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***Research paper***

# Simulation modeling and analysis of job release policies in scheduling an agile job shop with process sequence dependent setting time

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**Abstract**

This paper analyses the effects of job release policies, priority scheduling rules and setup times on the performance of a dynamic job shop in a sequence dependent setup time environment. Two job release policies namely, immediate job release and job release based on a specified work-in-process are 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, simulation, regression models.*

## 1. Introduction

Scheduling involves projecting the manufacturing-related activities of a production system on a time scale. A job shop production system specializes in low-to medium-volume production. Machine tools are selected in a Job shop essentially would be of Multipurpose functioning so as to cater the machining of varieties of jobs without compromising the quality requirement. The job scheduling problem involves finding the sequence of processing the jobs on machines to achieve a specified criterion. Setup time denotes the time that elapses in changing from one product type to another on a machine (Xu et al. 2015). Setup activity is a non-value added activity. 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. The setup time can be classified as sequence independent or sequence dependent. In the case of process sequence independent setting time situations, any job setting time is not dependent on previous job. There are some situations in which it may not be realistic to assume that the time required to setup a machine for the next operation is independent of the immediate preceding operation. This can be better explained with the example of paint manufacturing where the same machinery has to be cleaned and used for manufacturing different colours. Such a shop floor is an example of a system operating under Sequence Dependent Setup Time (SDST) environment. SDST environment is characterised by the dependence of the setup time on the current job and also on the previous job that has been processed on that machine. Recent research on scheduling incorporates explicitly setup time in addition to processing time (Allahverdi and Soroush [1], Allahverdi [2]). This results in realistic schedules that lead to better performance of the system. The present research takes into account SDSTs in scheduling jobs on machines.

In a manufacturing system with dynamic arrival of orders, jobs arrive at the shop for processing at random points in time. Saad et al. [24] 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: (1) Immediate job release (2) Job release based on a specified work-in-process (number of jobs undergoing processing in the system). 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 policies has not been studied yet. The development of the analytical models for post-simulation studies of a job shop operating in an SDST environment with dynamic arrival of jobs is a novelty of the present study. The analysis of the effects of job release procedures in a dynamic job shop with SDST and dynamic due date assignment is another noteworthy addition to the literature. Thus, the following are the objectives of the present study:

- Develop a simulation model for scheduling a dynamic job production system operating in an SDST environment.
- Analyze the interactions among job release policies, setup times and priority decision rules.
- Develop regression-based analytical models using the simulation results for performance prediction.

In this article Part 2 presents the background of present research. Part 3 describes the Job shop system. Part 4 deals with the due date assignment method, job release procedures and priority decision rules adopted in the present study. Part 5 presents the details of the Job release method. Part 6 Job scheduling decision rules. Part 7 describes the simulation model. Part 8 describes measures of performance computed for analysis. Part 9 presents results and analysis. Part 10 presents regression-based analytical models and Part 11 provides overall conclusion.

## 2. Background for the present research

This section provides the salient aspects of the literature pertaining to job release and job scheduling.

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 [15] 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. [4] provided a review of the literature on order review/release procedures in job shop production systems. Sabuncuoglu and Karapinar [25] compared order review/release methods under several experimental conditions using a simulation model of an agile job shop. They observe that consideration of system load and job duedate sis very important for the effective implementation of the job release policies. Saad et al. [24] investigated order release and due date assignment rules for an agile job shop. The modified number of operations rule is found to perform better than the other due date assignment rules analyzed.

Gentile and Rogers [9] extended the work of Kim and Bobrowski [15] and infer that order release based on work load control and job dispatching based on similar setup dispatching rule provides better performance. Lu et al. [17] adopt an integrated approach for investigating order release rules and desptach procedures for planning and scheduling f 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 [28] provided a review of the literature on order acceptance and scheduling from a problem-oriented perspective. Thurer et al. [29] applied the workload control approach in a high-variety production environment and observe that order release policies and dispatching rules complement each other. Sharma and Jain [26] report on a simulation study of a dynamic job shop with sequence dependent setup times. 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 [15] and Gentile and Rogers [9] use the Total Work Content (TWK) style in assigning the despatch 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.

