

A Model for Comparison of Job Sequencing Techniques and Generation of an Alternate Route Path

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Abstract: Planning and scheduling are two key tasks to run a manufacturing system at the optimal level of productivity. In a practical industrial environment, a manufacturing system typically has different batches of jobs to manufacture using a given number of machines, which are flexible in performing operations but have certain constraints. With the sequence and time of operations known, the real challenge is to find the most suitable planning and scheduling approach for the given case. Furthermore, any machine failure during the production of a job batch poses an additional challenge of resorting to the most suitable alternative route. This study addresses these two challenges by presenting a dual-function model. The first part of the model, called the Job Sequencing and Scheduling Model (JSSM), is designed to compare the different job sequencing approaches to find out which approach is most suitable for the required application. The second part of the model, called the Alternating Route Path Model (ARPM), suggests the most suitable alternate route path for completing the job in case of a machine failure. Hamiltonian path is used in the design of ARPM. Both Computer-Aided Process Planning (CAPP) models are designed using MatLab® programming code. The function of the presented models is demonstrated using a valid dataset.

Keywords: Manufacturing System, Scheduling, Job Sequencing, Planning, Alternate Route Path, Hamiltonian Path.

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1. Introduction

The production systems are becoming more complex with time due to the stringent requirements for efficiency. At the beginning of the 20th century, the production system was developed from simple craft production into classical production, then after the mid-20th century, it was transformed into lean production, and in the next decade or so, it was improved to adaptable production [1]. Production is frequently planned in the supply business (e.g., in the automotive industry) as a network with various scattered production areas serving the inclusive market. Organizations are forced to constantly adjust their generation network as market opportunities are quickly altering and competition is on the upswing [2]. Toyota is a well-known production system nowadays [3]. Compared to earlier days of manufacturing, nowadays the manufacturing system is more complex and more profitable [3]. The manufacturing system got revolution from manual processes to semi-automated processes and then to a fully automated system, and finally converted into an intelligent or smart manufacturing system. At present, Numerical Control (NC) equipment has generally improved from 40% to 60%. With processing efficiency enhanced by more than 20%, the

manufacturing abilities of enterprises have advanced considerably [4]. The statistically significant difference between the 2000 survey to 2007 survey is that the complex manufacturers face growing business, global requirements, and also an increasing international diversity of suppliers, partners, and customers. Correspondingly, the need for enhanced round-the-clock responsiveness and additional remote locations has changed the communication requirements for complex project-based manufacturers [5]. In conclusion, the success or failure of the market economy is determined by the aptitude of a company to adapt to market changes. The extraordinary variability and adaptable production systems help this capability to attain a competitive advantage. The essential changes may be covered within the flexibility of production systems by effective production planning and low effort [6]. The complexity of a system refers to the influences between the same parts of the system or the number of connections. A “simple” system consists of a limited number of conditions, but a complex system consists of several separate parts with special functions. The components of the system are hierarchically organized, and they are related by various non-linear connections. These non-linear connections make an impossible analytical approach for the description of every part of the system, although it is essentially a synthetic approach for the understanding of the entire system [4]. Process planning and production scheduling are two indispensable subsystems of a manufacturing system [7]. In a complex manufacturing network, process planning and scheduling are considered even more vital jobs. They perform an essential role in timely product supply and optimal resource consumption, including product manufacturing profitability. Process planning emphasizes technical requirements, while scheduling focuses on the time aspect. Process planning determines the process route for each job, and scheduling allocates the manufacturing resources based on the results of process planning [7-8]. Traditionally, process planning and scheduling are performed independently in series. The independent and serial running mode of planning and scheduling results in inappropriate process routes, uneven resource utilization, and bottlenecks in production scheduling [7-9]. Integration of scheduling and process planning functions has been the key focus for several researchers to ease flexibility and improve profitability of manufacturing a product, development of precise process strategies that can be implemented enthusiastically on the workshop floor, including better delivery time [10].

1.1 Planning

Planning is a task to find a sequence of activities that transfers the initial world into one in which the goal description is true. The process planning function produces process plans and operational sequences that specify the fresh materials required to produce the product, including the operations and processes compulsory to convert raw ingredients into the final product. For the planning task, external words act as input and specify some sequences of processes to perform work which meet the required output frugally [11]. There are some sequencing rules in planning, which are: First Come First Serve (FCFS), Shortest Processing Time (SPT), Longest Processing Time (LPT), Earliest Due Date (EDD), Slack Time Remaining (STR), and Critical Ratio (CR) [12].

