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A Comparison of Job Shop Dispatching Rules Using a Simulation Study

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Abstract

In this paper, a stochastic dynamic job shop scheduling problem with sequence-dependent setup times, which is among the most difficult and complex scheduling problems, is addressed. The objective of the problem is to determine a schedule that minimizes the makespan, mean flow time, mean tardiness, total setups, and mean setup time performance measures. For investigation purpose, a discrete event simulation model of the problem is developed. Six dispatching rules i.e. shortest processing time (SPT), job with similar setup and shortest processing time (JSPT), earliest due date (EDD), job with similar setup and earliest due date (JEDD), shortest sum of processing time and setup time (SSPT), and job with similar setup and shortest sum of processing time and setup time (JSSPT) are incorporated in the simulation model. The simulation experiments are conducted under due date tightness factor of 3, shop utilization percentage of 90%, and setup time less than processing time. The results indicate that the EDD, SSPT, SPT, JEDD, and JEDD rules provide best performance for makespan, mean flow time, mean tardiness, total setups and mean setup time performance measures respectively.

Keywords: Scheduling, Stochastic Dynamic Job Shop, Sequence-Dependent Setup Times

1. Introduction

In a shop, production scheduling is concerned with allocation of set of jobs on a set of production resources over time to achieve some objectives. In a job shop, jobs are processed on a set of machines. Each job has its specific operation order. The job shop scheduling problem is a combinatorial optimization problem and one of the most complex problem among various production scheduling problems [1,2]. In a dynamic job shop scheduling problem jobs arrive continuously in the manufacturing system. In a stochastic dynamic job shop (SDJS) scheduling problem at least one parameter of the job (release time/processing time or setup time) is probabilistic [3,4].

Setup time is a time required to prepare the resources such as machines to perform a operation [5]. A setup operation often occurs while shifting from one type of operation to another. Sequence-dependent setup time depends on both current and immediately preceding operation [5]. Manikas and Chang [6] and Fantahun and Mingyuan [7] reported that in job shop scheduling problems with sequence-dependent setup times limited research is available. Dispatching rules are used to select the next job to be processed from the set of jobs awaiting processing in the input queue of a machine. Dispatching rules are also named as sequencing or scheduling rules.

Ramasesh [8] provides review of simulation research in dynamic job shop scheduling problems. Allahverdi et al. [9] provides a survey of literature on scheduling problems with setup times/costs. Panwalkar et al. [10] presented a survey of scheduling rules used in manufacturing systems. Blackstone et al. [11] presented a survey of scheduling rules used in job shop scheduling problems. Jayamohan and Rajendran [12] proposed seven dispatching rules for minimizing performance measures such as mean flow time, maximum flow time, variance of flow time and tardiness in dynamic shops. The proposed rules are found to be effective in minimizing different performance measures.

Jain *et al.* [13] developed four new dispatching rules for makespan, mean flow time, maximum flow time and variance of flow time measures in a flexible manufacturing system. They observed that the proposed dispatching rules are superior compared to existing rules. Wilbrecht and Prescott [14] studied the influence of setup times on dynamic job shop scheduling problems. They concluded that job with Smallest Setup Time (SIMSET) rule outperforms other existing scheduling rules. Kim and Bobrowski [3] studied impact of sequence-dependent setup times on the performance of a dynamic job shop scheduling problems and concluded that setup oriented scheduling rules i.e. SIMSET and job with similar setup and Critical Ratio (JCR) provides better performance compared to ordinary scheduling rules such as Shortest Processing Time (SPT) and Critical Ratio (CR) for mean flow time, mean work-in-process inventory, mean finished good inventory, mean tardiness, proportion of tardy jobs, mean machine utilization, mean setup time per job, mean number of setups per job and mean total cost per day performance measures. Vinod and Sridharan [15] proposed and assessed performance of five setup oriented scheduling rules. They concluded that proposed rules provides better performance than the existing scheduling rules for mean flow time, mean tardiness, mean setup time and mean number of setups performance measures.

The literature review revealed that there is a need to assess performance of dispatching rules in a SDJS scheduling problem with sequence-dependent setup times and present paper is an attempt in this direction.

The remainder of the paper is organized as follows. Section 2 describes salient aspects of configuration of the SDJS scheduling problem. The outline for development of simulation model is explained in section 3. Section 4 presents details of simulation experimentations. Section 5 provides analysis of experimental results. Finally, section 6 gives concluding remarks and directions for future work.

