Simulation Modeling and Analysis of Job scheduling and Release Policies using Work in Process limit in an Agile Job Shop

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Abstract

This paper intends to analyze the performance of a job shop with the dynamic arrival of jobs and setup times that are sequence dependent. Job release policy based on specified values for work-in-process inventory limit is investigated. A simulation model of a realistic manufacturing system is developed for detailed analysis. The dynamic total work content method is adopted to assign the due dates of jobs. Six priority rules are applied for prioritizing jobs for processing on machines. Several performance criteria are considered for analyzing the system performance. The simulation results are used to conduct statistical tests. Analytical models have been formulated to represent the simulation model for post-simulation studies. These models are found to yield a satisfactory estimation of the system outputs.

Keywords: Dynamic job shop, sequence dependent setup, job release work in process limit, simulation, regression models

1. Introduction

Production and service systems involve scheduling as an important decision in planning and control of activities. Scheduling deals with the time-based allocation of resources to tasks based on one or more performance measures. (Pinedo 2008).In a dynamic job shop production system, jobs for processing in the system arrive at various times with each job requiring a set of operations. The sequence of operations may vary among the jobs and each operation requires a specific processing time. Each job may have a due date, the time by which all the operations of the job need to be completed. The objective is to obtain the starting time and ending times of operations of jobs such that the intended criterion is met (Rajendran and Holthaus 1999). For this purpose, a scheduling rule is used as a heuristic method for identifying the job to be processed from among the jobs waiting at a machine when the machine completes its current processing. In industrial practice, scheduling rules are developed and employed such that a reduction in the in-process inventory costs is obtained and prompt delivery of jobs to customers is ensured.

In production systems, activities such as obtaining tools, setting the machines, fixing and removing jobs, returning tools, cleaning the machines, inspecting materials, etc. constitute setup time. Setups can be sequence independent or sequence dependent. In a sequence independent setup time environment, the setup time for a job is independent of the preceding job. In a system operating under sequence dependent setup time (SDST) environment the same machinery has to be cleaned and used for manufacturing different Products.SDST environment is characterized by the dependence of the setup time on the current job and also on the previous job that has been processed on that machine (Vanchipura and Sridharan 2013, Zeidi and Mohammad Hosseini2015). In industries such as textiles, paint manufacturing, paper cutting, chemical manufacturing, etc., the setup time has immense importance and it is sequence dependent. Allahverdi (2015) and Allahverdiand Soroush (2008) describe the importance of reducing setup time and cost in manufacturing industries.

In a manufacturing system with dynamic arrival of orders, jobs arrive at the shop for processing at random points in time. Saad et al. (2004) state that there are three stages in production control: (1) order entry, (2) order release and (3) job scheduling. Upon arrival of a job, a due time of completion is assigned. Total work content method is the commonly used procedure for determining the due time of jobs. This method ignores the information on the status of the shop. Due date determination methods that consider the condition of the system in terms of existing work load at the time of arrival of a job are known as dynamic due date methods. In simulation studies it is generally assumed that arriving jobs are immediately released to the shop floor for processing. However, in practice, the arriving jobs are initially collected in a pool and then released for processing according to some criterion. After the job release decision is made, the jobs are dispatched to machines for processing using scheduling or dispatching rules.

This paper focuses on the analysis of the effects of job release policies, priority scheduling rules and setup times in a job shop system operating in an SDST environment with the dynamic arrival of jobs. In the present research, due dates of jobs are set dynamically using the dynamic total work content method. Two job release policies are investigated namely Immediate job release and release based on specified work-in-process (number of jobs undergoing processing in the system) limit. Here work in process limits are selected as 20, 25, 30 and 35 .Six priority rules are applied for prioritizing jobs for processing on machines. Based on the factual data, simulation tests are conducted. System efficiency is arrived based on different metrics. Analytical models have been formulated to represent the simulation model for post-simulation studies. These models are found to yield a satisfactory estimation of the system outputs. To the best knowledge of the authors, scheduling an SDST job shop with dynamic due date method and job release based on work in process limits has not been studied yet. Analytical models have been developed for post-simulation studies of a job shop operating in an SDST environment with dynamic arrival of jobs. The analysis of the effects of work in process limits in a dynamic job shop with SDST and dynamic due date assignment is another noteworthy addition to the literature. Thus, the objectives of the present research are as follows:

- Develop scheduling decision rules for a job shop with the dynamic arrival of jobs operating in an SDST environment
- Develop a simulation model based on discrete-event approach for describing the operation of the job shop
- The analysis of the effects of work in process limits in a dynamic job shop with SDST and dynamic due date assignment

The structure of the remaining sections of this paper is as described hereunder. Section 2 deals with the description of the scheduling problem. Section 3 provides a brief review of the pertinent literature. Sections 4 provide the description of job shop configuration. Section 5 deals with Due date assignment methods, job release methods and the scheduling rules respectively. Section 6 explains the logic of the simulation model. Section 7 presents performance measures. Section 8 elucidates the experimentation procedure. Section 9 illustrates the results along with the analyses carried out. Section 10 highlights the Regression based analytical models and section 11 provide conclusion.