## 3. Job shop configuration

The typical production system conditions are revealed in this research article. The configuration of the system agrees with that adopted by Rangsaritratsamee *et al*. [23]. The job shop comprises six non-identical machines. Each machine can process a specific operation. However, different types of types can be processed on a machine by altering the setup. The job data are determined using the procedure described by Hall and Posner [12]. The following are the assumptions made.

- There exists in the shop only one machine for processing each type of operation, i.e., no alternative machines.
- A machine can process one operation only at a time.
- Once a job is loaded on a machine for processing, the machine processes the job without interruption.
- There is a precedence relationship among the operations of an order. i.e., the sequence of operations of a job is fixed.
- The setup times are sequence dependent and are deterministic.
- The machines are available for production without any failures.
- There is adequate space for jobs to wait.

### 3.1. Job data

There are eight different job-types processed in the shop. An incoming job can fit into anyone among 8 job category of same kind. The number of operations for a job-type is generated using a uniform distribution, U (3-6). The sequence of operations of a job-type (machine visitation order) is generated randomly such that a machine is not repeated in the sequence. The processing time for an operation becomes an average of half an hour. Each machine requires a setting time for processing an operation. The setting times are dependent on the operation series. The average setting time for an operation is achieved by the fixing the ratio of average setting time to average machining time at 20% and 40%. These two ratios yield the average setup time of 6 minutes and 12 minutes respectively. The setup times of operations are generated using an exponential distribution with the above average values.

Generally, in job shop studies, the job arrival process is found to be the Poisson process (Rangsaritratsamee et al. [23]) with the inter arrival time exponentially distributed. The inter arrival time is related to the utilization of the shop. For simulating a job shop, the average value of the inter arrival time is computed for a stated utilization of the shop and the attributes such as the average number of operations of a job, the average processing time of an operation, the average setup time of an operation, and the number of machines in the shop. In the simulation study done here in this research, the average inter arrival time of a job-type had been fixed at 27 minutes. With a corresponding value that provide a shop utilization of 85%

## 4. Due date assignment methods

In the present study, Dynamic Total Work Content (DTWK) procedure is followed for fixing the dispatch dates of orders. DTWK is a modification of the total work content method. The total process cycle time includes the setting time also in this research. The Total Work Content (TWK) is calculated by the multiplication of process movement factor to the manufacturing time of the job. This calculated time is added to the job receipt time to fix the dispatch date. 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 [5] and Sha and Liu [27]. Thus, the job movement allowance factor $K_t$ could be computed based on the dynamic conditions follows the relationship depicted hereunder:

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

Where $J_t$= unfinished jobs in the system at time $t$, $\lambda$ = average incoming time of jobs at the system, $\mu_p$ = average machining time for each operation, $\mu_s$ = average setup time of an operation and $\mu_g$ = average number of operations per job. The dynamic flow allowance factor for due date determination is derived as maximum ($Kt$, 1). This guarantees a minimum value of 1 for $Kt$. 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 for a job is determined as

Due date= Arrival time+ dynamic flow allowance (2)

## 5. Job release methods

The following methods are used in the present study for releasing jobs for processing in the system;

(1) Immediate release of jobs (without Job release).
In this method, arriving jobs are immediately released to the shop floor for processing without considering any information about the system. This method of job release is equivalent to release of jobs without any release policy. This method is used for the purpose of comparison.

(2) Work in process based release of jobs (with Job Release).

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 highest batch size of jobs that could be kept in machining in pipe line is limited as 25.

## 6. Job scheduling decision rules

A preference value is designated through job scheduling procedure for every component that are waiting. The job with the smallest preference value has the highest preference for selecting to be processed next on the machine. Two scheduling rules MSRPT 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 [3]. 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 + rest of mean setting time).

From the machine queue, the job assigned by lowest preference value is taken up for work.

(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 having lowest preference value is taken up for work.

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

This rule chooses the job similar to the job which was finished on the machine. If there is no similar job present in the machine queue, this procedure chooses a job which is assigned with lowest critical ratio.

(4) SIMilarSETup, SIMSET (Kim and Bobrowski, [14]):

This rule chooses the job similar to the job that is just completed on the machine. If there is no identical job present in the machine queue, this procedure chooses a job that has the lowest value of setting time.

