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A Simulation Modeling Approach for Job Shop Scheduling Problems: Case of Metal Industry

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Abstract: ***In most of the manufacturing units job shop scheduling is a difficult task due to the complexity of the system. Job shop scheduling problem (JSSP) is very important and has a lot of application in industrial and service sectors. To maintain the good job shop scheduling, facilities can save time and money. A case study was conducted on a metal Industry located in Ethiopia. In metal and engineering company is facing a job shop-scheduling problem in its spare part manufacturing plant. The higher make span (lead-time) to produce parts resulted from conventional scheduling is dissatisfying customers and causing low machine utilization. This study aims at reducing make span and improving the performance of the manufacturing system. The data collected from the case company to get the time taken by the conventional scheduling method and also gathered data for four jobs requiring five machines that arrived during the research period. The proposed method Arena simulation software used to find the shortest processing time (SPT) was found to be the optimum for the five performance measures. The results indicate that by using the SPT dispatching rule the make span was reduced from 25 hours to 19 hours with 24% improvement.***

Keywords: Job shop scheduling problem, dispatching rules, make span, simulation, Arena

1. Introduction

The job shop-scheduling problem is a practical problem and has many applications in manufacturing and supply chain scheduling problems. JSSP has numerous applications in manufacturing and service sectors. In manufacturing, JSSP is the process that assigns jobs to machines satisfying the precedence and resource constraints over time such that certain objective(s) is optimized. The JSSP is one of the strongest NP-hard problems [1]. In the current markets, manufacturers have to respond orders fast and attain shipping dates promised to the end users, as failure to do so, at least, may result in a significant loss of good will of the manufacturer [2]. Scheduling is assigning of shared (common) resources over time to competing activities to satisfy end users' requirements. It has been the subject of an essential amount of literature in the field of operations research (OR). Emphasis has also been given on examining machine-scheduling challenges where jobs represent activities and machines represent resources so that each machine will process at most one job at a time. Many production control tools and techniques can be employed to increase the total production out rate, minimize the total time of completion and deliver the product on the promised date. Among the methods to raise production rate of an industry, one is to create proper scheduling for the parts on the available machineries so that the order will finish on time, maximizing the use of the resources and reducing the average waiting time. There is scheduling in most of manufacturing and production facilities. To explore potential capacities of production systems and run production systems orderly, scheduling is necessary in a given firm [3].

Job shop scheduling problem is extremely challenging both in theory and in practice. It is because so many parameters need to be considered when scheduling production. Among the approaches to scheduling problems are; analytical techniques, Meta heuristic algorithms, rule based approaches and simulation approaches. Currently, the conventional analytical models and simple mathematical models are incapable to analyze the complex manufacturing systems.

In addition, analytical models often apply mathematical programming techniques and it is not practical for solving a complex scheduling problem. Simulation modeling is one of the powerful tools used to test the efficiencies of different scheduling policies. The simulation model is capable of simulation a long period in real life with in a reasonably short computer running time of several seconds or minutes. These save long time and observation costs. In addition, simulation modeling helps get the result of future time without any real change to machine layout or the number of machine [3]. Scheduling gives a basis for assigning jobs to work center. Sequencing (also known as dispatching) clearly specifies the order in which jobs should complete at each center. Arena simulation software is employed to construct the simulation model for the job shop scheduling problems. Arena has a lot benefits in modeling and simulation of discrete and continuous models.

The case company is a job shop type of manufacturing and is continuously challenged by scheduling problems. The study aims to find an optimum job schedule that will minimize the make span with optimum utilization of limited resources. The study is limited to only the machine building section and jobs came to the factory at specific time during the study. There is no scheduling technique or software application in the case company. Jobs are assigned in random fashion that may result higher make span and low resource utilizations. Similar jobs to this case have consumed more than a day to produce (make span). The study attempts to reduce the total production time of specific jobs using Arena simulation modeling software by comparing the different dispatching rules. In the case company, four jobs arriving at specific time requiring five machines with specific processing sequences are considered.