2. **Problem Description**

This research deals with scheduling a job shop with the dynamic arrival of jobs in an SDST environment with the consideration of multiple performance measures. The setup times depend on the sequence in which jobs are processed. This problem is addressed in the literature as scheduling a Sequence Dependent Setup Time job shop (SDST job shop)and is denoted as $A/m/G, s_{ijk}$/MC where the first symbol specifies the job arrival process (e.g. Poisson arrival), the second symbol specifies the number of machines in the shop, the third and fourth symbol denote the general job shop in an SDST environment (*G* stands for a general job shop and s_{ijk} stands for SDSTs) and the last symbol specifies the performance measures (MC stands for Multi-Criteria). s_{ijk} indicatesthe setup time on machine *i* when job *j*precedes job *k*.The performance measures considered are average flow time, average tardiness, percentage of tardy jobs, average setup time and average flow allowance. In the present study, the following aspects are postulated:

- The shop consists of one machine of each type.
- A machine can carry out one operation during any one period.
- A job can undergo processing on one machine during any one period.
- There is no choice of machines for an operation of a job, i.e., only one machine can carry out a given operation of a job
- Once a job is taken up for processing, there is no interruption in processing
- Operations of jobs follow a strict precedence structure.
- Setup times are sequence dependent and are known.
- Transportation time of jobs are negligible.
- There is no failure of machines.
- There is adequate space to accommodate waiting jobs.

3. Literature Review

In a job shop, setup time denotes the time needed to adjust a machine between two consecutive operations on the machine. Setup time may or may not be sequence dependent. As observed by Allahverdi and Soroush (2015), industris such as textile, printing, chemical, plastic, etc. face sequence dependent setup times. The approaches for solving SDST scheduling problems can be categorized as (1) Optimization methods (2) Heuristics/Metaheuristics and (3) Simulation. Optimization methods involve formulating the scheduling problem as a mathematical model and solving using branch-and-bound algorithm (Cheng 1996, Brucker and Thiele 1996, Artigues and Feillet, 2008). Zeidi and Hosseini (2015) state that the SDST scheduling problem belongs to the category of Non deterministic

Polynomial (NP) hard and hence optimization methods are not computationally efficient for large-sized problems.Heuristic methods involve the application of priority dispatching rules in combination with various schedule generation schemas.Metaheuristics based on genetic algorithm (Choi and Choi 2002, Naderi et al. 2009), simulated annealing (Tavakkoli-Moghaddam et al. 2009), ant colony optimization (Yu and Ram 2006), and particle swarm optimization (Anghinolfi and Paolucci 2009) have also been developed for solving SDST job shop scheduling problems.

Simulation modelling has emerged as the most commonly used method for scheduling dynamic job shops (Jayamohan and Rajendran 2000). Using simulation modeling, one can evaluate scheduling rules for various dynamic and stochastic conditions of the operation of the system. Dynamic job shops with SDST have been investigated by a few researchers. Kim and Bobrowski(1994)adopted simulation modeling for analyzing a dynamic job production system with SDST. The researchers investigate scheduling rules under different due date settings, setup times and costs. For a production system with a dynamic arrival of jobs and sequence dependent setup time, Vinod and Sridharan (2008)developed a simulation model for analyzing various scheduling rules with and without the consideration of setup time. They conclude that the use of scheduling rules that incorporate setup time lead to better results than the scheduling rules that do not include setup times.

In production systems, the releasing of jobs/orders arriving at the system is known as input control, input/output control, input sequencing and order review/release. Kim and Bobrowski (1995) have investigated order release policies and dispatching decisions in an SDST job shop. Their study revealed that controlled job release in combination with non-setup time oriented dispatching rules has a positive impact on total cost. However, no improvement is performance is observed for controlled job release mechanisms when setup oriented dispatching rules are used. Bergamaschi et al. (1997) provided a review of the literature on order review/release procedures in job shop production systems. Sabuncuoglu and Karapinar (1999) compared order review/release methods under several experimental conditions using a simulation model job shop. They observe that consideration of system load and job duedates are very important for the effective implementation of the job release policies.

Saad et al. (2004) investigated order release and due date assignment rules for a dynamic job production system. The modified number of operations rule is found to perform better than the other due date assignment rules analyzed. Thurer et al. (2010) reported workload Control research on the practical considerations of job size variations using simulation, the impact of job sizes on overall performance is analyed using three aggregate load approaches. Results revealed that assigning priority based on routing length improves performance, for large jobs. Gentile and Rogers (2009) extended the work of Kim and Bobrowski (1995) and inferred that order release based on work load control and job dispatching based on similar setup dispatching rule provides better performance. Lu et al. (2011) adopted an integrated approach for investigating order release rules and dispatch procedures for planning and scheduling of an assembly shop.Their results reveal that interaction between order release procedures and dispatching rules is more relevant for the mean absolute deviation of order completion dates while less relevant for the mean shop floor throughput time. Slotnick (2011) provided a review of the literature on order acceptance and scheduling from a problem-oriented perspective. .. Baykasoğlu and Karaslan (2017) proposed a dynamic scheduling algorithm with the consideration of due dates of orders and sequence-dependent setup times

The review of the literature reveals that there a few studies reported on the analysis of order release procedures and job dispatching rules in the context of an SDST job shop. Both the studies of Kim and Bobrowski (1995) and Gentile and Rogers (2009) used the Total Work Content (TWK) style in assigning the dispatch dates of orders. Further, regression-based models using simulation results have also been developed for post-simulation analysis. This literature is a value added one in SDST job shops.

4. Job shop configuration

A job shop configuration similar to a real-world production system has been developed in the present research. This configuration is in agreement with the systems considered by Hall and Posner (2001) and Rangasaritratsamee et al. (2004). There are six non-identical machines in the job shop considered in the present study. Each machine in the shop can process different varieties of jobs by altering the setup. The shop processes eight varieties of jobs. An arriving order can belong to any one of the eight varieties of jobs with equal probability. Each job-variety has the number of operations following a uniform distribution between 3 and 6. The machine required for the operations of a job-variety is generated randomly such that a machine is not repeated in the machine-visit sequence. The average processing time for an operation is fixed at 30 minutes and the individual processing times of operations are obtained using an exponential distribution with this average value. A separate setup time matrix is constructed for each machine in the shop. The ratio of average setup time to average processing time is kept at 20%. Using this ratio and the average processing time, the average setup time is computed. The setup times of job-varieties on machines are obtained using an exponential distribution with this average setup time.