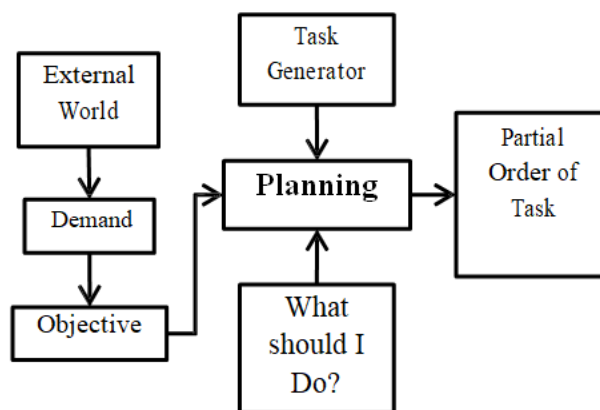


Figure 01 Process planning

Figure 01 shows the planning task in which the planning acknowledges access from outside with an attention on particular necessities or conditions and makes a progression of exercises to meet the requirements of the outside world. Figure 1 also shows that requirements can come from a marketing department that relates to a market demand or directly from a customer who applies for a realizable plan that meets the needs of a particular situation. To give these requirements, a blueprint to meet the requirements is the main goal. A real planning task then identifies the set of actions that can be met when the demand is met. The planning task can be categorized into three major classifications, such as Classical planning paradigm, planning, and Decision-theoretical planning, Hierarchical Task Network (HTN) [13].

1.2 Scheduling

The exact division of jobs over time is the basic purpose of scheduling. For scheduling problems, there are some basic concepts that are: Choice of available resources, selection of the appropriate time period for the execution of a task, limited by various constraints (hard constraints, soft constraints, and preferences) [11]. There are two approaches for production scheduling: the first is the traditional approach, including simple dispatching rules, composite dispatching rules, the computer simulation approach, and mathematical programming.

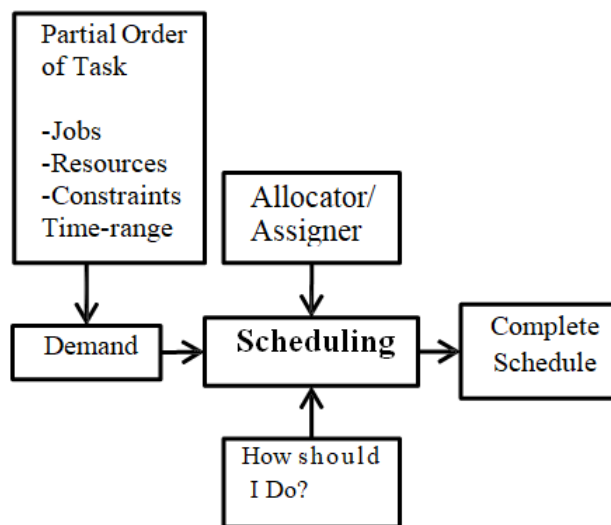


Figure 02 Scheduling

Branch and bound. The second approach is a modern approach, including genetic algorithm, simulated annealing, artificial neural network, tabu search, case-based reasoning, expert system, beam searches, fuzzy systems, and Petri-net [14]. Figure 2 depicts that a partial order of tasks gives the demand for the scheduler and allocator to assign the jobs according to the prerequisites.

1.3 Brief comparison of Planning and Scheduling

A comparative study between planning and scheduling is that planning is often influenced by the external influences of the environment and creates a subordinate sequence of tasks, as we have seen in the figure 01. This subtask of assignments helps as an input for the scheduling task. And from the same figure, it can also be seen that the planning task is about "what am I supposed to do?", while scheduling mostly involves the question "how can I do that?" Figure 02 demonstrates the scheduling in its best form. Planning and scheduling tasks were prepared into two totally detached areas. Be that as it may, in actuality, such a division

between planning and scheduling regularly winds up powerless, and the illustration of the isolation between both tasks is frequently troublesome for some causes.

Planning is viewed as a generator of exercises in the underlying period of a venture, in which a grouping of exercises is characterized, while scheduling is conveyed in the second stage, in which the produced exercises are chosen to allocate/allot assets and time.