2. Literature Review

In the field of scheduling problem, job shop scheduling is an Np-Hard combinatory [4]. It is probably one of the most computationally combinatorial problems considered interactible so far. The fact that a small example with 10 jobs and 10 machines posed by Fischer and Thompson (1963) remained open for over 15 years is practical proof of this intractability [2]. The job shop is defined as a group of manufacturing operations where the productive resources are organized according to function and the work passes through in varying lots and routings. Job Shop production is characterized by the manufacture of one or few numbers of a single product designed and manufactured strictly according to customer's specifications, within, the given period [5]. A basis for assigning jobs to a work center with a time table is provided by scheduling technique. Sequencing specifies the order in which jobs should be processed at each work center. The sequencing methods are referred to as priority rules for sequencing jobs to a work center. In the manufacturing world, scheduling problems are extensively implementing the dispatching rules with procedures designed to provide good solutions to complex problems in a real-time production environment[6] . Generally, JSP uses various representations in its model. In a manufacturing facility, let a job shop consists of a set of Mi machines where i=1, 2... m, n jobs, and a predefined plan which states the assigning of these jobs in different machines in some desired sequences (constraints). Each job has a specified number of operations to be performed in different machines, with individual setup times, processing times, a due date, etc. The job shop-sequencing problem deals with the search of an optimal sequencing of the operations in different machines within the specified sequences [4]. A job shop differs from a flow - shop in which jobs are processed in same order. In a job-shop, jobs can be processed on machines in any order. From research stand point, the common job shop is one in which there are "m" machines and "n" jobs to be performed on the machines. Each job requires m operations, one on each machine, in a specific order, but the order can be different for each job [4].In the past different methods were applied to JSSP and different job shop type manufacturers use the different method. According to different researchers, the methods are mainly categorized in to three. First approach is exact methods, such as branch and bound, relaxation and liner programming. These exact methods guarantee global convergence and have been successful in solving small instances. However, they require a very high computing time as the size of problem increases and they are not capable of dealing with stochastic problems. Second method is approximation methods, such as the shifting bottleneck approach, particles warm optimization, and colony optimization, simulated annealing, Tabu search, genetic algorithm, neural network, immune algorithm, different evolution and others. The third one is dispatching rules and simulation based approaches.[1][7][8][9].

The sequencing methods are referred to as priority rules for sequencing or dispatching jobs to a work center. In the manufacturing world, scheduling problems are extensively implementing the dispatching rules. One of the most commonly used methods to schedule manufacturing systems is to use priority dispatching rules (pdrs)[10].

The procedure is designed to provide good solution to complex problems in a real time production environment. Most of the previous researchers, until this current time, are using dispatching rules to optimize the job shop-scheduling problem [3][10]. These rules are classified in to static and dynamic rules. Static rules are the ones in which the job priority values do not change as function of the passage of time, i.e. they do not depend on time (not time dependent). They are just a function of a job and/ or machine data. Dynamic rules are time dependent [3] [10].Dispatching rules are better than genetic algorithms in three respects. They found that dispatching rules are able to create various solution to solve many problems observed, whereas genetic algorithm only provide one solution to minimize make span. In addition, solutions obtained by genetic algorithms yielded scattering results, whereas results obtained by dispatching rules yielded steady results. Thirdly, genetic algorithms need the use of computer due to the large number of parameters to specify, while dispatching rules can obtain simple solutions in urgent production situations [3]. In this research, Arena software is used to find an optimum sequence of operation of four jobs on five machines by comparing the different dispatching rules.

3. Problem Description

In the job shop scheduling-problems (JSSP) there are "m" machines and" jobs. Each job has a fixed processing route that visits some or all the machines in a predetermined order. In this study, four jobs requiring four machines are sampled from the company. The goal of the study is to reduce the higher make span faced by the case company resulting customers' delivery complains and lower machine resource utilization. The following assumptions are taken in to account to model the problem.

1) Processing times are deterministic
2) All the components and parts are readily available at the beginning of the simulation modeling process
3) Each machine can carry out only a single operation at a time
4) Each machine is used by each job once at most
5) The machines are continuously available.
6) There is only one machine of each type of machines.
7) Process time includes the set-up times
8) Preemption of operations are not allowed
9) The transportation times between different workstations are neglected.
10) Parts leave the manufacturing system after their operations
11) The Job Shop works 24 hours a day in three shifts on 8 hours basis.

3.1 Methods

In this research, primary data are collected from production department of the case company for four jobs competing for five four machines. In order to model and simulate the jobs for optimum make span and resource utilization, the figurer 1 representation below is used.

