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Shop Utilization in a Stochastic Dynamic Job Shop Manufacturing System

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Abstract

Job shop scheduling problems occurs in automobile industry, aerospace industry, printing industry, and chemical industry. Job shop scheduling problems are real world and complex. The present work assesses the effect of change in shop utilizations levels on makespan, maximum flow time and maximum tardiness measures. The model of the job shop is developed in PROMODEL simulation software. Three levels of shop utilization i.e. 90%, 85% and 80% are considered in order to assess the effect of change in shop utilization levels on system performance. Simulation results indicate that the change in shop utilization levels has a significant effect on system performance..

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

1. Introduction

Production scheduling in a manufacturing system 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).

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. A setup operation often occurs while shifting from one type of operation to another. Setup time is a time required to prepare the resources such as machines to perform a operation (Ali and Soroush, 2008). 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. 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.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.

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.

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).

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

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%, 85% and 80%. 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 ± 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.

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

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.

$$F_{max} = \max_{1 \le i \le n} \{F_i\} \quad (3)$$

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

$$T_{max} = \max_{1 \le i \le n} \{T_i\} \quad (4)$$

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

Three different shop utilization levels i.e. U=90%, U=85% and U=80% are considered in order to investigate the effect of change in shop utilization level on manufacturing system performance. Since dispatching rules and shop utilization levels are two experimental factors, 1080 (03 shop utilizations level x 13 dispatching rules x 30 replications) simulation runs are performed for evaluation purpose. The mean values of 30 replications for 39 simulation experiments are shown in figures 1-3 for 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.

	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

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 ime
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

Figure 1 shows that there is increase in makespan values as the shop utilization is decreased. This is due to the fact that as shop utilization decreases, the inter-arrival time of the jobs increases and hence, makespan increases. Figures 2-3 indicate that as shop utilization decreases maximum flow time and maximum tardiness performance measures decreases. This is due to the fact that at low shop utilization, jobs wait for shorter duration for processing at various machines queues and hence, decrease in values of these performance measures is observed. The above discussion clearly reveals that the shop utilization level is an important parameter and it affects the system performance as measured by makespan, maximum flow time and maximum tardiness performance measures respectively.