1.4 Integration of Process Planning and Scheduling

Typically, integration of process planning and scheduling (IPPS) problem is defined as “Given a set of n parts that are to be processed on m machines with operations including alternative manufacturing resources, select suitable manufacturing resources and sequences of operations to determine a schedule in which the precedence constraints among operations can be satisfied and the corresponding objectives can be achieved” [15]. Disregarding the way that planning and scheduling jobs have their own particular presence as exploration logic, to make an intelligible working climate, they can be associated with each other. Such a sort of climate is regularly called an integrated process planning and scheduling condition. The accompanying figure 03 demonstrates the integrated process planning and scheduling condition. IPPS emerged as a popular approach in the 1980s when integration of planning and scheduling was proposed [16]. Saygin and Kilic [17] proposed a working framework for integrating process planning and scheduling for machine tool selection, process plan, scheduling, and rescheduling modules. A mobile agent-based approach was proposed for integrating process planning and scheduling [18]. Li et al. [19-20] have concluded that the industry has a huge

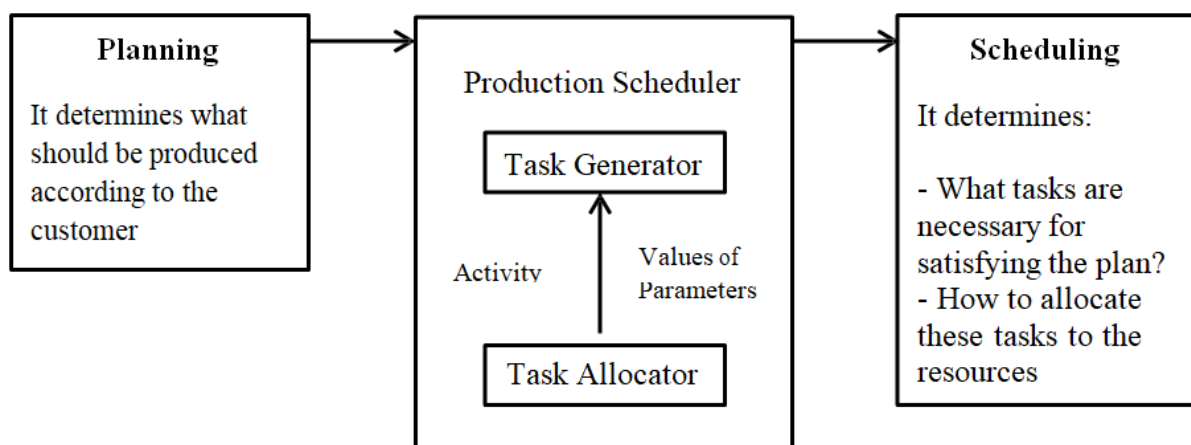


Figure 03 Integration of Process Planning and Scheduling (IPPS)

impact on increasing production flexibility, planning, and planning integration, and systematic uncertainty considerations. Many integration approaches and uncertainties for planning and process scheduling have been reviewed in the process industries [21]. It

presents an advanced review of IPPS and describes several approaches to IPPS, along with their merits and demerits, containing three common approaches: NLPP, CLPP, and DA. Furthermore, the influences of different researchers have been presented briefly. Tadsanee and Jirarat [22] chipped away at a contextual analysis and thought about the aftereffects of understood scheduling systems, FCFS, SPT, EDD, and LPT. They partitioned these systems into two classifications, name as job based govern and order-based running the show. From the outcomes, it was found that activity-based guidelines dependably give preferred outcomes over request-based standards, and EDD and SPT are the best approaches.

1.4.1 Categories of IPPS

Sequential Methods: Traditionally, integration of process planning and scheduling was done sequentially. This worked well for manufacturers that had little time for analysis and preferred to approach the matter head-on, with as much simplicity as possible. Leaders sit down and create the process plan based on their financial goals and parameters. The plan is matched with scheduling so that a workable process can be developed for production, one step after another. **Genetic methods:** these are a newer version of integration, processing, planning, and scheduling that seeks a more tightly integrated approach. Genetic algorithms take all available data and use expert systems to analyze the best possible approaches to manufacturing. As parameters change, the algorithm learns different and better ways to arrange the production schedule and compensates accordingly. This system is more advanced and allows for greater and sometimes unexpected efficiencies [19].