Poisson distribution is used to model the arrival of job-varieties. This implies that job-varieties arrive at the shop with the time between arrivals following an exponential distribution. The averageinterarrival time of job varieties is obtained using the following expression that relates resource input, work output, and the system utilization (Rachamadagu 1993, Rangasaritratsamee et al. 2004):

$$\rho = \frac{work\ output}{work\ input} = \frac{\lambda\, \mu_p \mu_g}{n_m} \quad (1)$$

whereρ = system utilization, λ = arrival rate of job varieties, μ_p = average processing time per operation, μ_g = average number of operations per job, n_m =number of machines in the shop.

From (1), the average interarrival time $=\frac{1}{\lambda}$.For experimentation, the averageinterarrival time of job varieties is determined for the system utilization of 90 %.

5 DUE DATE ASSIGNMENT METHOD

5.1 Dynamic Total Work Content Method

The dynamic total work content (DTWK) method is a modification of the total work content method.Since setup times of operations are considered in the present study, the work content of a job includes setup time also. The total work content (TWK) method computes the flow allowance for a job as equal to the product of flow allowance factor and the processing time of the job. This flow allowance is added to arrival time of the job to determine the due date in the TWK method. In the DTWK method, the flow allowance factor is computed from the data on shop conditions on the arrival of a job as followed by Cheng and Jiang (1998) and Sha and Liu (2005). Thus, the flow allowance factor K_t is computed based on the dynamic conditions follows the relationship depicted hereunder:

$$K_t = \frac{J_t}{\lambda\,(\mu_p + \mu_s)\,\mu_g} \quad (1)$$

The dynamic flow allowance factor for due date determination is derived as maximum (K_t, 1). This guarantees a minimum value of 1 for K_t .The flow allowance for a job is computed using the following relationship:

Dynamic flow allowance = [max (K_t, 1)][p_i+$n_i\mu_s$]

Hence, the due date (D_i) for a job is determined as

D_i =Arrival time+ dynamic flow allowance (2)

Where =

5.2 Job Release Method

The following method is used in the present study for releasing jobs for processing in the system;

Work in process limit based release of jobs

In this method, jobs are released for processing as and when the quantity of components find lower than the fixed level. In this research the batch size of jobs that could be kept in machining in pipe line are fixed at values 20,25,30 and 35and 40 .

5.3. Scheduling Rules

For each job waiting in the queue of a machine, a preference value is allotted using a scheduling rule. The job with the smallest preference value has the highest preference for selecting to be processed next on the machine. Two scheduling rulesMSRPT and MCSPT are proposed in the present research by incorporating the setup time, the processing and the due date. These scheduling rules are modifications of the schedules rules S/RPT + SPT and CR + SPT proposed by Anderson and Nyirenda (1990). In addition, four existing scheduling rules are also applied. These scheduling rules are explained hereunder.

(1) Modified Sequence dependent slack per Remaining Processing Time plus shortest processing time, MSRPT. In this rule, the preference value is computed using the following expression:

Preference value = Max {(S/RPT) ($p_{ij}^m + s_{ij}^m$), ($p_{ij}^m + s_{ij}^m$)}

where S/RPT = due date of job – current time – (remaining process time + remaining average setup time).

p_{ij}^m : Processing time of operation j of job i waiting in the queue of machine *m and*

s_{ij}^{m} : Setup time of operation *j* of job *i* waiting in the queue of machine *m*

From the machine queue, the job with the smallest preference value is chosen for processing in the machine..

(2) Modified sequence dependent critical ratio plus shortest processing time, MCSPT. In this rule, the preference value is computed using the following expression:

Preference value = Max $\{CR\ (p_{ij}^{m} + s_{ij}^{m}), (p_{ij}^{m} + s_{ij}^{m})\}$

where Critical Ratio, CR is defined as

$$CR = \frac{\text{Due date of job - Current time}}{\text{Remaining processing time}}$$

From the machine queue, the job with the smallest preference value is chosen for processing in the machine.

(3) Job with similar setup and Critical Ratio, JCR (Kim and Bobrowski, 1994):

This rule choosesthe job identical to the job that is just completed on the machine. If there is no identical job present in the machine queue, this rule selects a job that has the smallest critical ratio.

(4) SIMilarSETup, SIMSET(Kim and Bobrowski, 1994):

This rule choosesthe job identical to the job that is just completed on the machine. If there is no identical job present in the machine queue, this rule selects a job that has the lowestvalue of setup time.

(5) Shortest (Setup time + Processing Time), SSPT (Vinod and Sridharan 2008).

This rule chooses the job that has the lowest value of the sum of setup time and processing time.

(6) Shortest Processing Time, SPT

This rule chooses the job that has the lowset value ofprocessing time for the immediate operation.

