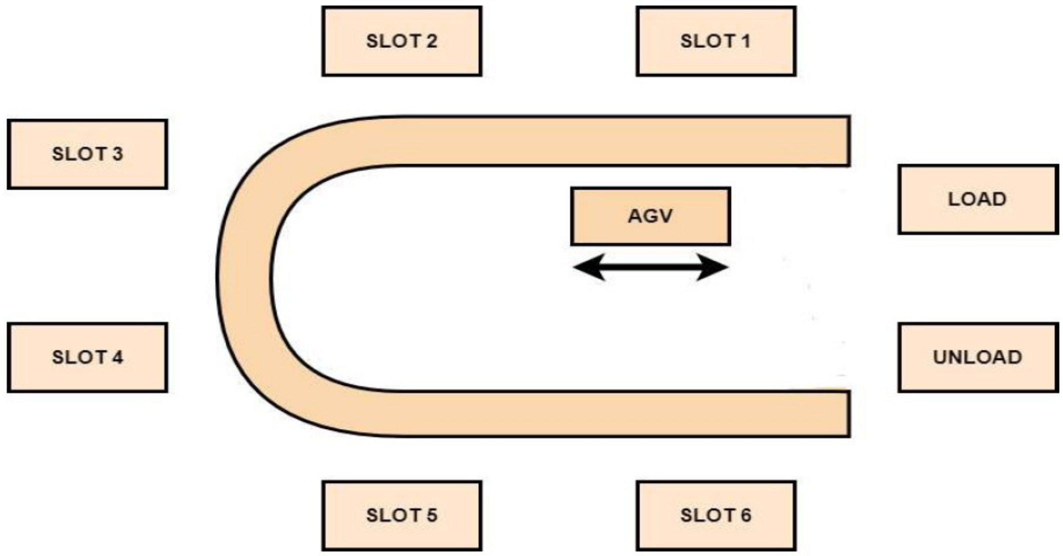

Figure 2. Layout of FMS

Table - 3 Operation Time for Case Study

Sl.No		Operation Time					
		M1	**M2**	**M3**	**M4**	**M5**	**M6**
1	P1	1	3	6	7	3	6
2	P2	8	5	10	10	10	4
3	P3	5	4	8	9	1	7
4	P4	5	5	5	3	8	9
5	P5	9	3	5	4	3	1
6	P6	3	3	9	10	4	1

IV. RESULTS AND DISCUSSION

To evaluate the efficacy and performance of the suggested Petrinet and Scatter Search, as well as the analysis, a case study of six machines and six goods was used. The outcome for the corresponding case study and the required parameter is provided. The Petrinet depicts the best sequence and machine usage for a single machine or a large system. When comparing the Petrinet to the Scatter Search method, the performance result demonstrates that the Petrinet is superior. Table 4 shows the results of Petrinet and Scatter Search in terms of machine utilization, as well as the graphs that correspond to Figure 3.

Table - 4 Petrinet and Scatter Search result

Sl.No	Details	M1	M2	M3	M4	M5	M6
1	Petrinet	72	74.8	66.7	62.2	94	91
2	Scatter Search	55.3	42.6	61.3	62.1	63	36

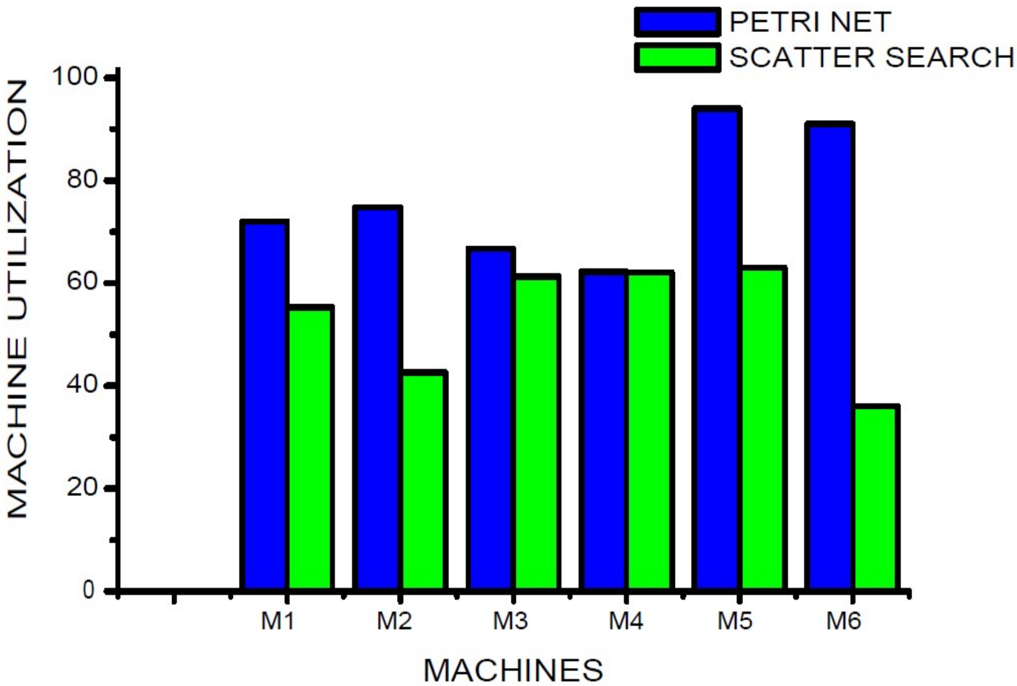

Figure 3. Performance of Petrinet and Scatter Search

V. CONCLUSION

The Petrinet and Scatter Search algorithms are included in this publication. The Petrinet demonstrates better machine utilization than the Scatter Search result in the aforesaid case study, and the performance of FMS was investigated. The Petrinet techniques have a number of unique implications for creating better optimization processes in future work. The results of several case studies were used to evaluate the Petrinet using various scheduling methods and to compare them.

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