1.4.2 Approaches for IPPS

Various approaches have been displayed to permit and resolve issues experienced in coordinating integrated process planning and scheduling for requests to attain ideal assembly execution. A portion of the approaches referred to for the most part are as follows: non-linear process planning, closed-loop process planning, and distributed process planning [21].

1.4.3 Implementation approaches for IPPS

Various approaches have been developed to solve IPPS. Different typical methods are agent-based approaches, pre-net-based approaches, and algorithm-based approaches. For the more than three use strategies of IPPS, the first and the second methods (agent-based approach and Petri-net) are used to demonstrate the joining structure. Additionally, the third one is used to upgrade the compromise system [19].

2. Statement of Problem

There are “m” machines and “n” kinds of jobs in a batch manufacturing system. Each job can be completed through a number of processes and delivered to the customer on a specific date.

The process plan of each job is known and can be completed through various specific numbers of selected routes. The output of the primary process is the input of the next process. Operation time and transportation time of each job on each processing step are known.

2.1 Purpose

The purpose is to design a model for comparing the results of different job sequencing techniques and subsequently completing the variety of jobs through the most appropriate alternative process routes, minimizing the number of tardy jobs in case of equipment failure.

2.2 Constraints

The system constraints are as follows and must be satisfied: Each machine can process only one part at a time. After a job accomplishment on a machine, it is immediately transported to the next machine on its routing. The number of jobs and their degree of customization are known. All jobs are available at time zero and delivered to the specified promised time. Setup time for each job on the machines is independent of the operation sequence and is included in the processing times. Different batches have the same priority.

3. Research Methodology

The research methodology is categorized into two phases for the integration of process planning and scheduling. In the first phase, a job sequencing and scheduling Model (JSSM) is developed, which satisfies the problem constraints and variables. The model can find the processing time, flow time, and tardiness of each job. It then finds the total processing time, mean flow time, and tardiness, which give the details of the whole system by using job sequencing approaches like First Come First Serve (FCFS), Early Due-date (EDD), Shortest Processing Time (SPT), Longest Processing Time (LPT), Slack Time (STR), and Critical Ratio (CR). Comparison of the results of all these approaches shows their acceptability according to our constraints. In the second phase, the assignment generated in JSSM also has the input values for the alternate route path Model (ARPM). For this purpose, computer simulation and mathematical modeling are used to get the most appropriate alternate route path. By using the Hamiltonian Path algorithm, the most appropriate alternate route path is found in case of equipment or machine tool failure. MatLab® computes very good results in real time for this sort of polynomial-time and NP-complete problem. The steps of modeling are listed below with reference to Figure 04.

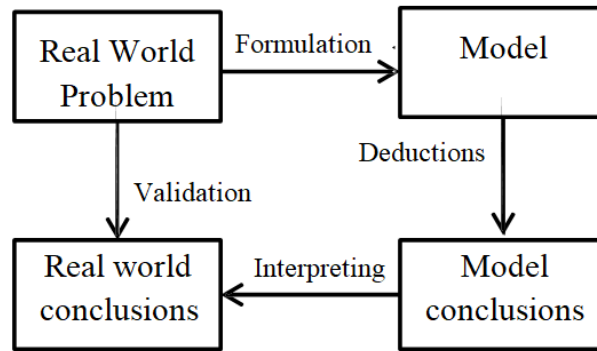


Figure 04 Modeling Steps

4. Case Study

Consider a manufacturing system having four flexible machines ($m=4$) and five jobs ($n=5$) are needed to operate on them in batch formation as shown in Fig 5. The time and sequence of job operations are defined, and the due date for each job is also defined, as shown in Table 1.

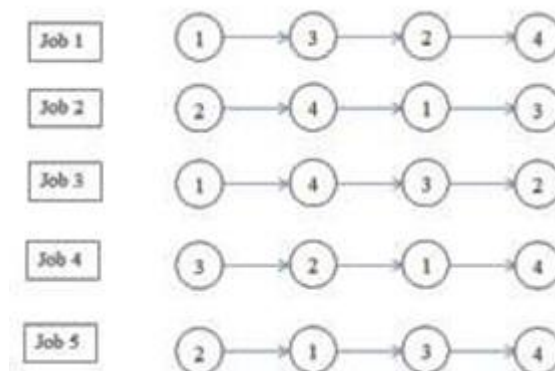


Figure 05: A 5-job and 4-machine manufacturing system

The order of operations and machine utilization is written in the sequential order.