2. Job Shop Configuration

In the present work, a job shop scheduling problem with ten machines is selected that is based on configuration of job shop considered by various researchers [3,14]. Six different types of jobs i.e. job type A, job type B, job type C, job type D, job type E and job type F arrive at the manufacturing system and all the job types have equal probability of arrival. Job types A, B, C, D, E and F require 5, 4, 4, 5, 4 and 5 operations respectively. Table 1 shows the machines visited by different job types in their routes. The processing times and setup times of each job are stochastic. They are assumed to be uniformly distributed on each machine. Processing time changes according to job type and route of the job. Table 2 list the processing times of each job on the each machine according to its route. The selection of pattern of processing times on various machines is based on research work carried out by previous researcher [16]. Table 3 shows the sequence-dependent setup times which encounters while shifting from one job type to another.

2.1. Inter-arrival time

It is average time between arrivals of two jobs. It is exponentially distributed and based on research work carried out by various researchers and calculated using the following relationship [3, 14].

$$b = \frac{1}{\lambda} = \frac{\mu_p \mu_g}{UM} \quad (1)$$

Where, b=Mean inter-arrival time, λ=Mean job arrival rate, μ_p =Mean processing time per operation (including setup time), μ_g =Mean number of operations per job, U=Shop utilization, M=Number of machines in the shop

In the present work, μ_p is computed by taking the mean of mean processing times of all operations (from Table 2) plus mean of mean setup times (from Table 3). Thus, μ_p =19. 45. For the taken input data, μ_g is 4.5 with M=10. In the present work, experiments are carried out at shop utilization (U) = 90%. Van Parunak [17] observed that due to stochastic nature of processing times and setup times, the actual shop load is approximated and fall within a range of ± 1.5% of the target value.

2.2. Due date of jobs

It is time at which job order must be completed. The total work content (TWK) method is used to assign due date of the job [15,18,19] and calculated using the following relationship.

$$d_i = a_i + k(p_i + n_i \times u_i) \quad (2)$$

Where, d_i = Due date of job i,a_i = Arrival time of job i,k = Due date tightness factor, p_i =Mean total processing times of all the operations of job i,n_i = Number of operations of job i,u_i = Mean of mean setup times of all the changeover of job i. In the present study, due date tightness factor (k) = 3 is considered.

Table 1. Routes of job types

Job type	Number of operations	Route of the job (Machine number)
A	5	1-6-10-2-4
B	4	8-3-5-10
C	4	7-9-3-1
D	5	5-7-9-2-4
E	4	2-8-1-10
F	5	6-9-1-3-5

3. Structure of Simulation Model

Using simulation modeling a discrete event simulation model for the operations of SDJS manufacturing system with each dispatching rule is developed using PROMODEL software. While developing simulation model, following assumptions are made.

- Each machine can perform at most one operation at a time.
- An operation cannot start until its previous operation is finished.
- The arrival of jobs in the job shop is dynamic and a type of job is unknown until it arrives in the shop.
- Unlimited capacity buffer is considered before and after each machine.

- Processing times and setup times are stochastic. Both are known with their distribution in priori.

3.1. Dispatching rules

Dispatching rules (DRLs) are used to select a next job to be processed on the machine from a set of jobs awaiting input queue of the machine. In the present study, following dispatching rules identified from the literature are used for making job sequencing decision [3,14].

- Shortest Processing Time (SPT): The job with shortest processing time for the imminent operation is selected for processing.
- Shortest Setup Time (SIMSET): The job with shortest setup time for the imminent operation is selected for processing.
- Earliest Due Date (EDD): The job with earliest due date is selected for processing.

3.2. Performance measures

In the present work, the performance measures used for evaluation purpose in experimental investigations are as follows:

- Mean flow time ($\overline{F}$): It is average time spent by a job in the job shop floor during processing.

$$\overline{F} = \frac{1}{n}[\sum_{i=1}^{n} F_i] \quad (3)$$

Where, $Fi = c_i - a_i$, F_i=Flow time of job i,c_i =Completion time of job i,a_i =Arrival time of job i,n=Number of jobs produced during simulation period (during steady state period)

- Mean tardiness ($\overline{T}$): It is average tardiness of a job in the job shop floor during processing.

$$\overline{T} = \frac{1}{n}[\sum_{i=1}^{n} T_i] \quad (4)$$

Where, $T_i = max \{0, L_i\}$,$L_i = c_i - d_i$, T_i=Tardiness of job i,L_i=Lateness of job i, d_i =Due date of job i

4. Experimental Design for Simulation Study

Using simulation modeling, a number of experiments on SDJS scheduling problem are conducted. The first stage in simulation experimentation is identification of steady state period i.e. end of the initial transient period. For this purpose, Welch's procedure described in Law and Kelton [20] is used. A pilot study for SDJS scheduling problem is conducted with SPT dispatching rule and 30 replications are considered for simulation experimentation. For each replication, simulation is made to run for 20000 jobs completion. It is found that manufacturing system reaches steady state at 5000 jobs completion. Finally, the experimental investigation is carried out to analyze the performance of six dispatching rules identified from literature in a SDJS scheduling problem for 20000 jobs completion (after warm up period of 5000 jobs).