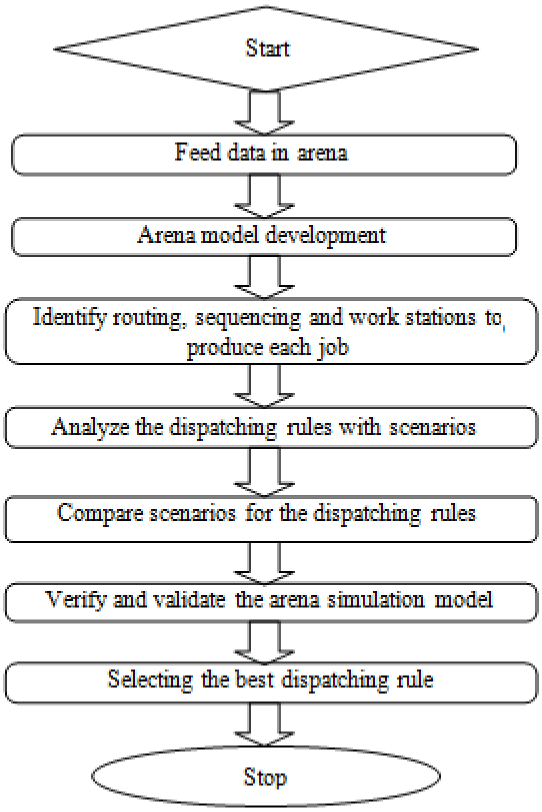

Figure 1:.Methodology, source [own]

3.2 Arena Model Development

The research employed Arena Simulation software, which industrial and system engineers are familiar and comfortable with, of version 14 to build the JSSP. The rules of dispatching used by the research are; FIFO(first in fist out), LIFO(last come first out), SPT(shortest processing time (SPT), LPT(longest processing time), EDD(earliest due date),TSPT(total shortest processing time), and TLPT(total longest processing time). The performance measures selected for comparison of the dispatching rules are; flow time (make span), average work in process (WIP), over all utilization, system average Waite time and system average queue length. Data are collected from the case company representing the four jobs, sprocket gear (**J_1**), stepped shaft with key ways (**J_2**), spur gear (**J_3**) and fitting (**J_4**)**.**The jobs require the following machines; power hacksaw (**M_1**), CNC lathe machine (**M_2**), V. milling machine (**M_3**), drilling machine (**M_4**) and grinding machine (**M_5**). Table 1. Shows that the Routing matrix for four jobs and five machines . The data in table 1 were fed in to arena simulation software. The create module, from the basic process template panel, is used for job arrival creation for each job, the assign module and from the basic process template panel, is used to assign entity type, entity picture, entity sequence and attributes related to the jobs are assigned. The due dates, processing times, total processing times, job arrival times and job creation times are assigned specific attributes and values for each job has been given. The operation sequence of each job is established in the assign module and linked with the sequence module, from advanced transfer template panel, to route jobs to their predefined machine sequence. The "enter module" from the advanced transfer template panel is used to receive jobs in the respective work stations.

Table 1: Routing matrix for four jobs and five machines

	Jobs Processing Sequence (Processing time(Hour)					*Due date(Day)*
1	M1(3)	M3(3)	M2(2)	M4(2)	M5(3)	4
2	M1(1)	M2(2)	M4(1)	M3(3)	M5(2)	3
3	M1(1)	M2(2)	M3(3)	M4(2)	M5(2)	5
4	M1(2)	M3(2)	M4(1)	M2(1)	M5(2)	2

The route module, from the advanced transfer module, is used to guide jobs find their processes by sequence. In this module, the destination type is selected to be by "sequence". The performance measures are make span, average WIP for all processes, average Waite time for all jobs, average queue length for all processes and overall system utilization. The make span is recorded in the "record module" from basic process template panel. These performances are recorded in the statistics module, from advanced process template panel, for final analysis of results from the simulation outputs on the user defined section. Figure 2 shows simulation of job shop model generated by arena software.