The study is divided into two phases. In the first phase, a job sequencing and scheduling model is designed to compare the job sequencing techniques. In the second phase, another model is designed that computes an alternate route path for a job to be completed without delaying in case of machine tool failure.

4.1 Mathematical Modeling

In this work, there is a set of ‘n’ jobs (J) which is given as: $J = \{J1, J2, J3, \dots, Jn\}$ and each job consists of more than one operation (O) that must be processed on a set of ‘m’.

Table 01: Five jobs of the case study with details

JOBS	MACHIN	TIME	DUE DATE
Job1	1	5	900
	3	3	
	2	3	
	4	6	
Job2	2	8	1900
	4	2	
	1	4	
	3	2	
Job3	1	6	2340
	4	3	
	3	7	
	2	4	
Job4	3	2	2770
	2	4	
	1	6	
	4	3	
Job5	2	4	1000
	1	8	
	3	3	
	4	3	

number of machines (M), which may be given as: $M = \{M1, M2, M3, \dots, Mm\}$. Each operation occupies one machine at a time for a fixed time interval. To simplify the problem, the following notations are used.

Jobs = {Job1, Job2, Job3, Job4, Job5}

Machines = {1, 2, 3, 4}

Operations = {O1, O2, O3, O4}

j = job (j=1, 2, 3, 4, 5)

i = machine (i= 1, 2, 3, 4) PST = Processing Time

FT = Flow Time = Queue time + Processing Time

DDB = Due-Date Bases

TARD = Tardiness of job

Processing Time for each operation = $PST_{ij} = (PST_{11}, PST_{12}, \dots, PST_{ij})$

Where

$i = 1, 2, 3, \dots, n$ and $j = 1, 2, 3, \dots, m$

Job $j = \{(i, PST)\}$

According to the given data, we can write the table in a set formation as follows.

Job1 = {(1,5), (3,3), (2,3), (4,6)}

Job2 = {(2,8), (4,2), (1,4), (3,2)}

Job3 = {(1,6), (4,3), (3,7), (2,4)}

Job4 = {(3,2), (2,4), (1,6), (4,3)}

Job5 = {(2,4), (1,8), (3,3), (4,3)}

Here, it is needed to make a programming model for finding the total processing time, each job's processing & flow time, and tardiness. For that purpose, it is needed to put the jobs in the system in a different sequence to get a difference in results. So we select the FCFS, EDD, SPT, LPT, STR, and CR approaches to get the job sequence for the system and compare their results. MATLAB computed the results in the table format, and these results were used in Excel to get graphs.

5. Results

5.1 Phase 1 Results

This research is divided into two phases, and the results for the first phase are given in Fig 06.

<pre> >> my_input >> production(Jobs, Pieces, DBS) FCFS strategy: ----- Process time Flow time Tardiness Job1 850.00 850.00 0.00 Job2 480.00 1330.00 0.00 Job3 800.00 2130.00 0.00 Job4 1200.00 3330.00 560.00 Job5 630.00 3960.00 2960.00 Total process time: 3960.00 Mean flow time: 2320.00 Mean tardiness: 704.00 EDD strategy: ----- Process time Flow time Tardiness Job1 850.00 850.00 0.00 Job5 630.00 1480.00 480.00 Job2 480.00 1960.00 60.00 Job3 800.00 2760.00 420.00 Job4 1200.00 3960.00 1190.00 Total process time: 3960.00 Mean flow time: 2202.00 Mean tardiness: 430.00 SPT strategy: ----- Process time Flow time Tardiness Job2 480.00 480.00 0.00 Job5 630.00 1110.00 110.00 Job3 800.00 1910.00 0.00 Job1 850.00 2760.00 1860.00 Job4 1200.00 3960.00 1190.00 Total process time: 3960.00 Mean flow time: 2054.00 Mean tardiness: 632.00 </pre>	<pre> LPT strategy: ----- Process time Flow time Tardiness Job4 1200.00 1200.00 0.00 Job1 850.00 2050.00 1150.00 Job3 800.00 2850.00 510.00 Job5 630.00 3480.00 2480.00 Job2 480.00 3960.00 2060.00 Total process time: 3960.00 Mean flow time: 2708.00 Mean tardiness: 1240.00 STR strategy: ----- Process time Flow time Tardiness Job1 850.00 850.00 0.00 Job5 630.00 1480.00 480.00 Job2 480.00 1960.00 60.00 Job3 800.00 2760.00 420.00 Job4 1200.00 3960.00 1190.00 Total process time: 3960.00 Mean flow time: 2202.00 Mean tardiness: 430.00 CR strategy: ----- Process time Flow time Tardiness Job1 850.00 850.00 0.00 Job5 630.00 1480.00 480.00 Job4 1200.00 2680.00 0.00 Job3 800.00 3480.00 1140.00 Job2 480.00 3960.00 2060.00 Total process time: 3960.00 Mean flow time: 2490.00 Mean tardiness: 736.00 </pre>
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Figure 06 Results of 1st phase