6. Development of the Simulation Model

In the present study, the job shop is modeled based on the concept of discrete-event simulation. The model is constructed in C++. The jobs to be processed and the machines in the shop constitute the entities in the simulation model. The events that occur in the system are arrival of an order (job-variety) for production and the departure of a job after completion of an operation. These events occur in a chronological order. At the start of simulation, the system is in an idle state. As described in section 4, job-varieties arrive according to the

Poisson distribution. The first job arrives at the system based on the time between arrival of jobs obtained using an exponential distribution with the average interarrival time corresponding to the Poisson arrival process. The simulation time advance mechanism makes this arrival to occur. Once a job-variety arrives at the system, the details of operations, routing, processing time and due date are obtained. In the immediate job release policy, an arriving job is released to the machine for the first operation immediately on arrival. In the work-in-process (WIP) based release of jobs, an arriving job is released for processing whenever the total number of jobs in the system WIP inventory falls below the set work in process limit i.e 20,25,30,35and 40 . After an arrival is released, the machine required for processing the first operation is identified. The job joins the machine queue if the machine is engaged otherwise the job undergoes processing in the machine. When a machine finishes the assigned operation of a job, there are two decisions involved, i.e., one for the machine and the other for the job. If there are no jobs in the machine queue, the machine remains idle. Otherwise, the next job to be processed in the machine is chosen based on a scheduling rule. For the job which has its operation just completed, a check is made to determine whether there are any more operations to be processed for the job. If there are operations remaining for the job, the job is routed to the machine for the next operation; else, the details such as flow time, tardiness, setup time, flow allowance, etc. for the job are computed. The completed job exits from the shop.

In the present research, the performance measures are evaluated after the end of the transient period. For determining the steady state of the system, the method of moving averages proposed by Welch (1981) is adopted. The measures such as average flow time, average tardiness, percentage of tardy jobs, average setup time, and average flow allowance are calculated using the simulation results after the steady state of the system.

7. **PERFORMANCE MEASURES**

The performance measures evaluated in the simulation experiments are average flow time, average tardiness, percentage of tardy jobs, average setup time and average flow allowance. These measures are described as follows.

- Average flow time: It is the average time spent by a job in the shop.

  Average flow time $=\frac{1}{n}\sum_{i=1}^{n} F_i$

- Averagetardiness: It is the average tardiness of a job.

  Averagetardiness $=\frac{1}{n}\sum_{i=1}^{n} T_i$

- Percentage of tardy jobs $=\frac{n_T}{n}\times 100$
- Average setup time: It is average setup time of a job.

  Averagesetup time $=\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{ni} s_{ij}$
- Average Flow Allowance: It is the average flow allowance assigned to a job.

  Average Flow Allowance $=\frac{1}{n}\sum_{i=1}^{n}(D_i - A_i)$

8. EXPERIMENTATION

In the present research, due dates of jobs are determined using DTWK method. The jobs waiting in machine queues are prioritized using six scheduling rules. The Job release methods namely immediate Job release and work in process limit based release of job. The average setup time is set at two levels namely, 6 and 12 minutes. Hence, the factors in the simulation experiments are, six scheduling rules, two values for average setup time and five corresponding values for job release methods. Each experiment is replicated ten times with the simulation run length fixed as completion of 1800 jobs. The simulation results from the first 300 jobs correspond to the results of the transient condition of the system and hence these results are discarded. The performance measures are evaluated using the outputs for the remaining jobs

9. RESULTS AND DISCUSSION

Results obtained from simulation are represented pictorially in the following figures 1, 2, 3, 4 and 5. These interaction plots show the combined effect of work in process limit based Job release method and scheduling rule on the performance of the system. Figure 1 to 4 reveals that all performance measures except average flow allowance are minimum for work in Process Limit 40 and maximum for work in process limit restricts to 20.In Figure 5 reverse trend is observed, i.e average flow allowance is minimum when work in process limit is restricted to 20 and maximum for work in process limit 40.SSPT rule provides the minimum average flow time. From the literature, it is found that SPT rule leads to minimum average flow time in general job shop scheduling. However, the SSPT rule considers both the setup time and the processing time of operations for deciding the priority of jobs. Therefore , it provides the minimum average flow time. It is found that, scheduling the job shop with immediate job release methods provides smaller values of average flow time for SSPT,MCSPT and MSRPT rule. It is also observed that JCR rule provides high value for flow time when work in process limit is restricted to 20.

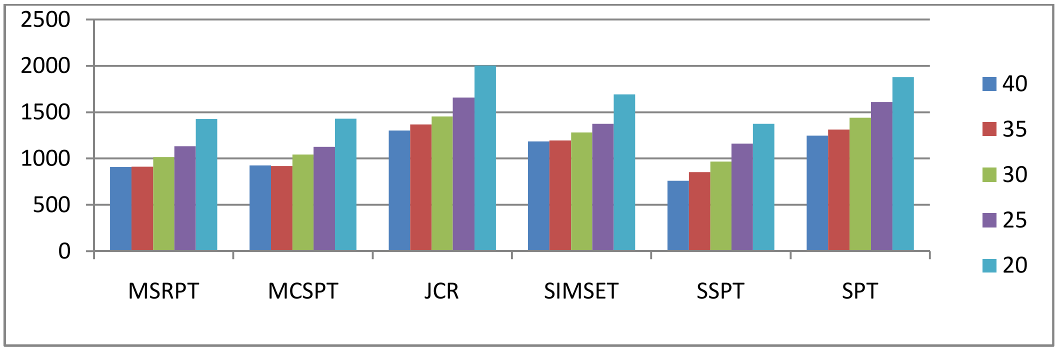

Fig 1 : Average flow time

From the simulation results presented in Figure 2 , it is found that average tardiness increase steadily from work in process limit of 40 to a reduced work in process inventory limit of 20.It is also observed that the proposed modified scheduling rule namely, MSRPT and MCSPT provide minimum values for average tardiness .