(5) Shortest (Setup time + Processing Time), SSPT (Vinod and Sridharan [30]).

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 lowest value of processing time for the immediate operation.

## 7. 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-type) 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 3, 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 inter arrival 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, cycle time and despatch dates were 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 falls below25.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 completes the assigned operation of a job, there are two decisions involved, i.e., one for the machine and the other for the job. The machine is kept idle as and when there is no job. 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 this study, 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 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.

## 8. 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 = $\frac{1}{n}\sum_{i=1}^{n} F_i$
- Average tardiness: It is the average tardiness of a job.

  Average tardiness= $\frac{1}{n}\sum_{i=1}^{n} T_i$
- Percentage of tardy jobs = $\frac{n_T}{n} \times 100$
- Average setup time: It is average setting time of a job.

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

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

## 9. Results and analyses

Results obtained from simulation are subjected to statistical analysis. Analysis of Variance method (ANOVA) is used to to study the effect of scheduling rules and average setup time under two scenarios namely immediate release of jobs and work in process based release of jobs . Three factor ANOVA-F test has been carried out to determine whether the treatment means are significantly different from each other. The null hypothesis (Ho) is that all the average values are equal and alternative hypothesis is that at least one average value is significantly different. the test is conducted at 5 % level of significance. The results are presented in Table 1.

**Table 1:** ANOVA Outcome

| Source of variation | Average Flow Time | | Average Tardiness | | Percentage of Tardy jobs | | Average Set up Time | | Average Flow Allowance | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F-Ratio | P-Value | F-Ratio | P - Value | F-Ratio | P-Value | F-Ratio | P-Value | F-Ratio | P- Value |
| Main Effects: | | | | | | | | | | |
| Job Release (J) | 5.394* | 0.021 | 66.083* | 0.000 | 176.37* | 0.000 | 4.76* | 0.030 | 50.92* | 0.000 |
| SetupTime (S) | 145.99* | 0.000 | 76.708* | 0.000 | 63.45* | 0.000 | 2622.71* | 0.000 | 71.21* | 0.000 |
| Scheduling Rule (R) | 51.174* | 0.000 | 47.752* | 0.000 | 94.15* | 0.000 | 381.530* | 0.000 | 10.50* | 0.000 |
| *Two Factor Interactions* | | | | | | | | | | |
| *JS* | 15.356* | 0.000 | 31.81* | 0.000 | 83.342* | 0.000 | 47.416* | 0.000 | 4.302* | 0.032 |
| *SR* | 5.363* | 0.000 | 7.08* | 0.000 | 8.472* | 0.000 | 27.916* | 0.000 | 3..057* | 0.011 |
| *JR* | 8.268* | 0.000 | 5.25* | 0.000 | 4.470* | 0.000 | 56.918* | 0.000 | 5.772* | 0.000 |
| Three Factor Interactions : | | | | | | | | | | |
| JSR | 3.123* | 0.010 | 2.683* | 0.022 | 6.013* | 0.000 | 18.872* | 0.000 | 2.426* | 0.034 |

The main effects namely, Job Release method (J), setup time (S) and scheduling rule (R) are found to be statistically significant at the 5% significance level for all the performance measures. The two-factor interaction effects such as, JS, JR and SR and Three-factor interactions JSR are found to be statistically significant for all the performance measures. The Tukey multiple comparison tests have been conducted to analyze the two-factor interaction effects.

The two-factor interaction plots for the two factors, namely, Job release procedure and scheduling policy are obtained for all the performance metrics as shown in Figures 1 to 5.