5. Results and Discussion

In SDJS scheduling problem, the performance of six dispatching rules identified from literature is analyzed. For each performance measure under each dispatching rule, the simulation output of 30 replications is averaged. Figures 1-5 show the average values of different performance measures.

5.1. Makespan

Figure 1 shows the performance of various dispatching rules for makespan measure. This figure indicates that EDD rule provides best performance for makespan and this rule is followed by JEDD, JSSPT JSPT, SSPT, and SPT rules in that order.

Table 2. Processing times of jobs on machines according to routes

Job type	Processing times of jobs according to machines
A	U(10,11), U(14,15), U(17,18), U(16,17), (18,19)
B	U(17,18), U(10,11), U(19,20), U(13,14)
C	U(17,18), U(11,12), U(16,17), U(13,14)
D	U(12,13), U(19,20), U(16,17), U(10,11), U(17,18)
E	U(13,14), U(19,20), U(10,11), U(16,17)
F	U(19,20), U(13,14), U(15,16), U(10,11), U(14,15)

Table 3. Job types/sequence-dependent setup times data

	Follower job type					
Preceding job type	A	B	C	D	E	F
A	0	U(5,5.25)	U(5,5.75)	U(5,5.50)	U(5,5.50)	U(5,5.25)
B	U(5,5.50)	0	U(5,5.25)	U(5,5.75)	U(5,5.25)	U(5,5.50)
C	U(5,5.25)	U(5,5.50)	0	U(5,5.50)	U(5,5.75)	U(5,5.25)
D	U(5,5.75)	U(5,5.25)	U(5,5.50)	0	U(5,5.25)	U(5,5.50)
E	U(5,5.50)	U(5,5.75)	U(5,5.25)	U(5,5.50)	0	U(5,5.25)
F	U(5,5.25)	U(5,5.50)	U(5,5.75)	U(5,5.25)	U(5,5.50)	0

5.2. Mean flow time

The performance of different dispatching rules for mean flow time measure is shown in Figure 2. It indicates that SSPT rule is best performing dispatching rule for mean flow time performance measure. This is followed by SPT, JEDD, EDD, JSSPT JSPT rules in that order. Thus, SSPT rule is best performing dispatching rule for mean flow time performance measure when a stochastic dynamic job shop scheduling problem with sequence-dependent setup times is considered.

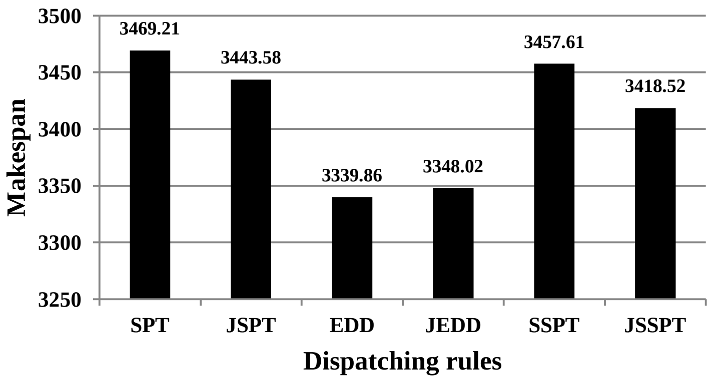

Figure 1. Performance of dispatching rules for makespan

5.3. Mean tardiness

This is due date based performance measure and related to better customer service and satisfaction. Figure 3 shows the performance of various dispatching rules for mean tardiness measure. It clearly indicates that SPT rule is best performing dispatching rule and it is followed by SSPT, JEDD, EDD, JSSPT, and JSPT rules in that order. Thus, SPT dispatching rule outperforms other dispatching rules for mean tardiness performance measure.