5.1.1 First Come First Serve (FCFS)

The results of FCFS for queuing and processing times, and job tardiness are depicted in FigFigure 07.

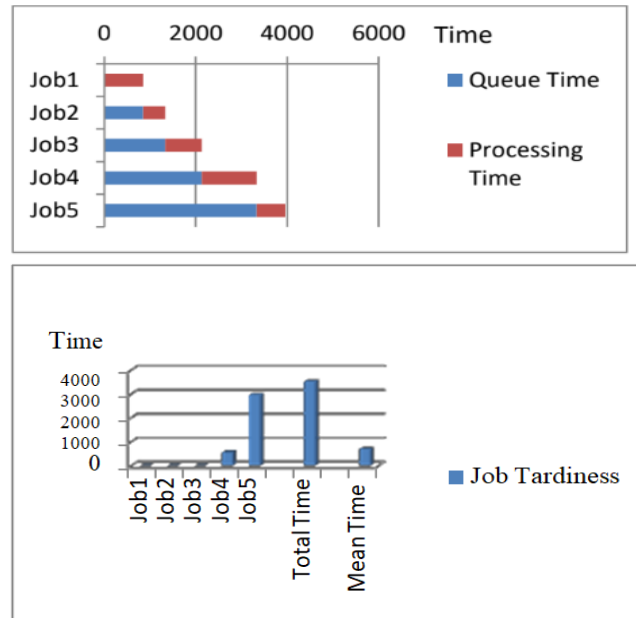


Figure 07: Queuing and processing times and Job tardiness for FCFS

5.1.2 Early Due Date (EDD)

The results of EDD for queuing and processing times, and job tardiness are depicted in Figure 8.



Figure 08: Queuing and processing times and Job tardiness for EDD

5.1.3 Shortest Processing Time (SPT)

The results of SPT for queuing and processing times, and job tardiness are depicted in Figure 9.

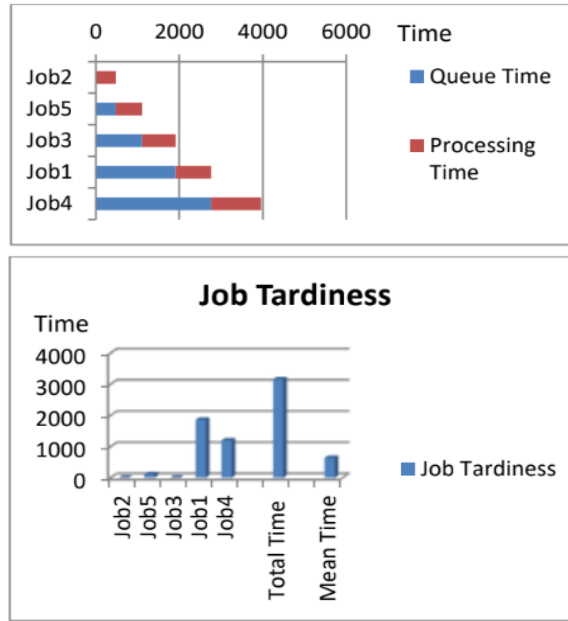


Figure 09: Queuing and processing times and Job tardiness for SPT

5.1.4 Longest Processing Time (LPT)

The results of LPT for queuing and processing times, and job tardiness are depicted in Figure 10.



Figure 10: Queuing and processing times and Job tardiness for LPT

5.1.5 Slack Time Ratio (STR)

The results of STR for queuing and processing times, and job tardiness are depicted in Figure 11.



Figure 11: Queuing and processing times and Job tardiness for STR

5.1.6 Critical Ratio (CR)

The results of CR for queuing and processing times, and job tardiness are depicted in Figure 12.