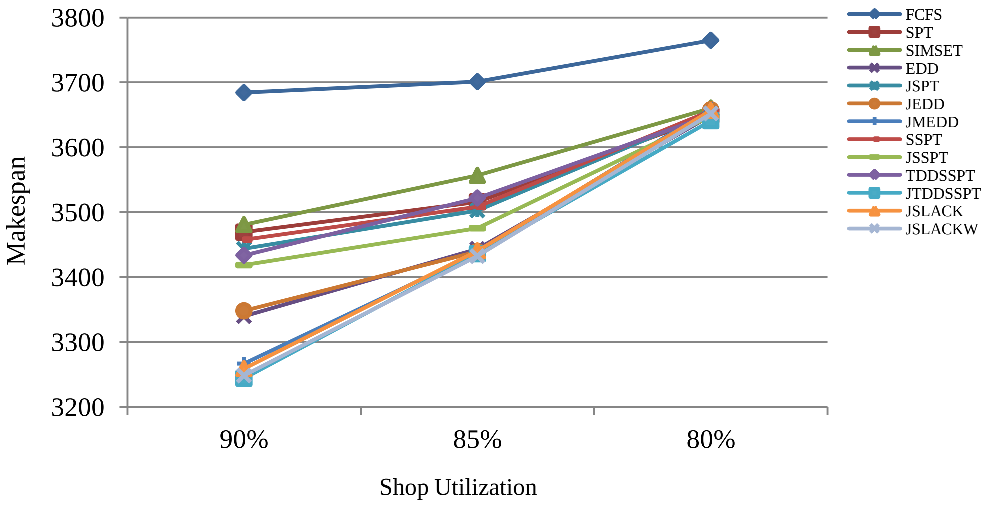

Figure 1. Effect of shop utilization on makespan

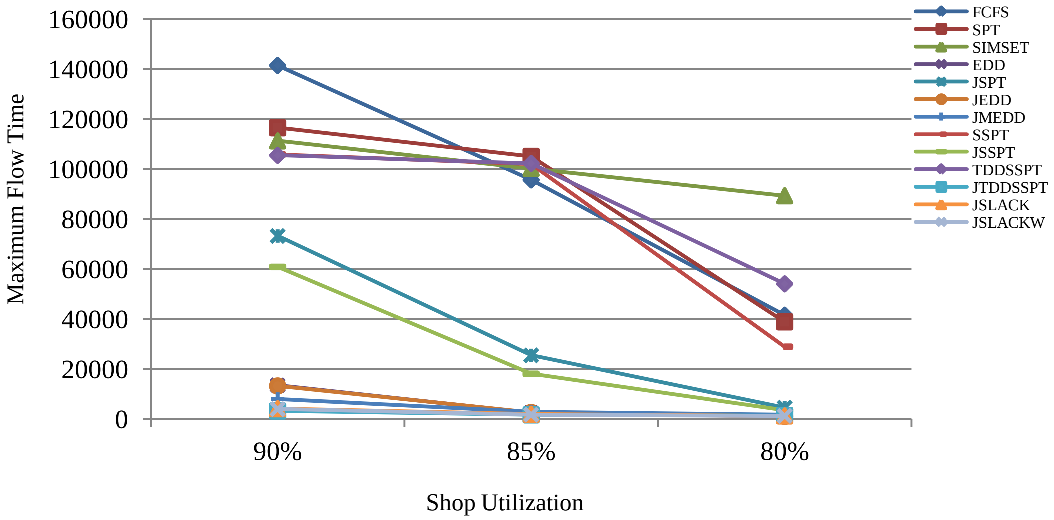

Figure 2.Effect of shop utilization on maximum flow time

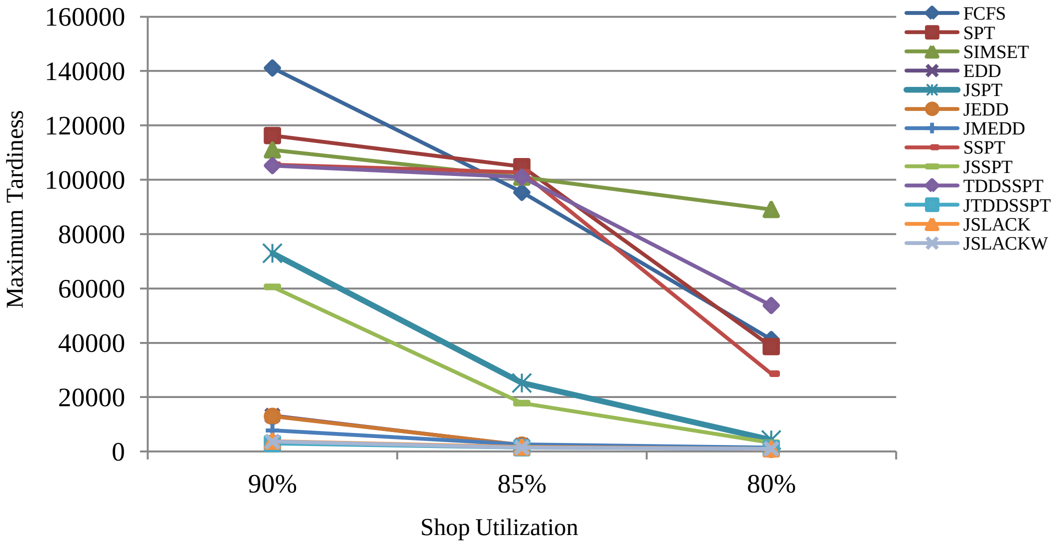

Figure 3. Effect of shop utilization on maximum tardiness

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 there is increase in makespan values as the shop utilization is decreased while as shop utilization decreases maximum flow time and maximum tardiness performance measures decreases. 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.

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