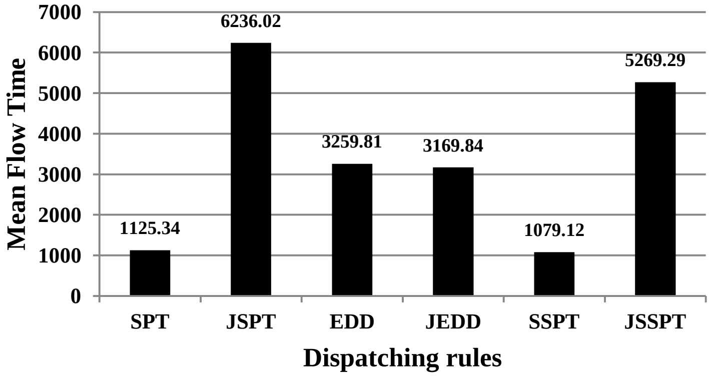

Figure 2. Performance of dispatching rules for mean flow time

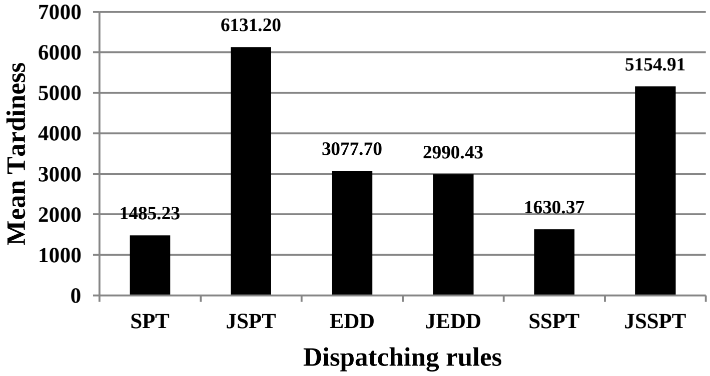

Figure 3. Performance of dispatching rules for mean tardiness

5.4. Total setups and Mean setup time

Figures 4 and 5 show the performance of various dispatching rules for total setups and mean setup time measures respectively. These figures indicate that JEDD rule is best performing dispatching rule for both measures. This is followed by EDD, JSSPT, JSPT, SSPT, and SPT in that order. Thus, JEDD dispatching rule outperforms other dispatching rules for these both performance measures.

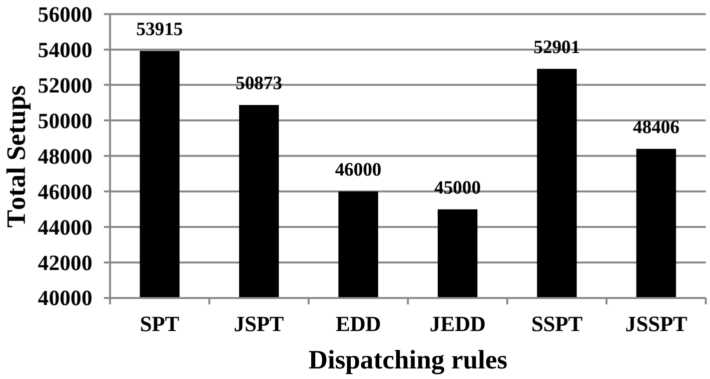

Figure 4. Performance of dispatching rules for total setups

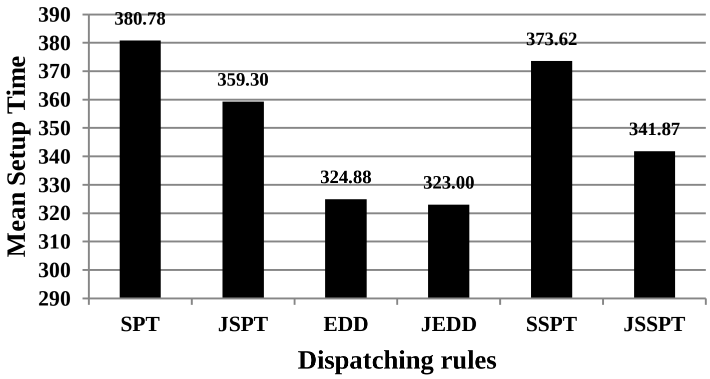

Figure 5. Performance of dispatching rules for mean setup time

6. Conclusions

The present work addresses a SDJS scheduling problem with sequence-dependent setup times. The performance of six dispatching rules as identified from literature is assessed. The experimental results indicate that the EDD rule provides best performance for makespan. The SSPT rule provides best performance for mean flow time, SPT rule provides best performance for mean tardiness, and JEDD rule provides best performance for total setups and mean setup time performance measures.

The present work can be extended in a number of ways. Further experimental work is required to address SDJS scheduling problems with sequence-dependent setup times which involve the situations like limited capacity buffer between machines, machine breakdown, batch mode schedule and external disturbances viz. order cancellation and job pre-emption. The development of new better dispatching rules is also essential and desirable.

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