Figure 12: Queuing and processing times and Job tardiness for CR

5.1.7 System Utilization

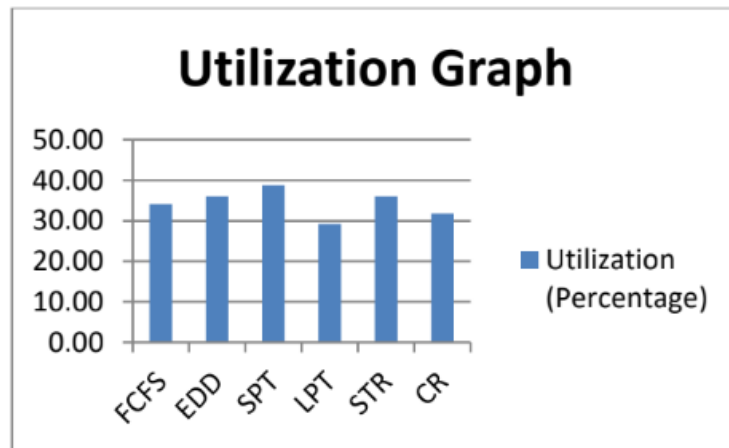


Figure 13 System Utilization Graph

5.1.8 Make-span Graph

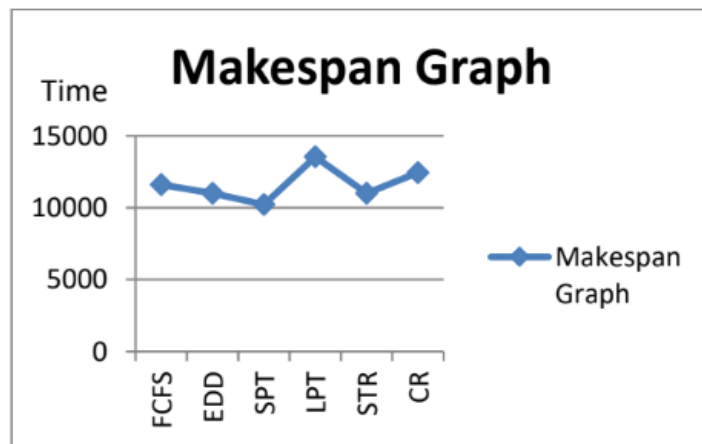


Figure 14 Make-span Graph

5.1.9 Machine Utilization Graph

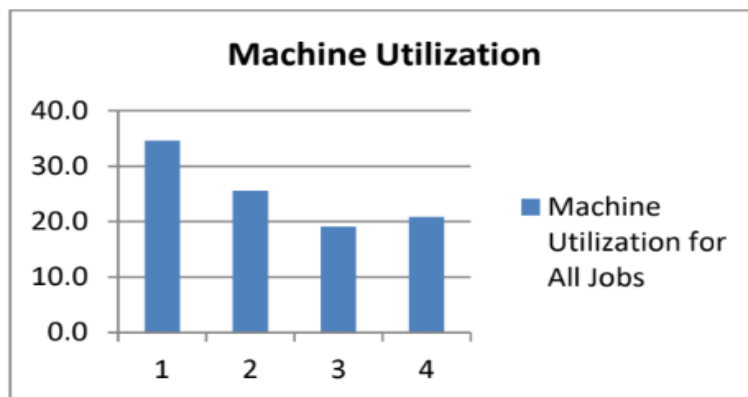


Figure 15 Machine Utilization Graph

5.1.10 Machine Utilization for each Job

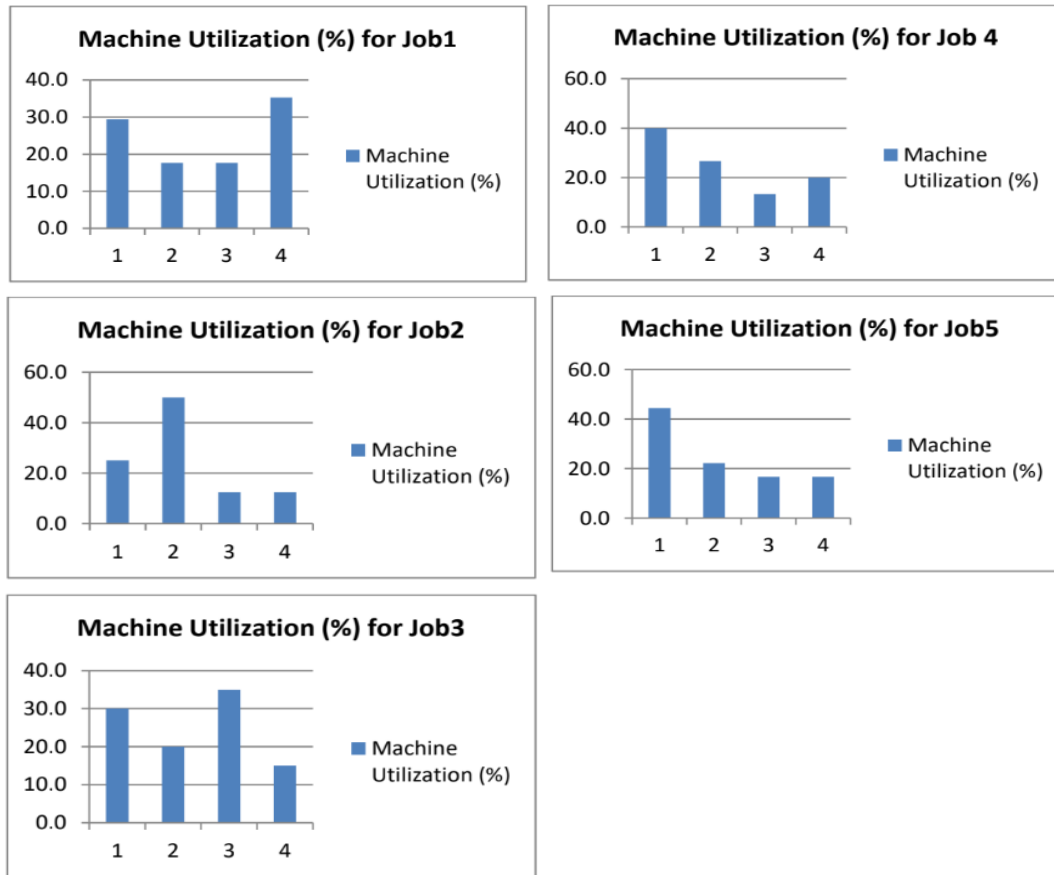


Figure 16 Machine Utilization for each job Graphs

5.2 Phase 2 Results

In the phase-II ARP model, the results were computed for each job in the form of the most appropriate alternate route paths for the completion of the job. These paths can be selected in case of machine equipment/tool failure. The selection of these paths cannot affect the total processing time of that job, which means no delay in the completion of jobs. Computer-Aided Alternate Route Path model's results for the assignment problem are in the following;

```

>> hamilton(J1, 1)
Path 1 :    1    2    3    4

Path 2 :    1    3    2    4

>> hamilton(J2, 1)
Path 1 :    2    1    4    3

Path 2 :    2    4    1    3

>> hamilton(J3, 1)
Path 1 :    1    3    4    2

Path 2 :    1    4    3    2

>> hamilton(J4, 1)
Path 1 :    3    1    2    4

Path 2 :    3    2    1    4

>> hamilton(J5, 1)
Path 1 :    2    1    3    4

Path 2 :    2    3    1    4

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Figure 17: Alternate route path results

These output results show only two alternate paths because of the given input values, which are actually derived from the given data of the assignment problem. The model can give results for more than 5 jobs, and by changing the input adjacency matrix, which actually changes the multifunction characteristics of machines, this model can compute more than two appropriate alternate route paths without having a delay in the job processing time.

6. Conclusions

In this study, two constituent CAP models have been developed as a part of a dual-function mathematical model: namely, the JSS Model and the ARP Model. The following conclusions are drawn from this study:

1. The designed JSS Model is very helpful for computing the total processing time, mean flow time, and mean tardiness of the jobs, as well as comparing the different job sequencing approaches.
2. The results of the problem solved depict that EDD and STR are the best for minimum job tardiness, and LPT is the worst.
3. In the comparison of mean flow time, SPT is found to be the best and LPT to be the worst based on the results of this study.

4. The designed ARP Model is very suitable for finding the appropriate alternate route paths without affecting the processing time and tardiness of jobs.
5. The Hamiltonian path method used in ARPM is very effective for job-shop batch production in a flexible manufacturing system.
6. The developed mathematical models using MatLab® are very effective for the generation of the finest results for 'n' number of jobs and 'm' number of machines.
7. Input values for these models are variable and can be adjusted according to the specified data and the current required condition of the system.

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