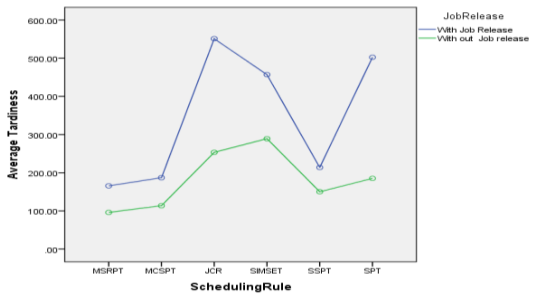


**Fig. 2:** Mean tardiness

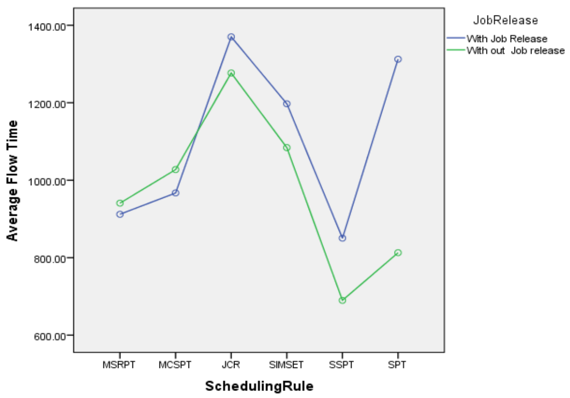


**Fig. 1:** Mean flow time

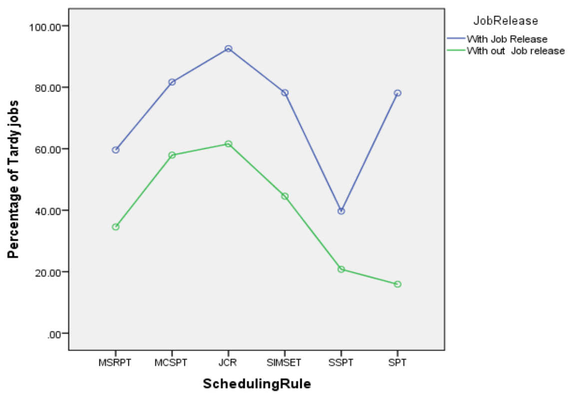


**Fig. 3:** Tardy jobs %:

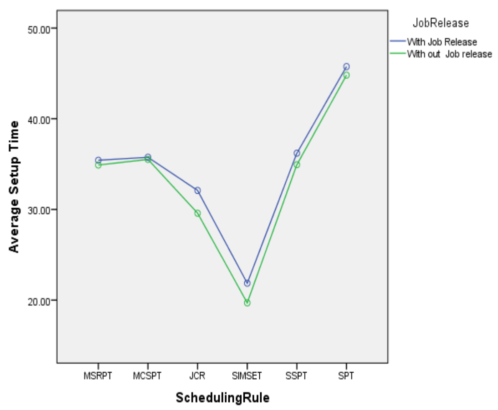


**Fig.4:** Mean setting time

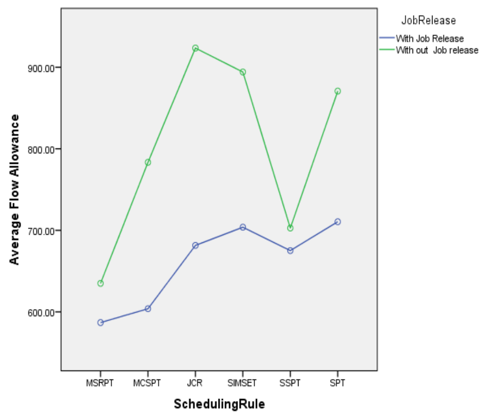


**Fig.5:** Mean movement allowance

These interaction plots show the combined effect of Job release method and scheduling rule on the efficiency of the system. Figure 1 shows that SSPT procedure that reveals 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 procedure uses both the setting time and the processing time of operations for deciding the priority of jobs. Hence, it provides the minimum average flow time. It is found that, scheduling the job shop with considering Job release provides smaller values of average flow time for MSRPT, MCSPT and SSPT. It is also observed that SPT provide a very high value of average tardiness in the case of work in Process based release of jobs.

From the simulation results presented in Figures 2 , it is found that the proposed modified scheduling rule namely, MSRPT and MCSPT provide minimum values for average tardiness for both conditions namely Scheduling with the consideration and without the consideration Job release methods. From Figure 3, it is found that SPT procedure gives lowest % of tardy jobs in the case of scheduling without the consideration of job release but very high value in the case of scheduling with the consideration of job release. SSPT rule provides minimum values in both these cases. As shown in Figure 4, the SIMSET procedure gives lowest value for average setting time in both the cases. However, as shown in Figure 5, the application of job release methods in scheduling results in reduction of average flow allowance, Among the scheduling rules, the proposed MSRPT rule followed by MCSPT rule provides minimum value for average flow allowance and average tardiness.