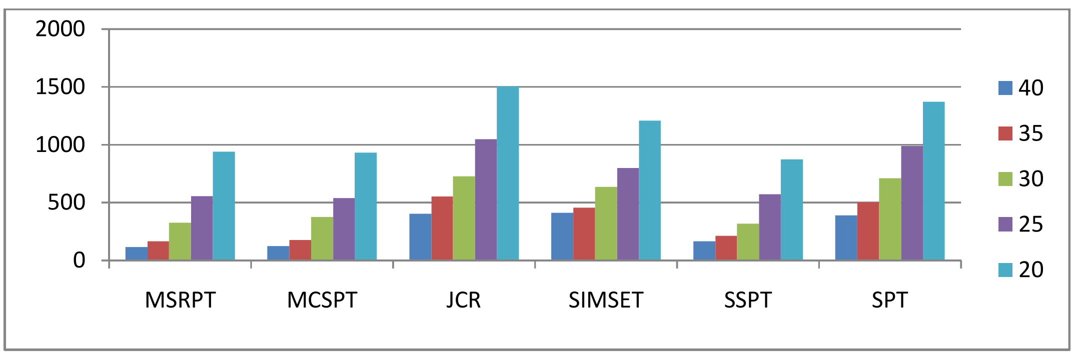

Fig 2: Average Tardiness

From Figure 3, it is found that SSPT rule yields minimum value for Percentage of tardy jobs followed by MSRPT rule . It is also observed that percentage tardy job measure is maximum when work in process limit is restricted to 20 and have a high value for JCR rule.

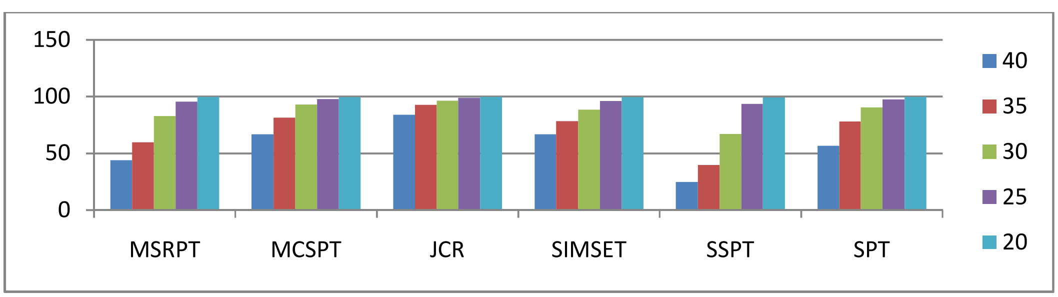

Fig 3: Percentage of Tardy Jobs

As shown in Figure 4, the SIMSET rule provides the minimum value and SPT rule provides maximum value for average setup time.

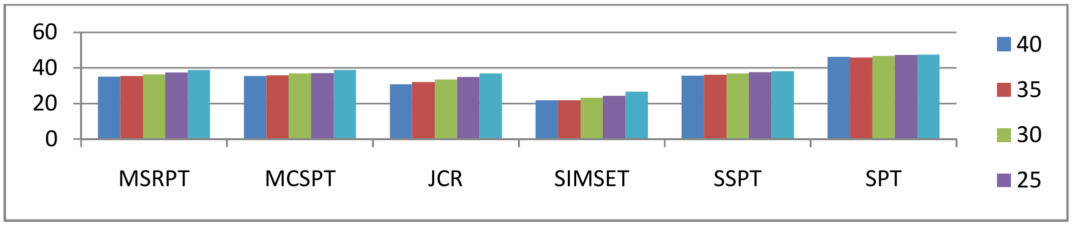

Fig 4: Average Setup Time

However, as shown in Figure 5, the application of job release methods in scheduling results in reduction of average flow allowance, it is observed that average flow allowance measure is minimum at work in process limit of 20. Among the scheduling rules, the proposed MCSPT rule followed by MSRPT rule provides minimum average flow allowance ,the best performing scheduling rules can be determined as shown in Table 2.

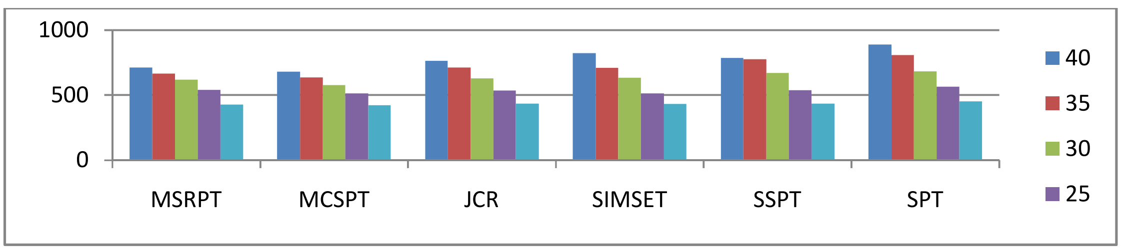

Fig.5: Average Flow Allowance

Table 2: Performance measure and result of best scheduling rule

Performance Measure	**limit**	**Work in process based release of Jobs**
Average Flow time	40	SSPT,MSRPT,MCSPT
Average Tardiness	40	MSRPT,MCSPT
Percentage of Tardy Jobs	40	SSPT,MSRPT
Average Set up Time	40	SIMSET
Average Flow Allowance	20	MCSPT,MSRPT

Simulation results are subjected to statistical analysis. The Analysis of Variance (ANOVA) method is used to to study the effect of scheduling rules and work in process limits under two setup times 6 minutes and 12 minutes . Three factor ANOVA-F test is conducted to determine, whether the treatment means are significantly different from each other. The statistical hypothesis are formulated as follows:

H_o : for each performance measure , the average values of experiments are equal .

H_1 : For each performance measure , at least one average value is significantly different from experiments .