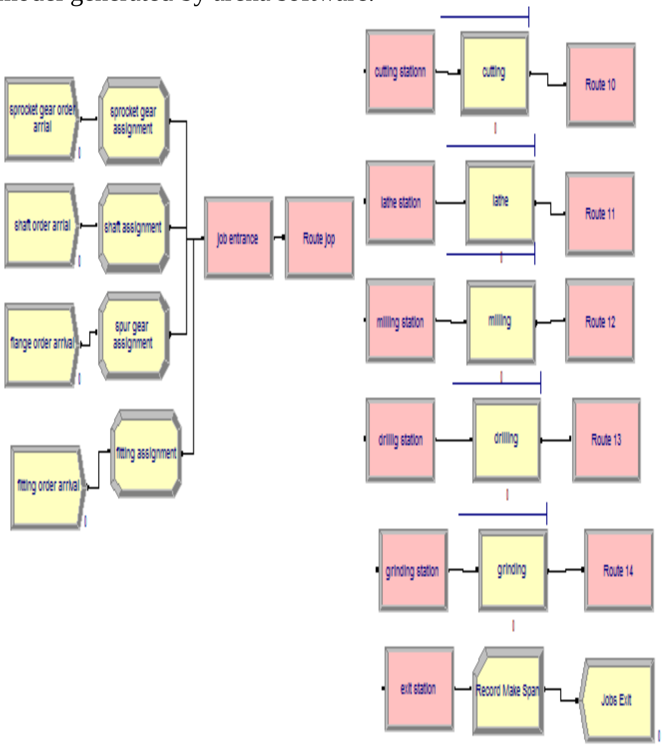

Figure 2: Job shop model generated by Arena simulation software, source [own].

Work stations are established using the station module, from advanced transfer module, to establish separation between the five processes and the job exit point and facilitate sequencing. The processing time of jobs on each machine is assigned to the delay time of each process module to be an expression and the value "processing time". Simulation runs for the seven selected dispatching rules was carried out by simply modifying the queue module, from the basic process template panel. From the queue module, the queue type is adjusted by interchanging "FIFO, LIFO, lowest attribute value and highest attribute value. For example for the earliest due date (EDD) dispatching rule, lowest attribute value is elected and the attribute name "due date" is selected from the drop option as it was defined in the assign module. The output analyzer is used to compare scenarios for the different dispatching rules against the performance measures.

4. Verification and Validation

Model verification and validation are critical in the development of a simulation model[1]. Verification makes sure that the model is conducted correctly, while validation ensures that the model represents the real system and that the model is truly representative of that system. Unfortunately, there is no set of specific tests that can easily be applied to examine the correctness of a model. Furthermore, no algorithm exists to decide what techniques or procedures to use [1]. One way to validate the model is to compare it with the real manufacturing system output and if this is not possible, to compare it with a model developed by a related software application Figure 3 show Gant chart of FIFO schedule.

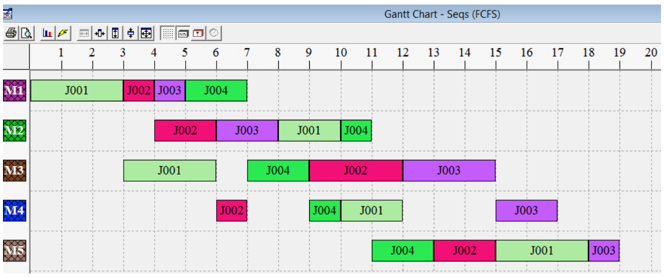

Figure 3: Gant chart for FIFO schedule

In order to verify the model, the job shop problem was modeled on LEKIN scheduler software package. The data were fed to the scheduler and similar make span was obtained for the different dispatching rules. For example, the make span, obtained using LEKIN scheduler for first come first out (FIFO), was 19 hours similar to the one obtained by Arena. A gant chart was developed using the scheduler for optimum dispatching rule, FIFO/FCFC. To verify to model, debugging was deployed and the model has been found to have no errors at all.

5. Results and Discussion

The results were obtained from Arena output for the user specified performance measures. The performance measures are designed to comprise the system performances instead of the individual processes and entities. The performance measures are:

1. Make Span
2. System Work In Process (WIP)
3. System Average Waite Time
4. System Average Queue Length
5. Over all resource utilization

The model was run for the seven dispatching rules by changing the queue types on the basic process template. For example, the shortest processing time (SPT), the lower attribute was selected on the "type" and processing time for the respective machines was selected for priority. The output below was obtained. Figure 4 show that output for shortest processing time.