Thus, depending on analysis of simulation outcome, the best performing scheduling procedures can be determined as shown in Table II.

**Table 2:** Performance measure and result of best scheduling Rule

| Performance Measure | Work in process based release (With Job release) | Immediate Release of Jobs (Without Job release) |
|---|---|---|
| Average Flow time | SSPT | SSPT |
| Average Tardiness | MSRPT | MSRPT |
| Percentage of Tardy Jobs | SSPT | SPT |
| Average Set up Time | SIMSET | SIMSET |
| Average Flow Allowance | MSRPT | MSRPT |

## 10. Regression-based analytical models

Analytical models developed from simulation results are useful for post-simulation analysis (Madu and Chanin [18]). Generally, such analytical models are derived using regression analysis. multiple linear regression analysis supports to describe as to how an independent variable affects a particular dependent variables under a given set of assumptions. This comprises of three modules. Viz. a) analyzing the inter relation and directionality of the data, b) estimating the framework i.e., fitting the line, and c) Validation of application of this framework.

In the present research, two scenarios namely , scheduling with the consideration of job release methods, Scheduling without the consideration of job release methods and average setting time are the independent variables. The measures of performance evaluated in the simulation experiments constitute the dependent variables. The average inter arrival time of jobs is set at 27 minutes. The average setting time of jobs is represented by the quantitative variable *S*. The average setup time is set at 6 and 12 minutes. Levin and Rubin [16] 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 strategies and scheduling procedures. A qualitative independent variable with '$q$' values is represented by '$q$-1' dummy variables. Hence, the two Job release methods are modeled using a dummy variable J which takes a value 0 for representing the job release method and 1 for representing 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 JS, JR and SR, and the three-factor interaction JSR are statistically significant for all the performance measures. Hence, these interaction effects are also modeled as products of the concerned variables. The regression-based analytical model is proposed as follows:

$$y= \beta_0 + \beta_1 J + \beta_2 S + \beta_3 R_1 + \beta_4 R_2 + \beta_5 R_3 + \beta_6 R_4 + \beta_7 R_5 + \beta_8 JS + \beta_9 J R_1 + \beta_{10} J R_2 + \beta_{11} J R_3 + \beta_{12} J R_4 + \beta_{13} J R_5 + \beta_{14} S R_1 + \beta_{15} S R_2 + \beta_{16} S R_3 + \beta_{17} S R_4 + \beta_{18} S R_5 + \beta_{19} J S R_1 + \beta_{20} J SR_2 + \beta_{21} J SR_3 + \beta_{22} J SR_4 + \beta_{23} J SR_5 + e \quad (3)$$

where

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

$\beta_0$ = Constant or intercept

$\beta_1$ = regression Coefficient for the main effect of Job Release method

$\beta_2$ = regression Coefficient for the main effect of average setting time

$\beta_3, \beta_4, \ldots, \beta_7$ = regression Coefficients with respect to the main effect of scheduling procedure

$\beta_8$ = regression Coefficient with respect to the interaction effect of Job Release method and average setting time

$\beta 9, \ldots, \beta_{15}$ = regression Coefficients with respect to the interaction effect of Job Release method and Scheduling procedure

$\beta_{14}, \ldots, \beta 18$ = regression Coefficients with respect to the interaction effect of average Setting time and Scheduling procedure

$\beta 19, \ldots, \beta_{23}$ = regression Coefficients with respect to the interaction influence of Job Release procedure, average setting time and scheduling procedure

$e$ = 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 outcomes are obtained for these experiments. Multiple linear regression analysis of the simulation outcomes 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 III.