The significance level used is 5 %.Table 1 depicts the results of ANOVA

Table 1: ANOVA Results:

Source	Mean Flow Time		Mean Tardiness		% Tardy Jobs		Mean setup Time		Mean Flow allowance	
	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Main Effects										
Setup Time (S)	30.951*	0.000	299.540*	0.000	29.522*	0.000	11782.970*	0.000	172.122*	0.000
Work-in-Process limit (L)	12.415*	0.000	215.123*	0.000	54.365*	0.000	33.464*	0.000	202.154*	0.000
Scheduling Rule (R)	11.909*	0.000	69.270*	0.000	17.596*	0.000	889.996*	0.000	21.559*	0.000
Two-Factor Interactions										
SL	0.298	0.880	17.683*	0.000	5.215*	0.000	8.686*	0.000	8.057*	0.000
SR	2.470*	0.032	12.277*	0.000	4.732*	0.000	110.836*	0.000	7.748*	0.000
LR	1.051	0.393	1.257*	0.202	1.623*	0.000	1.852*	0.014	2.636*	0.000
Three-Factor Interactions:										
SLR	.819	0.691	.746	0.779	1.043	0.445	0.280	0.999	1.026	0.429
* F-ratios significant at 5% level of significance										

For all the performance measures, the main effects arising out of the setup time (S),Job release work in Process limit(L), and the scheduling rule (R) are found to be significant. The two-factor interactions such as SL, SR and LR have significant effect on the performance of the shop. Among the three-factor interactions, the SLR is not found to have any significant effect on the performance of the shop.

The Tukey multiple comparison tests have been conducted to analyze the two-factor interaction effects. The interaction plots (for the two factors namely, work in process limit and scheduling rule) are obtained for all the performance measures as shown in Figures 6 to 10.