11:36:59PM **User Specified** July 5, 2015

Shortest processing time Dispatching Rule Replications: 20

Replication 1 Start Time: 0.00 Stop Time: 1,200.00 Time Units: Hours

Tally

Interval	Average	Half Width	Minimum	Maximum
make span	16.0000	(Insufficient)	13.0000	19.0000

Time Persistent

Time Persistent	Average	Half Width	Minimum	Maximum
over all utilization	0.03333333	(Insufficient)	0	4.0000
system average WIP	0.01066667	(Insufficient)	0	0.8000
System Average Queue length	0.1878	(Insufficient)	0	0.6000
system average queue waiting time	1.1927	(Insufficient)	0	1.2000

Figure 5: user specified output for shortest processing time (SPT)

In similar way the output was generated for the remaining dispatching rules by adjusting the queue type for first in first out (FIFO), last come first out (LIFO), longest processing time(LPT), total longest processing time(TLPT), total shortest processing time(TSPT) and earliest Due Date(EDD). In order to compare results obtained using the dispatching rules, a scenario analysis was carried out to choose a best dispatching rule satisfying the five performance measures, Make Span, System Work In Process (WIP), System Average Waite Time, System Average Queue Length and Over all resource utilization. Since the overall utilization is constant for all scenarios, by looking at the comparison chart below the shortest processing time dispatching rule **(SPT)** is chosen since it scores the minimum value for all dispatching rules. Utilization is best for highest value but in this case, it is found to be constant. If the utilization value was varying, Topsis analysis or similar way to the above by taking the reciprocal of the utilization could be used. The make span was found to be 19 hours. Since the performance measures are found to be best for the shortest dispatching rule(SPT), this rule is proposed to the case company for these specific jobs. The case company can also model its batch products and specific jobs with Arena to get the dispatching rule satisfying the given performance measures. Figure 6 and 7 show that the scenario analysis table and comparison chart for dispatching rules.

	Scenario Properties				Responses				
	S	Name	Program File	Reps	make span	over all utilization	system average WIP	System Average Queue length	system average queue waiting time
1		EDD	1 : EDD.p	20	20.000	0.033	0.011	0.211	1.341
2		FIFO	1 : FIFO.p	20	19.000	0.033	0.011	0.188	1.193
3		LIFO	1 : LIFO.p	20	19.000	0.033	0.011	0.188	1.193
4		LPT	1 : LPT.p	20	20.000	0.033	0.011	0.211	1.341
5		SPT	1 : SPT.p	20	19.000	0.033	0.011	0.187	1.192
6		TLPT	1 : TLPT.p	20	20.000	0.033	0.011	0.211	1.341
7		TSPT	1 : TSPT.p	20	20.000	0.033	0.011	0.218	1.390

Figure 6: Scenario Analysis table

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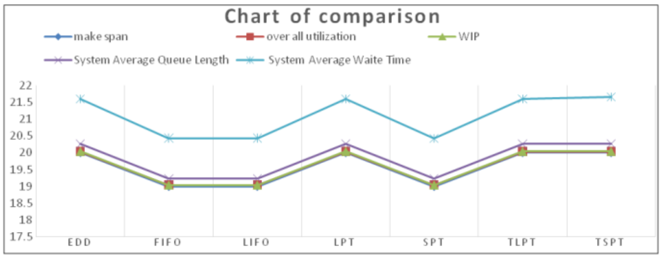

Figure 7: comparison chart for dispatching rules

6. Conclusion

In this paper a job shop schedule problem for specific jobs that arrived during the research period were used to introduce software based scheduling system in the case company. Seven dispatching rules were selected for comparison based on five system performance measurers. The system performance measures are make span, average Waite time, queue length, over all utilization and work in process (WIP). There was no any scheduling technique having been implemented in the case company. For similar jobs in the past, the make span was more than a day (25) hours. This study, using arena scheduling software application, has reduced the make span from more than a day (25 hours) to 19 hours. Using the shortest processing time as the dispatching rule, a 24% make span improvement is achieved. The shortest processing time (SPT) rule has better performance than FIFO, LIFO, TLPT, TSPLT, LPT, SPT and the conventional method for system performances of ,work in process (WIP), System average queue length, over all utilization and System average Waite time.

7. Future work

This research is limited to modeling and analysis of job shop problems encountered in a specific time during the research period. It is the researcher's plan to deal with both the batch production and mass production schedules of the case company in its different plants. Other researchers can attempt to model and simulate the different production shops of the case company to get a better schedule optimizing different performance measures as prioritized by the case company.

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