

## Stochastic dynamic job shop scheduling with sequence-dependent setup times: Dispatching rules based approach

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### Abstract

Job shop scheduling problems with stochastic processing and sequence-dependent setup times, and dynamic arrival of job types are real world and most complex among various scheduling problems. This paper extends the previous work of Sharma and Jain (2015) by assessing the performance of proposed four setup oriented dispatching rules with respect to bench mark dispatching rule taken from literature for makespan, maximum flow time, and maximum tardiness measures respectively. In order to carry out investigation, the system is modeled by using PROMODEL simulation software. Simulation results indicate that the setup oriented dispatching rules proposed by Sharma and Jain (2015) provide better performance than the existing rules for considered performance measures.

**Keywords:** Scheduling, Sequence-Dependent Setup Times, Dispatching rule

### 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 (Garey et al., 1976; Xiong et al., 2013). 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 (Kim and Bobrowski, 1994; Kim and Bobrowski, 1997).

Setup time is a time required to prepare the resources such as machines to perform a operation (Ali and Soroush, 2008). 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 (Ali and Soroush, 2008). Manikas and Chang (2009) and Fantahun and Mingyuan (2012) 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 (1990) provides review of simulation research in dynamic job shop scheduling problems. Allahverdi et al. (1999) provides a survey of literature on scheduling problems with

setup times/costs. Panwalkar et al. (1977) presented a survey of scheduling rules used in manufacturing systems. Blackstone et al. (1982) presented a survey of scheduling rules used in job shop scheduling problems. Jayamohan and Rajendran (2000) 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.* (2004) 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 (1969) 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 (1994) 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 (2008) 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. Sharma and Jain (2015) proposed four new setup oriented dispatching rules viz. (i) shortest sum of time to due date, setup time and processing time (TDDSSPT) (ii) job with similar setup and shortest sum of time to due date, setup time and processing time (JTDDSSPT) (iii) job with similar setup and shortest SLACK (JSLACK) and (iv) job with similar setup and shortest SLACK per unit work (JSLACKW) for stochastic job shop manufacturing systems considering sequence-dependent setup times. The performance of the system was evaluated in terms of mean flow time, mean tardiness and mean setup time measures. They concluded that the proposed dispatching rules provided better performance for considered measures.

Literature review indicates that Sharma and Jain (2015) proposed four new setup oriented dispatching rules and assessed their performance for mean flow time, mean tardiness and mean setup time measures respectively. The present work is an extension of previous work of the researchers (Sharma and Jain, 2015) wherein performance of proposed four setup oriented dispatching rules is assessed for makespan, maximum flow time, and maximum tardiness measures respectively.

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 (Wilbrecht and Presscott, 1969). 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 (Baykasoglu et al., 2008). 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 (Wilbrecht and Presscott, 1969).

$$b = \frac{1}{\lambda} = \frac{\mu_p \mu_g}{UM} \tag{1}$$

Where,  $b$ =Mean inter-arrival time,  $\lambda$ =Mean job arrival rate,  $\mu_p$  =Mean processing time per operation (including setup time),  $\mu_g$  =Mean number of operations per job,  $U$ =Shop utilization,  $M$ =Number of machines in the shop

In the present work,  $\mu_p$  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,  $\mu_p = 19.45$ . For the taken input data,  $\mu_g$  is 4.5 with  $M=10$ . In the present work, experiments are carried out at shop utilization ( $U$ ) = 90%. Van Parunak (1991) observed that due to stochastic nature of processing times and setup times, the actual shop load is approximated and fall within a range of  $\pm 1.5\%$  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 (Vinod and Sridharan, 2008; Yu and Ram, 2006; Baker, 1984) and calculated using the following relationship.

$$d_i = a_i + k(p_i + n_i \times u_i) \tag{2}$$

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 rule is used for selecting job for an operation on the machine from a set of jobs present in input buffer of machine. Table 4 shows thirteen dispatching rules as identified from the literature which are used for making job sequencing decision (Wilbrecht and Prescott, 1969; Vinod and Sridharan, 2008; Sharma and Jain, 2015). The four setup oriented dispatching rules proposed by Sharma and Jain (2015) are as follows: (i) Shortest sum of time to due date, setup time and processing time (TDDSSPT) (ii) Job with similar setup and shortest sum of time to due date, setup time and processing time (JTDDSSPT) (iii) Job with similar setup and shortest SLACK (JSLACK) (iv) Job with similar setup and shortest SLACK per unit work (JSLACKW).

#### 3.2. Performance measures

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

- Makespan (M): Makespan represents the completion time of last job in the system.
- Maximum flow time (Fmax): It is a maximum value of flow time that encounters during processing of jobs in the shop.

$$F_{max} = \max \{F_i\} \quad (3)$$

$$1 \leq i \leq n$$

- Maximum tardiness (Tmax): It is a maximum value of tardiness that encounters during processing of jobs in the shop.

$$T_{max} = \max \{T_i\} \quad (4)$$

$$1 \leq i \leq n$$

### 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 (1991) 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**

For different performance measures under different dispatching rules, the average value of simulation output of 30 replications is calculated. Figures 1-3 depict the average values of makespan, maximum flow time, and maximum tardiness measures respectively.