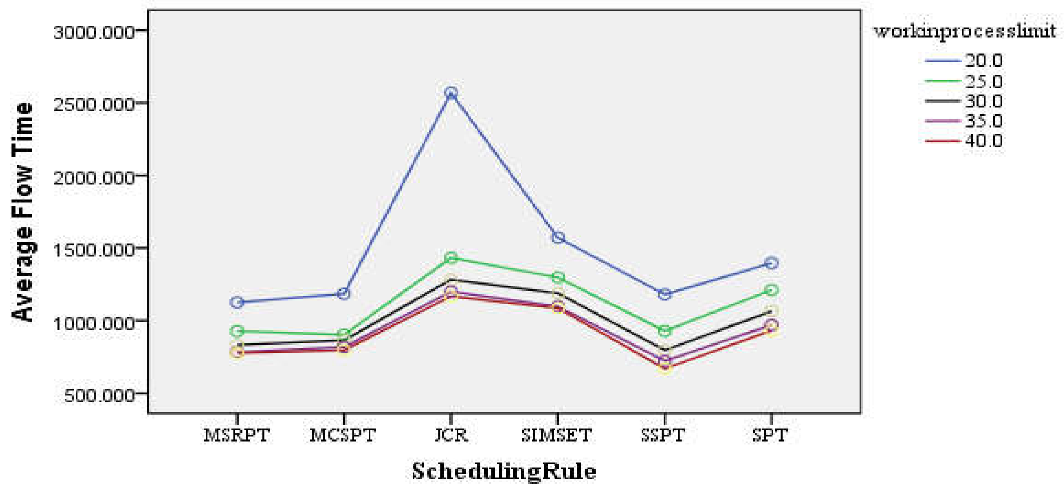

Fig 6 : Average flow Time

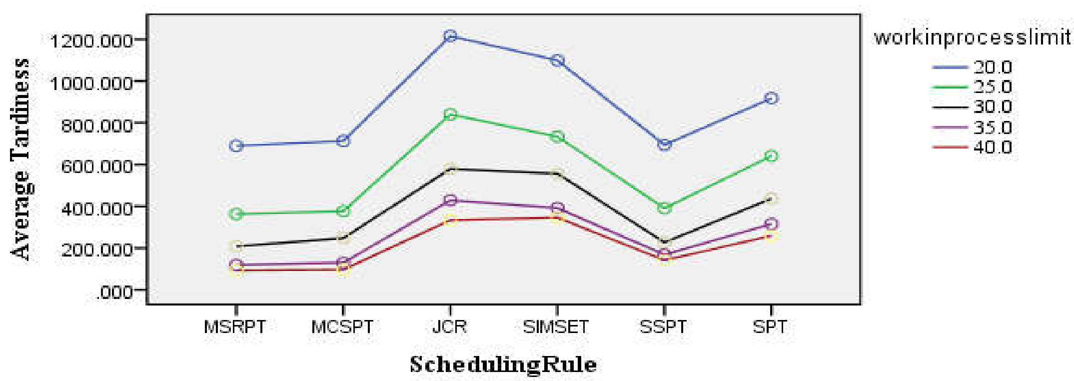

Fig 7 : Average Tardiness

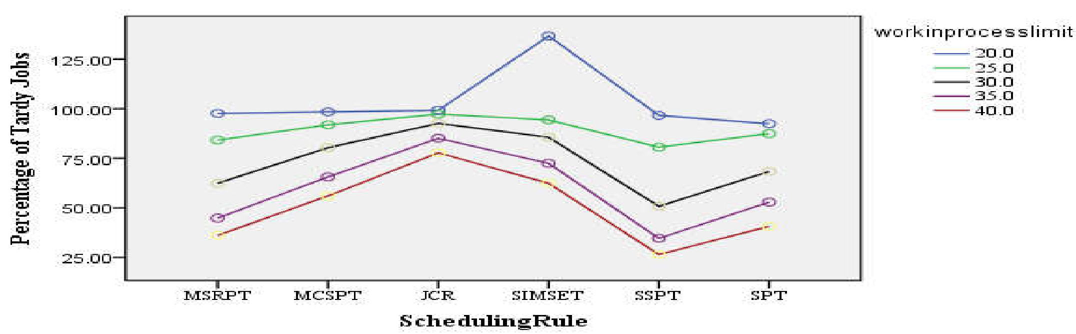

Fig 8 : Percentage of tardy Jobs

Fig 9 : Average Setup Time

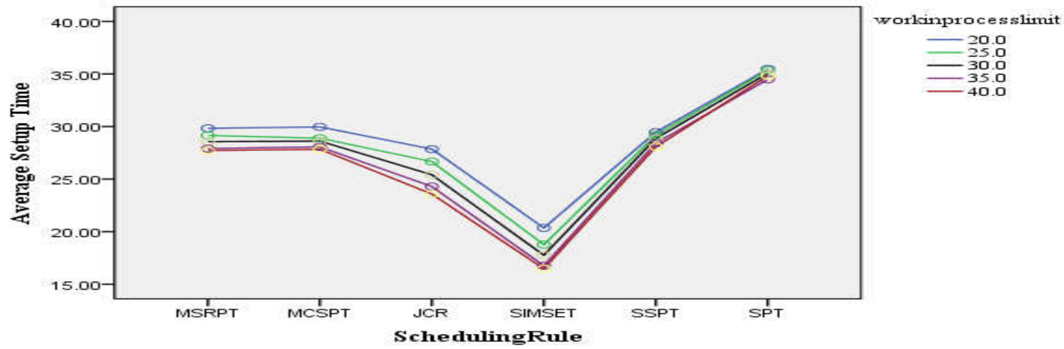

Fig 9 : Average Setup Time

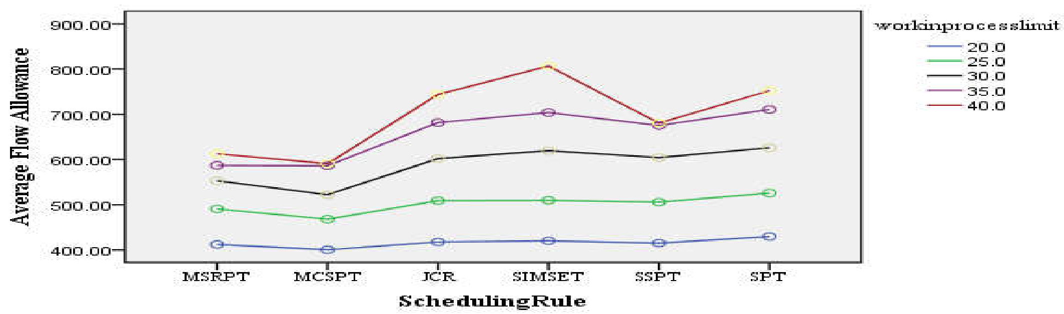

Fig 10 : Average Flow Allowance

10. REGRESSION-BASED ANALYTICAL MODELS

Analytical models developed from simulation results are useful for post-simulation analysis (Madu and Chanin1992). Generally, such analytical models are derived using regression analysis.Multiple linear regression analysis reveals ,how the independent variables affect a particular dependent variable under a given set of assumptions. The analysis consists of three stages (1)Identifying the significance of the factors and their interactions. (2) Formulation of Regression model .(3) Testing the validity of the model

In the present research, the job release methods, priority scheduling rules, and average setup time are the independent variables. The measures of performance evaluated in the simulation experiments constitute the dependent variables. The average interarrival time of jobs is set at 27 minutes.The average setup time of jobs is denoted by the quantitative variable *S*. The average setup time is set at 6 and 12 minutes. Levin and Rubin (1998) suggest that dummy variables can be used to represent qualitative variables in developing regression models. In the present study, dummy variables are employed to model the qualitative variables namely the job release methods and the scheduling rules. A qualitative independent variable with '*q*' values is modeled using '*q*-1' dummy variables. Hence, the two Job release methods are modeled using a dummy variable J which takes a value 0 for representing the release of jobs with job release methods and 1 for representing the release of jobs without job release method. The scheduling rules are modeled using five dummy variables R_1, R_2, R_3, R_4 and R_5.

The results of three-factor statistical analysis provided in Table 3 show that all the main effects, the two-factor interactions such as SL, SR,and LR, three-factor interaction JSR have no significant effect on the performance of the system. Hence, these interaction effects are also modeled as products of the concerned variables. The regression-based analytical model is proposed as follows:

$$y= \beta_0 + \beta_1 S + \beta_2 L + \beta_3 R_1 + \beta_4 R_2 + \beta_5 R_3 + \beta_6 R_4 + \beta_7 R_5 + \beta_8 SL + \beta_9 S R_1 + \beta_{10} S R_2 + \beta_{11} S R_3 + \beta_{12} S R_4 + \beta_{13} S R_5 + \beta_{14} L R_1 + \beta_{15} L R_2 + \beta_{16} L R_3 + \beta_{17} L R_4 + \beta_{18} L R_5 + e \quad (3)$$

where

y = Performance measure, i.e., average flow time, average tardiness, percentage of tardy jobs, average set up time, and average flow allowance

β_0 = intercept

β_1 = regression coefficient denoting the main effect of average setup time

β_2 = regression coefficient denoting the main effect of work in Process limit

$\beta_3, \beta_4, \ldots, \beta_7$ = regression Coefficient denoting the main effect of scheduling rules

β_8 = regression coefficient denoting the interaction effect of work in process limit and average setup time

$\beta_9, \ldots, \beta_{13}$ = regression coefficients denoting the interaction effect of average set up time and scheduling rule