**Table 3:** Outcome 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 Alowance |
|---|---|---|---|---|---|
| *F*-Ratio | 22.017 | 21.210 | 38.703 | 21.566 | 10.229 |
| *P*- Value | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Coefficient of determination$R^2$ | 0.943 | 0.963 | 0.913 | 0.959 | 0.926 |
| Adjusted $R^2$ | 0.926 | 0.921 | 0.904 | 0.955 | 0.912 |

From Table 3, it is found that the values of coefficient of determination $R^2$ for the regression models for the five performance measures are high. Hence, the independent variables such as the job release method, the average setup time and scheduling rules explain a larger proportion of the differences in the performance metrics. Since the *p*-values are less than the significance level, all the analytical models are significant. The values of the coefficient of determination $R^2$ and the adjusted $R^2$ are very close implying that the derived models have not been over-specified by incorporating terms that have no significant effect. Model adequacy has been cross checked by observing the plots of the residual values against the corresponding mapped values. These plots were found to have no patterns, thus confirming the adequacy of the models. Uniform conclusions have been made by plotting the residual values versus the corresponding values of the independent variables. The normal probability plots of residuals were found to have approximately straight line patterns. Thus, the developed regression models are adequate representations of the simulation model and thus 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 example, the average setting time is decided at 9 minutes as input value for the validation test.

The two job release methods 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 performance metrics. These predicted values are compared with the simulation-based computed performance measure values as shown in Table 4.

**Table 4:** Results of validation tests

| J | S | R | Performance Measure | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean Flow Time | | | Mean Tardiness | | | percentage of Tardy jobs | | |
| | | | Regression Results | Simulation Result | Relative error | Regression Results | Simulation Result | Relative error | Regression Results | Simulation Result | Relative error |
| With Job release | 9 | MSRPT | 782.56 | 779.25 | 0.004 | 103.204 | 100.03 | 0.031 | 44.850 | 43.195 | 0.037 |
| | | MCSPT | 841.253 | 838.554 | 0.003 | 115.152 | 118.718 | -0.031 | 65.693 | 62.578 | 0.047 |
| | | JCR | 1199.22 | 1229.16 | -0.02 | 429.30 | 424.703 | 0.011 | 85.1005 | 85.121 | -0 |
| | | SIMSET | 1097.59 | 1103.52 | -0.01 | 391.708 | 409.807 | -0.046 | 72.478 | 72.082 | 0.005 |
| | | SSPT | 722.163 | 697.747 | 0.034 | 169.7805 | 170.813 | -0.006 | 34.651 | 33.1 | 0.045 |
| | | SPT | 970.147 | 960.341 | 0.01 | 301.68 | 297.482 | 0.014 | 50.92 | 48.914 | 0.039 |
| With out Job release | 9 | MSRPT | 791.804 | 788.871 | 0.004 | 82.362 | 82.014 | 0.004 | 31.9775 | 30.413 | 0.049 |
| | | MCSPT | 1027.53 | 872.459 | 0.151 | 97.668 | 91.859 | 0.059 | 57.924 | 56.237 | 0.029 |
| | | JCR | 1145.33 | 1167.18 | -0.02 | 222.768 | 236.205 | -0.06 | 60.894 | 61.786 | -0.01 |
| | | SIMSET | 1018.51 | 1035.1 | -0.02 | 269.997 | 271.375 | -0.005 | 45.046 | 43.62 | 0.032 |
| | | SSPT | 632.901 | 621.337 | 0.018 | 134.120 | 133.57 | 0.004 | 24.496 | 23.374 | 0.046 |
| | | SPT | 707.492 | 691.933 | 0.022 | 152.973 | 153.314 | -0.002 | 20.049 | 19.81 | 0.012 |
| Average absolute % error | | | | | 2.599 | | | 2.284 | | | 2.969 |

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 (5) 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 scheduling decision procedures on the performance of a typical dynamic job shop operating in a sequence dependent setting time situation. 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.

- For both the Job release methods, the scheduling rule SSPT has the best performance for average flow time. This is followed by MSRPT.
- Application of the proposed scheduling rules, MSRPT and MCSPT yields lesser values of average tardiness.
- For minimizing percentage of tardy jobs, without Job release - SPT combination provides the best performance. The next best combination is with Job release - MSRPT.
- The setup time based SIMSET rule emerges as the best scheduling rule for average setup time for both Job release methods.
- The proposed MSRPT 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 consideration of sequence dependent setup time certainly enhances the performance of the system. With an appropriate mixup of delivery date designation and scheduling procedure, an improved efficiency of the system can be achieved under varying 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 can generate other benefits such as lower inventory levels, lower costs, and lesser forecasting error.

There is a need for further research to analyze the effects of Job release methods and scheduling rules for the scenarios that involve system disruptions namely, breakdowns of machines.

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