**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**

Preceding job type	Follower 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

**Table 4. Dispatching rules**

Dispatching Rule	Description
FCFS	First-come-first-serve
SPT	Shortest processing time
SIMSET	Shortest setup time
EDD	Earliest Due date
SSPT	Smallest sum of setup time and processing time
JSPT	Job with similar setup and shortest processing time
JEDD	Job with similar setup and earliest due date
JMEDD	Job with similar setup and modified earliest due date
JSSPT	Job with similar setup and shortest sum of setup time and processing time
TDDSSPT	Shortest sum of time to due date, setup time and processing time
JTDDSSPT	Job with similar setup and shortest sum of time to due date, setup time and processing time
JSLACK	Job with similar setup and shortest SLACK
JSLACKW	Job with similar setup and shortest SLACK per unit work

**5.1. Makespan**

Makespan represents completion time of the last job in the manufacturing system. Makespan values for different dispatching rules are shown in figure 1. Figure 1 indicates that the proposed JTDDSSPT rule performs best for makespan. This is followed by proposed JSLACKW and JSLACK dispatching rules in that order. The existing JMEDD rule ranks fourth while proposed TDDSSPT rule ranks eight in minimizing makespan of the jobs.

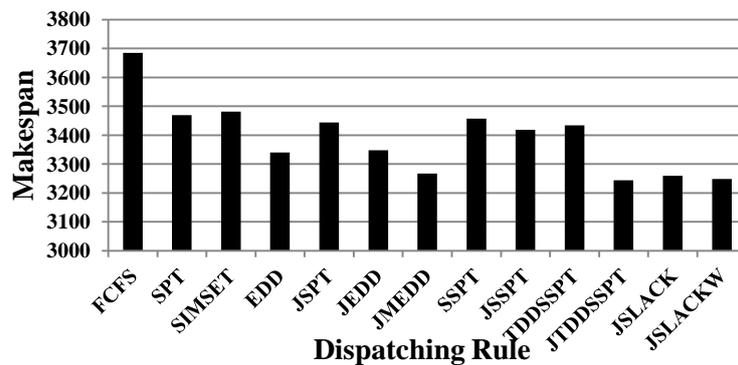
**5.2 Maximum flow time**

Figure 2 depicts the performance of various dispatching rules for maximum flow time measure. It is observed that the proposed JTDDSSPT, JSLACKW, and JSLACK dispatching rules provide best performance for maximum flow time measure. The best performing rule in this category is JTDDSSPT rule, followed by JSLACKW and JSLACK rules in that order as the next best performing dispatching rules. The existing JMEDD rule ranks fourth while the proposed TDDSSPT dispatching rule ranks ninth in minimizing maximum flow time of the jobs.

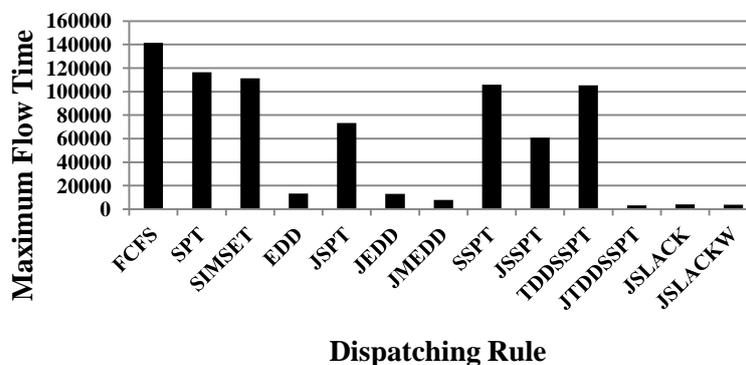
**5.3 Maximum tardiness**

Figure 3 depicts the performance of various dispatching rules for maximum tardiness measure and It indicates that the proposed JTDDSSPT, JSLACKW, and JSLACK dispatching rules are best performing dispatching rules in that order. The performance pattern of different dispatching rules for maximum tardiness measure is similar to the performance of different dispatching rules with respect to maximum flow time measure.