$\beta_{14}, \ldots, \beta_{18}$ = regression coefficients denoting the interaction effect of work in process limit and scheduling rule

e = error

As described in section 8, the two Job Release methods, six scheduling rules, two values for average setup time lead to 24 simulation experiments. Simulation results are obtained for these experiments. Multiple linear regression analysis of the simulation results has been carried out. Based on Equation (3), a regression-based analytical model is developed for each performance measure. The regression analysis yields the estimates of the regression coefficients of the independent variables in the analytical models. The results of analysis of variance for the regression-based analytical models are shown in Table 3

Table 3: Results of analysis of variance for the regression-based analytical models

	Average Flow Time	Average Tardiness	Percentage of Tardy jobs	Average Set up time	Average Flow Allowance
F-Ratio	14.647*	79.479*	21.393*	989.961*	66.284*
P- Value	0.000	0.000	0.000	0.000	0.000
Coefficient of determination r^2	0.923	0.931	0.922	0.977	0.912
Adjusted r^2	0.906	0.918	0.904	0.954	0.903

From Table 3, it is found that the values of coefficient of multiple determination r^2 for the regression models for all the performance measures are high.Thus the independent variables such as average set up time, The priority scheduling rules explain a larger percentage of the variation in the measures of performance. Since the *p*-values are less than the significance level, all the analytical models are significant. The values of the coefficient of multiple determination r^2 and the adjusted r^2 are very close implying that the derived models have not been over-specified by incorporating variables that have no significant effect. Model adequacy has been verified by observing the the residual plots . These plots were found to have no patterns, thus confirming the adequacy of the models. Thus, the developed regression models are adequate representations of the simulation model and are useful for post-simulation analysis.

10.1. Validation Test

For the purpose of validation of the regression models, the performance measures of the system obtained through simulation are compared with the predicted values. This involves conducting additional simulation runs. In these simulation runs, the values of the independent variables are set within the range used for developing the regression models. For instance , the average setup time is taken as 9 minutes for the validation test since this value lies in the range (6,12) used for developing the regression models. Two averge set up time values and 5 corresponding work in process limits and the six scheduling rules (MSRPT, MCSPT, JCR, SIMSET, SSPT, and SPT) are used. Equation (3) is applied to determine the predicted values of the measures of performance. These predicted values are compared with the simulation-based computed performance measure values as shown in Table 4.

Table 4: Results of validation tests

Set Up Time = 9								
Performance Measure		Scheduling Rule						Average absolute % error
		MSRPT	MCSPT	JCR	SIMSET	SSPT	SPT	
Mean Flow Time	Regression Results	1042.543	1085.23	1694.43	1440.42	1075.46	1256.73	
	Simulation Result	1047.268	1077.028	1687.47	1433.852	1063.93	1284.761	
	relative error	-0.005	0.008	0.004	0.005	0.011	-0.022	0.891
Mean Tardiness	Regression Results	546.32	584.68	1118.78	942.21	574.32	781.74	
	Simulation Result	533.522	564.717	1126.848	920.446	552.471	759.476	
	relative error	0.023	0.034	-0.007	0.023	0.038	0.028	2.650
Percentage of Tardy Jobs	Regression Results	90.32	92.96	102.21	94.43	98.75	94.32	
	Simulation Result	94.853	97.426	99.703	98.02	95.249	97.328	
	relative error	-0.050	-0.048	0.025	-0.038	0.035	-0.032	3.718
Mean Setup Time	Regression Results	28.696	28.685	25.429	17.795	28.738	34.886	
	Simulation Result	29.809	29.896	25.367	17.93	30.143	34.721	
	relative error	-0.039	-0.042	0.002	-0.008	-0.049	0.005	2.319
Mean Flow Allowance	Regression Results	476.23	458.35	468.67	462.78	455.32	465.96	
	Simulation Result	460.409	450.228	466.38	461.613	458.574	459.253	
	relative error	0.033	0.018	0.005	0.003	-0.007	0.014	1.359

For each performance measure, the relative error is within 5% and the absolute error percentage is within 4%. Hence, it be inferred that the regression models of equation (3) yield a good prediction of the job shop performance. The regression models can be applied in decision analysis.

11. conclusion

This study has provided insights on the interaction among the factors such as job release methods , average setup time and Priority scheduling rules on the performance of a typical dynamic job shop with sequence dependent setup time. Detailed statistical analysis of the simulation results has enabled the development of regression based analytical models. The inferences drawn from the present research can be encapsulated as follows.

- The scheduling rule SSPT provides superior performance for average flow time. The next best performance are by MSRPT and MCSPT.
- Application of the proposed scheduling rules, MSRPT and MCSPT yields lesser values of average tardiness.
- For minimizing percentage of tardy jobs SSPT rule followed by MSRPT rule provide better Performance.
- The setup time based SIMSET rule emerges as the best scheduling rule for average setup time .
- The proposed MSRPT rule and MCSPT rule provides lesser values for average flow allowance. This feature is attractive for setting tight due dates.
- The regression based analytical models adequately represent the simulation model and hence are useful for obtaining better insights about the job shop.

The explicit modeling of sequence dependent setup time certainly enhances the performance of the system. When a job release method with suitable work in Process limit is used in combination with scheduling rules, better performance of the system can be obtained under different shop floor conditions characterized by setup time and arrival rate of jobs. Reductions in average flow time and average tardiness lead to the fulfillment of timely delivery promises, thus resulting in better customer satisfaction. Reductions in average flow time and tardiness aid in obtaining reduced inventory and hence reduced inventory related costs.

In the Present Research it is assumed that production machines are available continuously .Hence future research can be directed towards the analysis of job release methods in scheduling job shops with sequence dependent set up time operating under machine break downs.

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