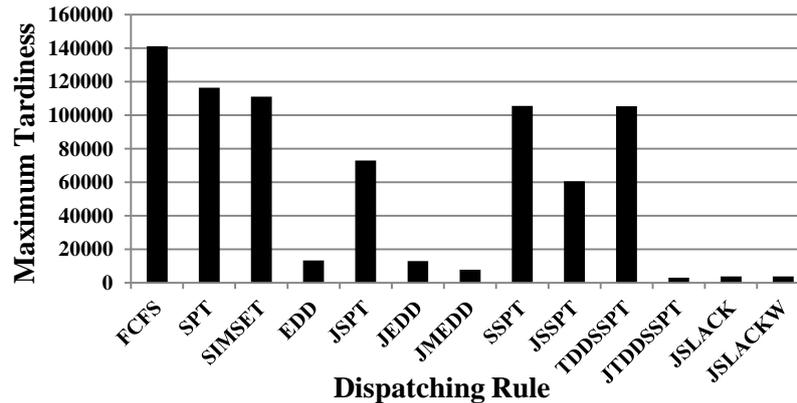
The above discussion clearly indicates that setup oriented dispatching rules as proposed by Sharma and Jain (2015) performs better than the other dispatching rules taken from literature.



**Figure 1. Performance of dispatching rules for makespan**



**Figure 2. Performance of dispatching rules for maximum flow time**



**Figure 3. Performance of dispatching rules for maximum tardiness**

## 6. Conclusions

The present work addresses a SDJS manufacturing system with sequence-dependent setup times. A simulation model of such system is developed. The results indicate that the proposed JTDDSSPT rule is best performing dispatching rule for makespan, maximum flow time, and maximum tardiness performance measures. Furthermore, future research work could be expanded by considering situations like limited capacity buffer between machines, schedule in batch mode, breakdown of machine and external disturbances like cancellation of order and pre-emption of job in SDJS scheduling problem with sequence-dependent setup times.

## References

- [1] Ali A, Soroush HM. The significance of reducing setup time/setup costs. *European Journal of Operational Research* 2008; 187: 978-984.
- [2] Allahverdi A, Gupta JND, Aldowaisan T. A review of scheduling research involving setup considerations. *Omega* 1999; 27: 219-239.
- [3] Baker K.R. Sequencing rules and due-date assignments in a job shop, *Management Science* 1984; 30:1093-1104.
- [4] Blackstone JH, Philips DT, Hogg GL. A state-of-the-art survey of dispatching rules for manufacturing job shop operations. *International Journal of Production Research* 1982; 20: 27-45.
- [5] Baykasoglu A, Göçken M, Unutmaz ZD. New approaches to due date assignment in job shops. *European Journal of Operational Research* 2008; 187: 31-45.
- [6] Fantahun MD, Mingyuan C. Job shop lot streaming with routing flexibility, sequence-dependent setups, machine release dates and lag time. *International Journal of Production Research* 2012; 50: 2331-2352.
- [7] Garey MR, Johnson DS, Sethi R. The complexity of flow shop and job shop scheduling. *Mathematics of Operations Research* 1976; 1:117-129.
- [8] Jain A, Jain PK, Singh IP. An investigation on the performance of dispatching rules in FMS scheduling. *International journal of simulation modeling* 2004; 3:49-60.
- [9] Jayamohan MS, Rajendran C. New dispatching rules for shop scheduling: A step forward. *International Journal of Production Research* 2000; 38: 563-586.
- [10] Kim SC, Bobrowski PM. Impact of sequence dependent setup time on job shop scheduling performance. *International Journal of Production Research* 1994; 32:1503-1520.

- [11] Kim SC, Bobrowski PM. Scheduling jobs with uncertain setup times and sequence dependent. *International Journal of Management Science* 1997; 25: 437-447.
- [12] Law AM, Kelton WD. *Simulation modeling and analysis*. New York: McGraw-Hill;1991.
- [13] Manikas A, Chang YL. Multi-criteria sequence-dependent job shop scheduling using genetic algorithms . *Computers and Industrial Engineering* 2009; 56:179-185.
- [14] Panwalkar SS, Iskander W. A survey of scheduling rules. *Operations Research* 1977; 25: 45-61.
- [15] Ramasesh R. Dynamic job shop scheduling: a survey of research. *Omega: International Journal of Management Science* 1990; 18: 43-57.
- [16] Sharma, P, Jain, A. New setup-oriented dispatching rules for a stochastic dynamic job shop manufacturing system with sequence-dependent setup times. *Concurrent Engineering: Research and Applications*, 2015, DOI: 10.1177/1063293X15599814.
- [17] Vinod V, Sridharan R. Dynamic job shop scheduling with sequence- dependent setup times: Simulation modelling and analysis. *International Journal of Advanced Manufacturing Technology* 2008; 36: 355-372.
- [18] Van Parunak H. Characterizing the manufacturing scheduling problem. *Journal of Manufacturing Systems* 1991; 10: 241-259.
- [19] Wilbrecht JK, Presscott WR. The influence of setup time on job shop performance. *Management Science* 1969; 16: 274-280.
- [20] Xiong J, Xing LN, Chen YW. Robust scheduling for multi-objective flexible job-shop problems with random machine breakdowns. *International Journal of Production Economics* 2013; 141: 112-126.
- [21] Yu X, Ram B. Bio-inspired Scheduling for dynamic job shops with flexible routing and sequence dependent setups. *International Journal of Production Research* 2006; 44:4793-4813.